Lake Illawarra entrance channel: management options assessment

Volume 1: main report

WRL TR 2024/07, November 2024

By I R Coghlan, B M Miller, A J Harrison, M Mason and T A Tucker

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Executive summary

Lake Illawarra is an estuary on the south coast of NSW, located 10 km south of Wollongong CBD, connected to the ocean at Windang via a 2,000 m long entrance channel. Historically, the lake entrance was intermittently connected to the ocean, with closures and openings occurring based on the balance between scour from catchment rainfall and accretion from longer term coastal processes.

Following community action in the 1990s and early 2000s regarding poor lake water quality, the entrance was connected to the ocean with the construction of entrance training walls in 2007. These works resulted in a permanently open entrance condition on the northern side of Windang Island. While this increased tidal flushing and permanently maintained marine water in the entrance channel, the channel is now hydraulically unstable. Scour from tidal velocities dominates the sediment processes, leading to continuous increases in tidal range and ongoing foreshore erosion, ingress of sediments into the lake from the channel erosion, and highly dynamic sand shoals. Erosion will continue to occur until the tidal range in the lake is the same as the tidal range in the ocean (0.8 m larger than today). Once the tidal ranges are the same, the entrance channel will become hydraulically stable, however this may take over 100 years and would require the cross-sectional area to increase by 7.5 times (compared to the 2012 cross sectional area). It is acknowledged that there are physical factors (e.g. the depth of the lake and the depth of the offshore bar) and restrictions (e.g. landform controls and the training walls) which may prevent the entrance from reaching this theoretical cross-sectional area. However, bedrock is deep below the existing entrance channel and not expected to become a future physical limitation to ongoing channel scour. The training walls also reduce potential sand replenishment from the ocean, significantly reducing the transport of marine sediments from coastal processes into the entrance channel which would have once led to the entrance channel becoming closed.

These changes are an ongoing issue for local stakeholders, the local councils, and state government asset managers. This study seeks to identify a range of long-term management options for Lake Illawarra which are capable of managing these complex processes.

Stage 1 of this study included consideration of 50 potential management options for the Lake Illawarra entrance channel, which were then refined to a short-list of long-term entrance management options to be assessed in detail during Stage 2 (this study). Stage 2 subsequently considered how each of the short-listed options could meet a range of management objectives. The primary management objectives of the options assessment were to (a) reduce foreshore erosion through (b) reducing the tidal range in Lake Illawarra to at least the range observed in 2008 (0.07 m) immediately following the entrance training works. Numerical modelling was utilised to determine engineering designs that were capable of meeting these objectives. The following five options (note that these are not numbered in order of preference) which met the primary management objectives were included in the study (see Figure ES-1):

- Option 1: Rock weir near Windang Bridge
- Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts
- Option 3: Rock weirs at the western end of the channel across all three channels
- Option 4: Staggered groyne field with armoured bed
- Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)

However, management of Lake Illawarra requires a balance of many objectives beyond managing erosion and tidal range. For this reason, the base case, along with the five identified options, were discussed in detail with a multi-agency project team at a workshop on 28 June 2024 and subsequent follow-up correspondence. The multi-agency project team included representatives from:

- Wollongong City Council
- Shellharbour City Council
- Transport for NSW
- Department of Primary Industries and Regional Development – Fisheries
- Department of Climate Change, Energy, Environment and Water
- Department of Planning, Housing and Infrastructure – Crown Lands
- Illawarra Local Aboriginal Land Council
- University of Wollongong
- University of New South Wales – Water Research Laboratory

Based on input from the multi-agency project team, each option was assessed against the base case (business as usual) for the following additional eight qualitative management criteria:

- Water quality in the lake, primarily related to tidal flushing
- Recreational safety for unpowered in-water activities, which improves with decreased velocities
- Flooding from catchment/rainfall, which improves with increased hydraulic efficiency
- Flooding from coastal storms, which improves with decreased hydraulic efficiency of the channel
- Fish passage, which is impacted by physical barriers as well as velocity and depth
- Flora and fauna, including changes to estuarine macrophytes, as well as bird and fish habitat
- First Nations Heritage, including risks to archaeological sites and cultural heritage
- Boating access, which is impacted by physical barriers as well as velocity and depth

The outcome of this assessment by the multi-agency project team is summarised in Table ES-1 (with a legend provided in Table ES-2) and indicative costings are shown in in Table ES-3.

Since the base case is the benchmark against which each of the options is compared, the overall rating for the base case against each criteria in Table ES-1 is “no change”. Under the base case, many of the current issues experienced in Lake Illawarra will continue to worsen over time. In other words, “no change” from the base case means that existing issues will be exacerbated into the future.

This report presents that there is no long-term entrance management option which does not have a negative impact on at least three key management criteria within the entrance channel. For example, each of the shortlisted management options will have a negative impact on water quality (i.e. tidal flushing), upstream flooding and boating access. As such, the selection of a preferred long-term entrance management option for Lake Illawarra is challenging, as it involves trade-offs between conflicting management issues/objectives. It is important that the community and other stakeholders are provided an opportunity to understand, engage and provide input into the ideal balance of these objectives.

For Options 1 to 4, there is a risk that the Lake Illawarra entrance channel may switch from the present unstable scour regime to an unstable accretionary mode (i.e. tending towards a closed entrance channel). This may result in the channel downstream of the weir(s)/groynes infilling and eventually, infilling of sediments upstream of the weir(s)/groynes. The rate at which this might occur is not known.

Option 5 is explicitly aimed at ensuring the entrance returns to a condition in which it tends toward a closed entrance in an immediate timeframe.

Lake Illawarra is a sensitive and dynamic system with important community and cultural values. Regardless of which option may be ultimately selected, ongoing monitoring and adaptive management will continue to be required in conjunction with the implementation of a long-term entrance management option. Members of the project control group have not formed a position on the preferred entrance management option as it is to be informed by community feedback, additional detailed studies and the overall Coastal Management Framework.

At this stage, there remains uncertainty in some of the management objectives, particularly with regard to First Nations' perspectives. Consultation and engagement with First Nations communities will be essential to the long-term success of the management of Lake Illawarra. Preliminary input suggests that hard engineering structures abutting onto natural foreshores (e.g. Cudgeree or Bevans Island) may not be culturally appropriate. Proactive and early engagement with First Nations communities is recommended following this study.



Figure ES-1 Summary of management options for Stage 2 assessment

Table ES-1 Summary options assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Base case	No change	No change	No change	No change	No change	No change	No change	No change	No change	No change
Option 1: Rock weir near Windang Bridge	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 3: Rock weirs at the western end of the channel across all three channels	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 4: Staggered groyne field with armoured bed	Improvement	Improvement	Deterioration*	Deterioration	Deterioration#	Improvement#	Improvement*	Further study required	Further consultation required	Deterioration
Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	Improvement	Improvement	Deterioration*	Improvement	Deterioration#	Improvement#	Further study required	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented with this option

Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

Table ES-2 Definitions and colouring for criteria ratings

Colour	Description
Improvement	There is a strong consensus among the multi-agency group that implementing an option will result in an improvement in a criteria with significant certainty, often supported by modelling or observations.
Improvement*/ Improvement#	The multi-agency group agreed that implementing an option will likely result in an improvement in a criteria, however more information is required to confirm this direction of change.
Further study/ consultation required	A consensus was not reached by the multi-agency project team, and further information is required to determine whether implementing an option would improve or deteriorate a certain criteria.
Deterioration*/ Deterioration#	The multi-agency group agreed that implementing an option will likely result in a deterioration in a criteria, however more information is required to confirm this direction of change. Alternatively, implementing the option would cause a deterioration, however this could be readily managed through additional mitigation measures.
Deterioration	There is a strong consensus among the multi-agency group that implementing an option will result in a deterioration in a criteria with significant certainty, often supported by modelling or observations.

Table ES-3 Preliminary estimates of capital and ongoing costs (excluding reactive management)

Option	Capital cost	Annual ongoing costs
Option 1: Rock weir near Windang Bridge	$20,000,000 to $45,000,000	$200,000 to $450,000
Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts	$60,000,000 to $105,000,000	$800,000 to $1,450,000
Option 3: Rock weirs at the western end of the channel across all three channels	$15,000,000 to $30,000,000	$150,000 to $300,000
Option 4: Staggered groyne field with armoured bed	$145,000,000 to $240,000,000	$750,000 to $1,250,000
Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	$35,000,000 to $70,000,000	$100,000 to $200,000

In addition to upcoming community and stakeholder consultation (planned to occur following the publishing of this final draft report), it is also recommended that further ecological studies into the impact of both the entrance training and subsequent implementation of each of the identified options is completed. This could include a fish passage and fish migration study specific to the Lake Illawarra estuary, as well as research into the optimal balance of estuarine habitats with changing tidal ranges. Further studies are also recommended regarding in-water recreational safety, modelling of flooding from catchment/rainfall and coastal storms and detailed water quality modelling.

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1 Introduction

1.1 Project introduction

A specialist project team was engaged by Wollongong City Council (hereafter, “WCC”), on behalf of funding partners consisting of WCC, Shellharbour City Council (hereafter, “SCC”) and the NSW Department of Climate Change, Energy, the Environment and Water (hereafter, “DCCEEW”; formerly the NSW Department of Planning and Environment), to undertake a two stage study of management options for the Lake Illawarra entrance channel. Several NSW Government agencies (Transport for NSW, Department of Primary Industries and Regional Development – Fisheries and Department of Planning, Housing and Infrastructure – Crown Lands) were identified as key Lake Illawarra stakeholders and invited to participate in the project control group (hereafter, “PCG”) that was subsequently formed with WCC, SCC and DCCEEW. The Water Research Laboratory (hereafter, “WRL”) of the School of Civil and Environmental Engineering at UNSW Sydney partnered with Manly Hydraulics Laboratory (hereafter, “MHL”) to carry out the study at the direction of the PCG.

1.2 Background

Lake Illawarra is an estuary on the south coast of NSW, located 10 km south of Wollongong CBD with a catchment of 235 km^2. The main lake waterbody of 36 km^2 is connected to the ocean at Windang via a 2,000 m long entrance channel (Figure 1.1). Historically, the lake entrance was intermittently connected to the ocean, with sand building up before elevated lake levels resulted in a breach and scouring of the entrance sand berm. This type of system is known as an Intermittently Closed and Open Lake or Lagoon (ICOLL). The entrance to the ocean would remain open until nearshore sediment processes infilled the entrance with sand again, limiting tidal interaction with the lake waterbody.

Following community action in the 1990s and early 2000s regarding poor lake water quality, the entrance was connected to the ocean with the construction of entrance training walls in 2007. These works resulted in a permanently open entrance condition on the northern side of Windang Island. Since the entrance was trained, significant changes have been observed within the connecting entrance channel and the wider Lake Illawarra waterbody including increased salinity, increased tidal range in the lake, and highly dynamic sediment processes within the entrance channel. The entrance channel is presently hydraulically unstable and these changes are continuing to evolve.

Changes within the entrance channel are driven by the large difference in tidal water levels between the lake and the ocean, resulting in fast flowing tidal currents through the entrance channel during daily flood and ebb tides. The high current velocities induce scouring of the entrance channel, foreshore erosion, ingress of sediments into the lake, and highly dynamic sand shoals. These changes are an ongoing issue for local stakeholders, the local councils (WCC and SCC), and state government asset managers.

This project has two aims:

1. To increase the understanding of interactions of the physical processes that drive changes within the entrance channel at Lake Illawarra. This information (documented in a separate report; Tucker et al., 2023a) was used to develop a conceptual understanding of what changes might continue to occur into the future if the management of the entrance remains unchanged.

2. To develop long-term management options that address both present and potential future issues/threats/hazards to the Lake Illawarra system. The identification, development and assessment of preferred long-term management options was undertaken in two stages outlined in Section 1.4.



Figure 1.1 Lake Illawarra location

1.3 Coastal Management Program (CMP)

The Lake Illawarra Coastal Management Program (CMP) was certified in 2020 to guide the management of Lake Illawarra. The intent and value of implementing the CMP (BMT, 2020a) is as follows:

"*Preserving and restoring the water quality and environmental habitats of Lake Illawarra is vital to the culture and economy of the local community, with benefits flowing on to the entire state of NSW. The Lake supports numerous important habitats including endangered ecological communities such as coastal saltmarsh, and these habitats in turn support a variety of species. In recognition of their high environmental values, NSW legislation requires such habitats to be protected and maintained.*

The Lake Illawarra CMP is a program of physical works, monitoring and investigations, and planning and education initiatives that target the threats to the Lake's ecological and cultural values. The CMP also includes actions directly aimed at improving recreational opportunities for the public; and targets coastal hazards that are present in the Lake now and may occur in future.

Investment in the Lake Illawarra CMP provides an opportunity to directly improve and preserve the water quality, environmental habitats, cultural spaces and recreational opportunities of Lake Illawarra, and in doing so, bring benefits to the public."

In response to the negative changes which have occurred since the entrance was trained, addressing erosion within the entrance channel of Lake Illawarra was identified as action EC1 of the CMP. Action EC1 is described in the CMP as: "*Investigate and Finalise Options to Manage Erosion and Accretion Changes in the Entrance Channel*". One of the tasks outlined within action EC1 is to prepare a "Lake entrance management options study". This scope of works addresses this task within action EC1.

1.4 Overview of project components

1.4.1 Preamble

The scope of works (agreed with WCC) included three reports generated during two study stages:

- Stage 1: Options development and preliminary assessment
    - Report 1: Preliminary management options assessment (Coghlan et al., 2023)
    - Report 2: Data compilation including multiple data collection campaigns (Tucker et al., 2023a)

- Stage 2: Detailed assessment of preferred options
    - Report 3: Management options assessment (this report)

All three reports for the study are described in the following sections 1.4.2 to 1.4.4.

1.4.2 Report 1: Preliminary management options assessment

The aim of this Stage 1 assessment was to produce a shortlist of preferred, long-term entrance management options to be assessed in detail during Stage 2. An initial list of 50 management options was developed by combining the outcomes from two ideas workshops with specialist staff from WCC, SCC, DCCEEW, WRL and MHL. A high level multi criteria analysis (MCA) of each of these management

options was then carried out. The criteria for the MCA, and their respective weightings, were facilitated by WRL and finalised by WCC, SCC and DCCEEW. As a result of the MCA, the 50 management options were ranked in order of preference for the consideration of the PCG to establish an agreed shortlist of five options which formed the basis of Stage 2 of the study. The following five management options were shortlisted during Stage 1 of the study:

- **Option 1:** Variable depth rock weir beneath Windang Bridge
- **Option 2:** Rock weir beneath Windang Bridge with gate structures to fine tune flow
- **Option 3:** Head loss structures at the western end of the entrance across all three channels
- **Option 4:** Staggered groyne field in the entrance channel
- **Option 5:** Remove both training walls (return to pre-2007 conditions)

1.4.3 Report 2: Data compilation

This Stage 1 report summarises relevant literature to date, including data collection and process understanding. It captured the learnings from data collection carried out in 2018, 2021 and 2022 as well as work undertaken as part of the Windang Bridge protection works being implemented by Transport for NSW following excessive erosion of sand beneath some of the bridge piers. This report includes valuable background/supporting information for the PCG to enable preliminary assessment of long-term entrance management options. A preliminary draft version of this Stage 1 report was used to inform the development of the initial list of 50 long-term entrance management options. This report also documents collected data that was used to inform the detailed numerical modelling in the Stage 2 assessment.

1.4.4 Report 3: Management options assessment (this report)

The aim of this Stage 2 assessment was to undertake further detailed analysis on the agreed shortlist of long-term management options confirmed at the end of Stage 1. A range of structure geometries for these options was established and tested using an updated, calibrated numerical model of Lake Illawarra estuary for present day tidal and flood conditions. This report included three steps:

Step 1: Defining the management objectives
Prior to further consideration of the five shortlisted options, the management objectives were defined for the project. These were used to refine the option geometry and compare the options. This is outlined in Section 2.

Step 2: Numerical modelling to refine the geometry of the five options
Modelling was used to determine the geometry (location, length, elevation) required in the design to meet the primary quantitative management objectives defined in Step 1. This is outlined in Section 3, with additional detail provided in the appendices.

Step 3: Options assessment
A qualitative assessment of each of the refined options is provided to discuss the relative benefits and compromises required to implement each option, compared to the present day management of the entrance channel. This is provided in Sections 4 to 9.

As a result of the Stage 2 numerical modelling and the options assessment, the descriptions for each of the five options from Stage 1 were updated as shown Table 1.1 and Figure 1.2. The number ordering of the options was also updated between Stage 1 and Stage 2. Note that while all five options are shown in Figure 1.2 for illustrative purposes (where Options 4 and 5 partially overlap), it is envisaged that only one of these options would be implemented in the future.

Table 1.1 Changes to names for the agreed shortlist of long-term management options

Option number	Option name (Stage 1)	Option name (Stage 2)	Rationale for name revision
1	Variable depth rock weir beneath Windang Bridge	Rock weir near Windang Bridge	The weir is no longer described as “variable depth” as the Stage 2 numerical modelling demonstrated that such a structure would not meet the quantitative management objectives. Variable depth weirs are presented in the modelling step (Step 2) of this report. Due to concerns over potential impacts of the weir on the bridge piers and associated maintenance access to them, the location has been changed from “beneath” to “near” Windang Bridge.
2	Rock weir beneath Windang Bridge with gate structures to fine tune flow	Rock weir near Windang Bridge with gate structures to manage flood impacts	While this structure has not been numerically modelled, its description has been revised as it was assumed during the Stage 2 options assessment that the primary purpose of the gate structures would be to mitigate potential upstream flood impacts rather than control daily tidal flows. The location has been changed from “beneath” to “near” Windang Bridge for the same reasons as Option 1.
3	Head loss structures at the western end of the entrance across all three channels	Rock weirs at the western end of the entrance across all three channels	Description updated for consistency with Options 1 and 2 so that the head loss structures are rock weirs.
4	Staggered groyne field in the entrance channel	Staggered groyne field with armoured bed	Bed armouring has been added to this option as the Stage 2 numerical modelling demonstrated that it is required to meet the quantitative management objectives, as shown in the modelling step (Step 2) of this report. The description that this option is “in the entrance channel” has been removed for brevity.
5	Remove both training walls (return to pre-2007 conditions)	Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	Large scale sand nourishment has been added to this option as it is assumed necessary to achieve the target historical state in a guaranteed period.

The purpose of this report is to provide sufficient information to the PCG, the community and other stakeholders to support decision-making regarding a long-term option for the management of the Lake Illawarra entrance channel. Members of the PCG have not formed a position on the preferred entrance management option as it is to be informed by community feedback, additional detailed studies and the overall Coastal Management Framework.



Figure 1.2 Summary of management options for Stage 2 assessment

2 Management objectives

2.1 Preamble

Without implementation of a long-term management option that reduces tidal flows through the Lake Illawarra entrance channel the following will occur:

- Erosion of the channel bed and both foreshores will continue (threatening to undermine assets including Windang Bridge, revetments, natural banks, the Windang groynes, boat ramps, cultural heritage and the training walls)
- The tidal range in the lake will continue to increase (until it is the same as the ocean) leading to nuisance flooding of assets on higher high tides, exposure of greater mud flat areas on lower low tides (which may reduce amenity for the local community associated with increased odours) and negative impacts on some flora and fauna species
- The safety of in-water recreation within the entrance channel will deteriorate with increasing tidal velocities

In order to specify what options should be analysed, it was essential to identify what the key management objectives were. These objectives were identified in consultation with the PCG.

2.2 Quantitative objective

There is a positive feedback loop between foreshore and bed erosion and the increasing tidal range in Lake Illawarra; these management issues are intrinsically linked. Accordingly, while both issues have been assessed in the Stage 2 numerical modelling, the primary performance measure for each option has been the resulting tidal range in the lake, as indicated by the numerical modelling (or observations for pre-entrance training for Option 5).

Determining the target tidal range must take into consideration how the lake has evolved since the training walls were completed. The first year of available tidal range measurements following completion of the training walls is from 1 July 2007 to 30 June 2008. While the lake tidal range that year was approximately only 40% of today, we know that the entrance channel was in an unbalanced condition because erosion has continued. The training walls significantly reduced the transport of wave-driven marine sediments into the entrance channel, and with this reduced inflow of sand, bed shear stress from tidal flows was sufficiently high in the year ending 30 June 2008 to result in foreshore and bed erosion.

It was therefore decided in discussion with the PCG that, for the purpose of this study, a **target tidal range equal to (or less than) the observed tidal range immediately following the entrance training (0.07 m)** should be analysed. This did not necessarily require the absolute elevation of high or low tide to be maintained; just the difference between the two elevations (the magnitude of the tidal range) was used as a quantitative objective for the modelling to refine option geometry. This has been assessed as the best quantitative measure for ensuring foreshore erosion will be effectively managed, although bed shear has also been utilised from the numerical model results.

For any tidal range larger than this (e.g. 2015 and 2016 conditions), the present rate of erosion would be reduced but not halted. Ongoing erosion would continue to result in increasing tidal flows and increasing lake tidal range, albeit at a slower rate of change than present. The reader is referred to the Stage 1 data compilation report (Tucker et al., 2023a) where case studies of three other NSW estuaries that were trained prior to Lake Illawarra (and are eroding comparatively more slowly) are presented.

2.3 Qualitative criteria

The tidal range, which is inherently linked to the foreshore erosion, was adopted as the primary quantitative objective for the options study. However, it is recognised that the entrance channel influences the Lake Illawarra system in numerous complex and interrelated ways. While training of the entrance has had a detrimental impact on erosion of the foreshore, it has had a positive impact on other aspects of the Lake. For example, one benefit of the unstable scour occurring in the entrance channel as a result of the construction of the training walls in 2007, is that upstream flood drainage has improved due to increased hydraulic efficiency. The community also values the recreational amenity provided by the clear marine water in the channel.

To account for the balance between changing the tidal regime in the lake through manipulating the entrance, eight qualitative criteria (in addition to achieving the target tidal range and managing foreshore erosion) have been included when assessing the impact of each potential management options. These include:

- Water quality in the lake, primarily related to tidal flushing
- Recreational safety for unpowered in-water activities, which is related to tidal velocities and is also impacted by localised turbulent or high velocity flows in the vicinity of any new structures
- Flooding from catchment/rainfall, which improves with increased hydraulic efficiency of the channel
- Flooding from coastal storms, which improves with decreased hydraulic efficiency of the channel
- Fish passage, which is impacted by physical barriers as well as velocity and depths across the channel
- Flora and fauna, including changes to estuarine macrophytes, as well as bird and fish habitat
- First Nations heritage, including risks to archaeological sites and cultural heritage
- Boating access, which is impacted by physical barriers as well as velocity and depths across the channel

2.4 Balancing management objectives

The key objectives for this study (recommended by WRL and adopted by the PCG) have been to identify management options which reduce foreshore and bed erosion by reducing the tidal range in Lake Illawarra from its current range to the 2008 observed range. Option geometries were refined using numerical modelling, presented in Section 3, to achieve this.

Management options that met the key objectives were then qualitatively assessed against the other key management criteria listed above with the assistance of the multi-agency project group. Commentary has also been provided on whole of life cost, the potential for staging and reversibility and other risks for each option assessed. This report presents that there is no long-term entrance management option which does not have a negative impact on at least three key management criteria within the entrance channel. For example, each of the shortlisted management options will have a negative impact on water quality (i.e. tidal flushing), upstream flooding and boating access. As such, the selection of a preferred long-term entrance management option for Lake Illawarra will be challenging, as it involves trade-offs to find the optimal compromise between potentially conflicting management objectives/criteria in the Lake Illawarra CMP.

3 Numerical modelling

3.1 Preamble

To assess the hydrodynamic impacts of implementing various management options within the entrance channel, WRL developed an updated hydrodynamic model of the Lake Illawarra estuary using the modelling package RMA. An RMA-2 (King, 2023), two-dimensional, depth-averaged, finite element hydrodynamic model was developed based on bathymetry surveys in the entrance channel undertaken between 29 November and 16 December 2021. This model was calibrated against tidal flow data captured on 6 December 2021 and water level data recorded between 1 December 2021 and 28 February 2022. Appendix A provides further details of the development and calibration of this updated model.

Assessment of the hydrodynamic numerical model results for the range of option geometries was undertaken in two parts. The first assessment focused on the key objectives of reducing foreshore and bed erosion and reducing the tidal range (Section 3.5). For option geometries which met these hydraulic objectives, their impacts on other key management criteria were then considered in a second assessment part (Section 3.6).

3.2 Model simulation period

Since the quantitative objective for the management options is for the lake tidal range to not be greater than the 2008 conditions to prevent ongoing erosion in the entrance channel, the model was run with a 14 day warm up period (16 June 2008 to 29 June 2008) and a 28 day simulation period (30 June 2008 to 27 July 2008) on a 15 minute timestep. While any period of ocean tides could have been selected, this simulation period was adopted because it included larger spring tide conditions and minimal rainfall. Water level measurements were also available during this period for direction comparison with modelled water levels for the base case and management options. That is, the base case conditions (tidal range) are based on observed water levels only. WRL has not modelled the 2008 conditions in Lake Illawarra; historical water level measurements from 2008 have been used as a boundary condition in conjunction with model bathymetries based on 2021 surveys (see Section 3.4.1 for further details on bathymetry). This allows the model results to be directly compared to observed 2008 conditions.

3.3 Modelled scenarios

The following management options were modelled during Stage 2:

- **Option 1:** Rock weir beneath Windang Bridge (Figure 3.1)
- **Option 3:** Rock weirs at the western end of the entrance across all three channels (Figure 3.2)
- **Option 4:** Staggered groyne field (Figure 3.3 and Figure 3.4)

Note that while the name of Option 1 in the Stage 2 assessment is “Rock weir *near* Windang Bridge” it was modelled beneath Windang Bridge and is referenced as so throughout Section 3 and Appendices B, C and D. Where options were not explicitly modelled, engineering judgement was utilised to assess the most appropriate assumptions about which model scenario was most appropriate to inform decision making. Option 5 was not modelled, however observed data from 2008 was used to assess this option.



Figure 3.1 Option 1 and 2 location: rock weir beneath Windang Bridge

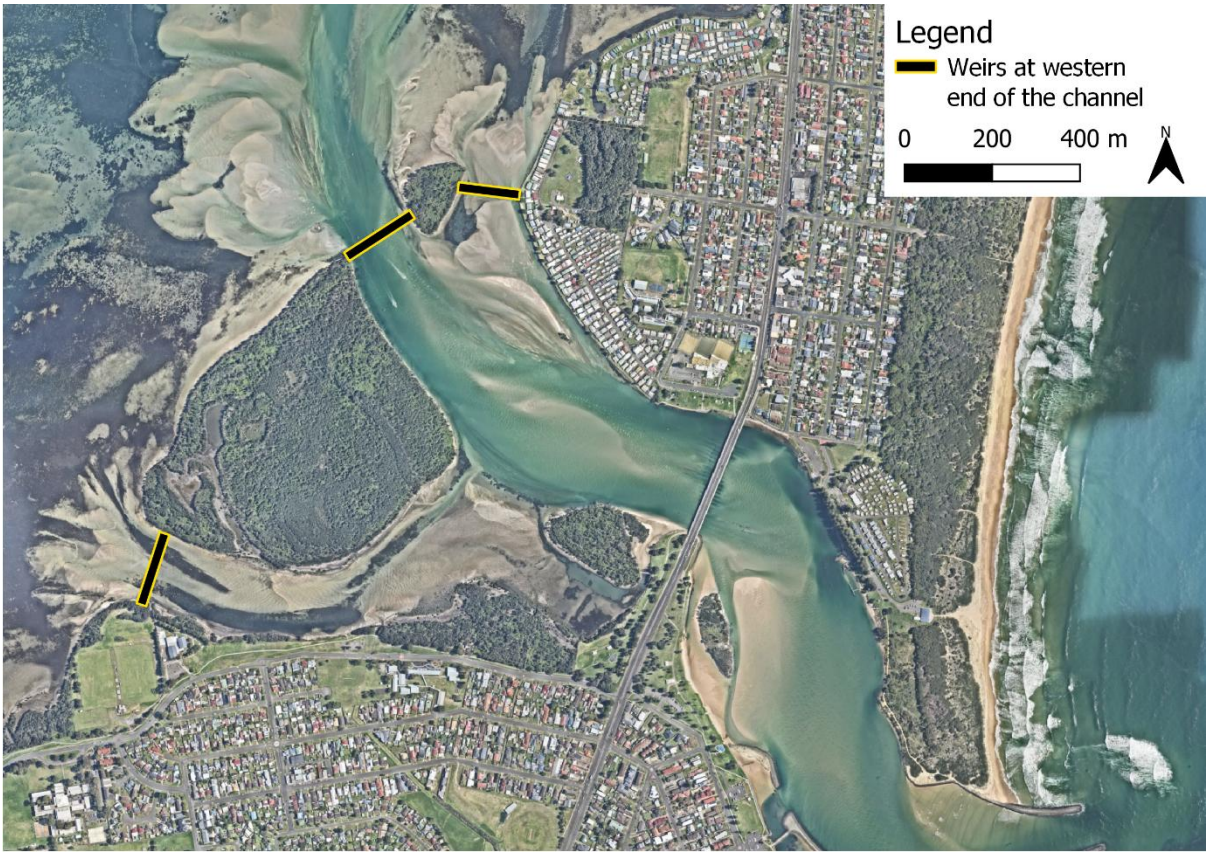


Figure 3.2 Option 3 location: weirs at the western end of the entrance across all three channels

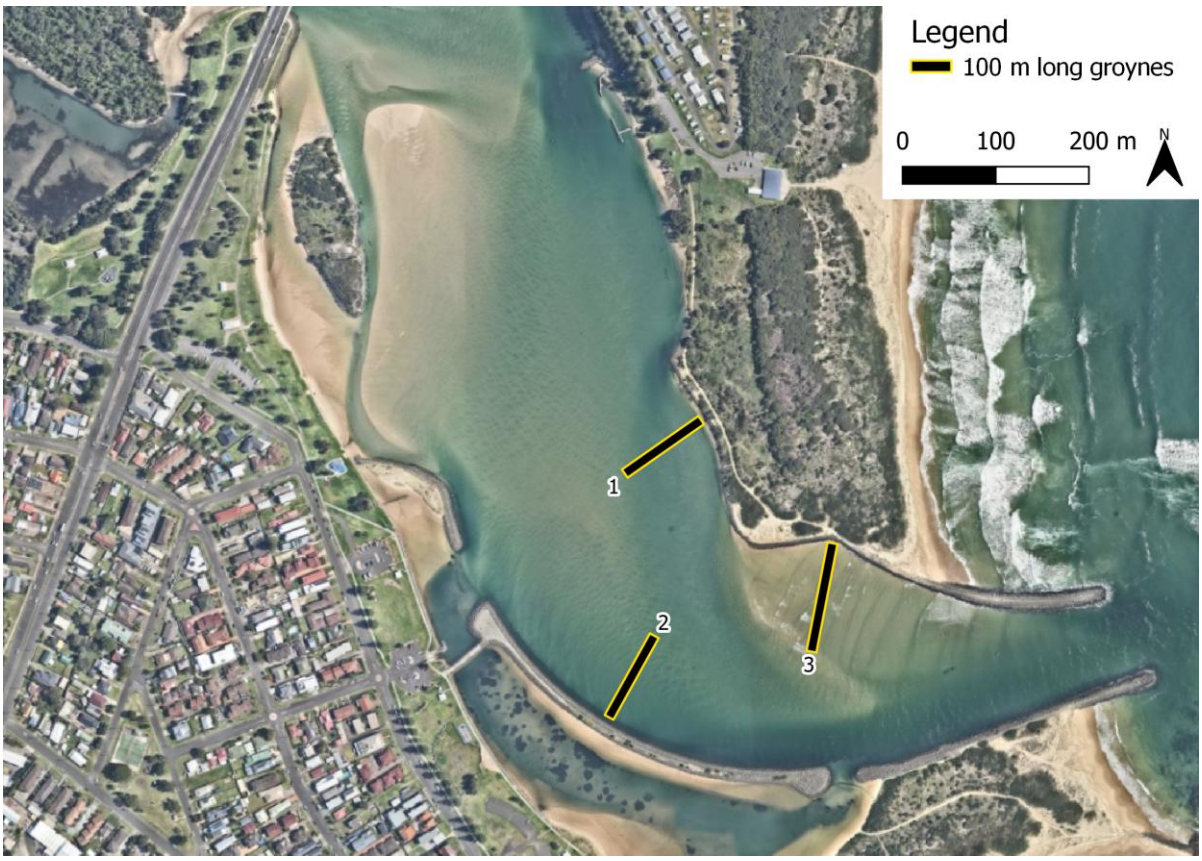


Figure 3.3 Option 4A location: staggered groyne field

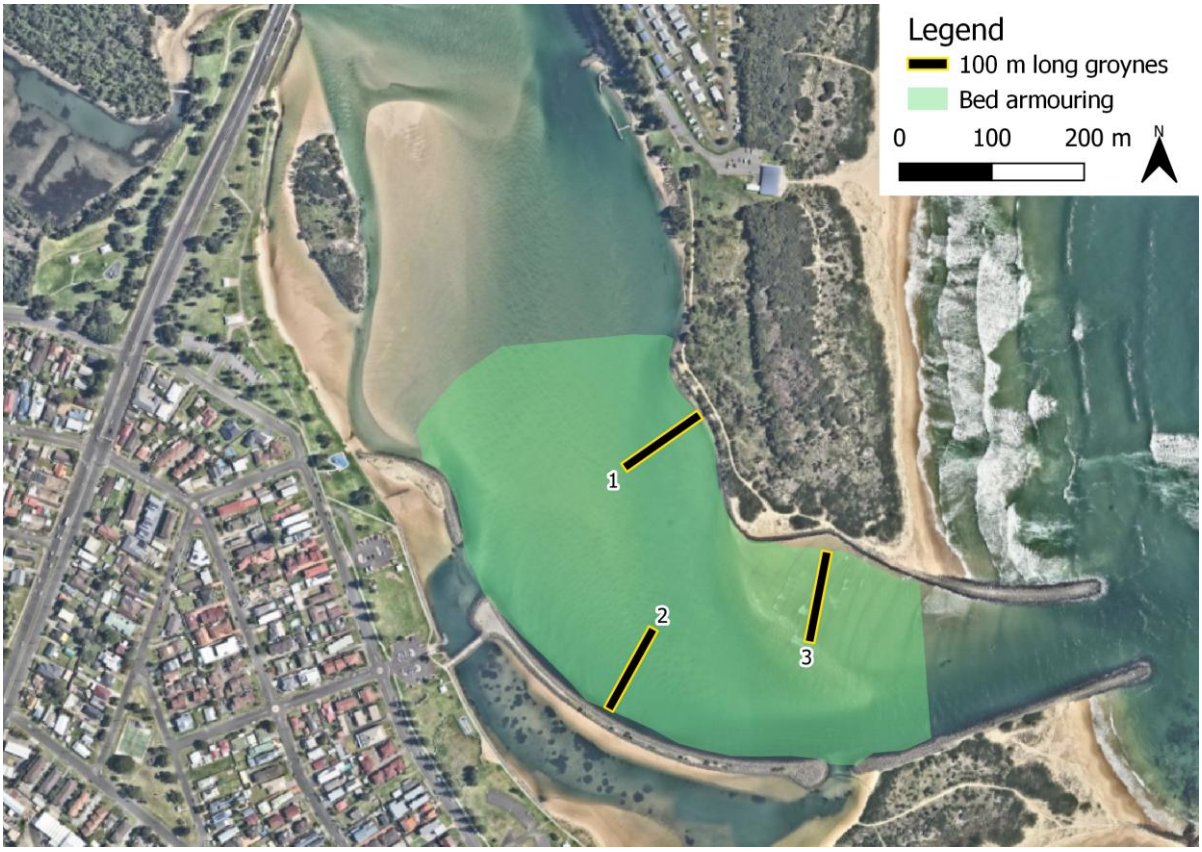


Figure 3.4 Option 4B location: staggered groyne field (with armoured bed)

A summary of the “base case” and three management options (including 14 different structure geometries) modelled to date are shown in Table 3.1. Cross-sections for each structure geometry are provided in the Appendix B along with the mean tide level and recent (2021) and historical (2008 and 2012) bed surveys at these locations.

Table 3.1 Summary of modelled management options

Management option	Structure geometry
Base case	no structure
1. Rock weir beneath Windang Bridge	1A: -0.5 m AHD weir with 1×100 m wide channel at -2.5 m AHD 1B: -0.5 m AHD weir with 2×50 m wide channel at -2.5 m AHD 1C: -0.5 m AHD weir with 1×50 m wide channel at -2.5 m AHD 1D: -0.5 m AHD weir with 1×25 m wide channel at -2.5 m AHD 1E: 0 m AHD weir with 1×50 m wide channel at -2.5 m AHD 1F: -0.5 m AHD weir all the way across (no channel) 1G: 0 m AHD weir all the way across (no channel) 1H: 0.1 m AHD weir all the way across (no channel) 1I: 0.25 m AHD weir all the way across (no channel) 1J: 0.5 m AHD weir all the way across (no channel)
3. Rock weirs at the western end of the entrance across all three channels	3A: Central channel: -0.5 m AHD weir with 50 m wide channel at -2.5 m AHD; Northern and Southern Channels: -0.5 m AHD weir 3B: -0.5 m AHD weirs across all three channels
4. Staggered groyne field	4A: Three 100 m long groynes 4B: Three 100 m long groynes (with armoured bed)

3.4 Boundary conditions

3.4.1 Bathymetry

The RMA-2 hydrodynamic model was not coupled with a sediment transport model but rather was used to simulate flows with a fixed bed. That is to say the model does not actively predict erosion, deposition or marine sediments entering the entrance. Rather, with the available data the model predicts currents and water depths from which calculations were made of whether the uncontrolled scour that is currently being observed is likely to continue into the future.

The model bathymetry for the base case simulation was the same as that in the calibrated model (29 November to 16 December 2021 surveys), except that any areas lower than -2.5 m AHD below the southern two-thirds of Windang Bridge (between piers 11 and 33) were raised to an elevation of -2.5 m AHD. This was undertaken to match the Stage 3 scour protection works currently being installed at the time of writing by Transport for NSW (TfNSW, 2022) based on the 16 December 2021 bathymetry survey. This had a limited impact on the cross-sectional area of flow under the bridge and, accordingly, there was negligible difference in the hydraulic conditions resulting from the calibrated and base case models.

For each option geometry tested, the base case mesh was modified to include the structure and the numerical model was re-run.

Initial model tests with the groyne field indicated that bed shear at the heads of the groyne structures (Option 4A only) and beyond the proposed extent of the bed armouring (Option 4B only) was still likely to be sufficient to cause localised bed scour. To test the sensitivity of the results to potential scour, additional model scenarios were included where the bed was lowered to simulate plausible scour. Figure 3.5 shows the existing and scoured bathymetries applied for Option 4A. In addition to general lowering of the bed within the groyne field for the scour sensitivity test, deep holes were added off the head of each groyne (similar to what has occurred with the existing Windang groynes). Figure 3.6 shows the extent and depth of scour applied upstream of the bed armouring (based on the high modelled maximum bed shear stresses upstream of the bed armouring shown in Appendix D Figure D-16) for the sensitivity test for Option 4B.

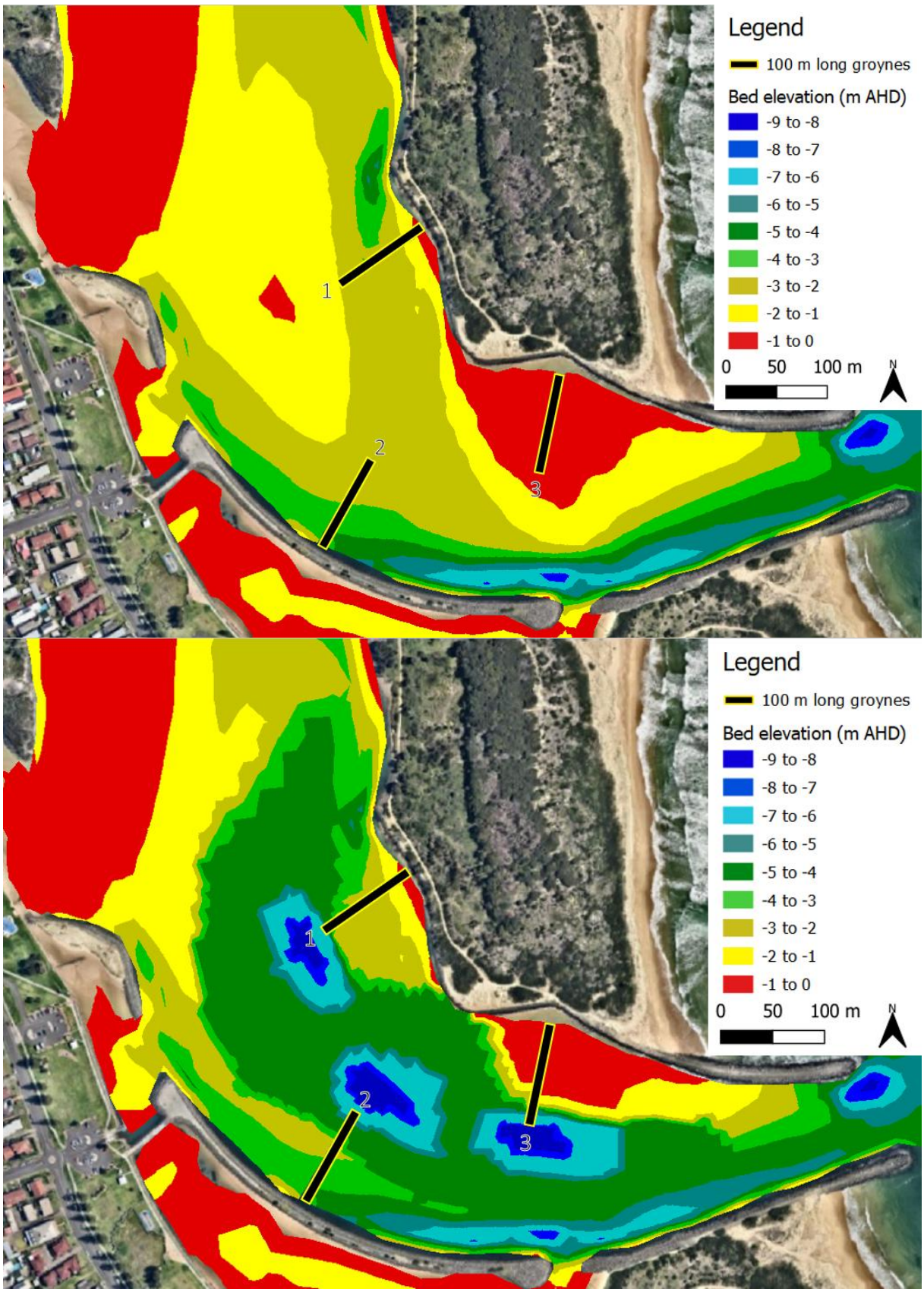


Figure 3.5 Existing bathymetry (top) and scoured bathymetry (bottom) applied for sensitivity test for Option 4A (groyne field)

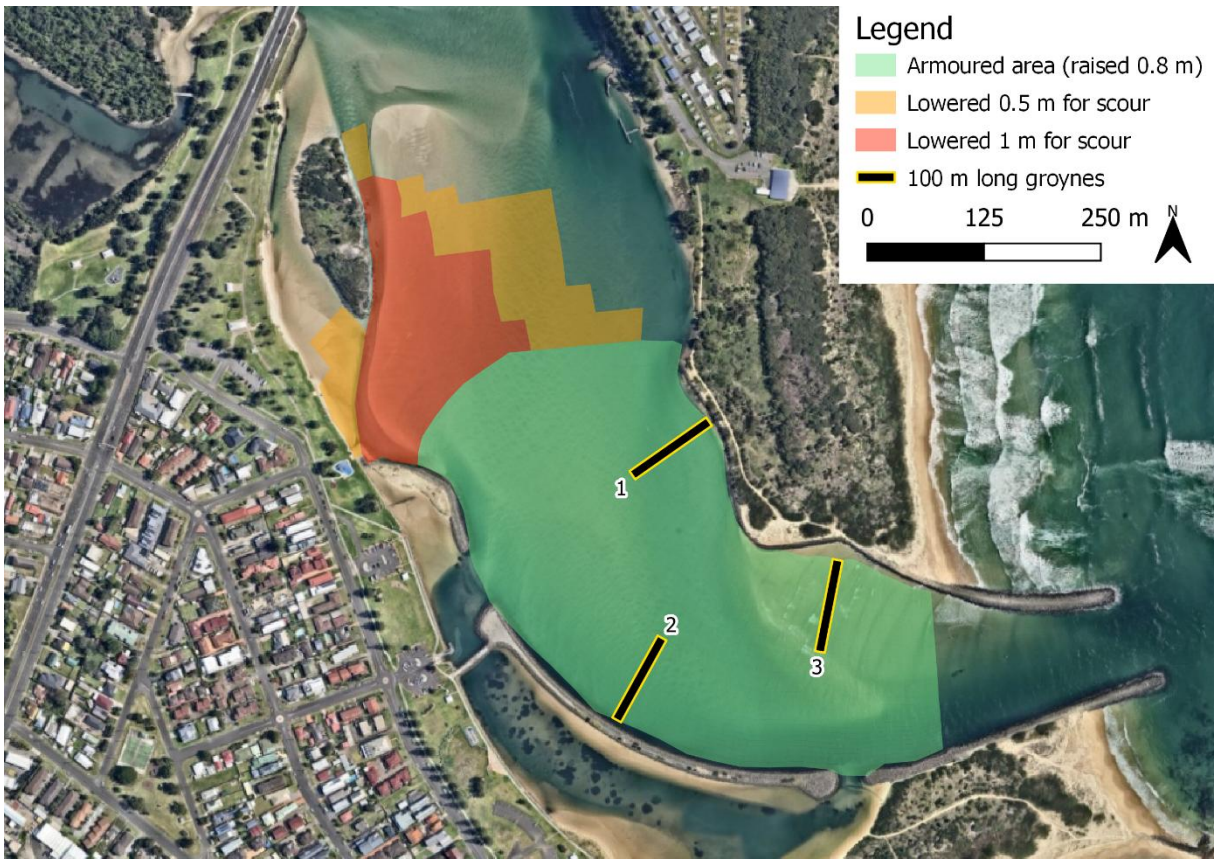


Figure 3.6 Extent and depth of bed scour applied for sensitivity test for Option 4B (groyne field with armoured bed)

3.4.2 Offshore tide (downstream boundary condition)

The downstream boundary of the model was the full ocean tide immediately offshore of the training walls. Measurements from the tide gauge at Port Kembla (operated by National Tidal Centre [NTC] / Bureau of Meteorology [BoM] station number 068253) were adopted as the oceanic boundary condition for all model simulations.

Note that sea level rise was not considered in the model simulations.

3.4.3 Other boundary conditions

There were no catchment inflows or rainfall included in the model tidal simulations. Review of the daily rainfall at Albion Park indicated that this was a reasonable assumption for the model warm up and simulation periods given that the maximum daily rainfall recorded during this time was 4 mm. Peak tidal flow through the Lake Illawarra entrance channel was observed to be almost 800 m^3/s in December 2021, with significant flows on both the ebb and flood tides. Median flows from the surrounding catchment are two orders of magnitude smaller than the peak tidal flows and are hence unlikely to significantly influence erosion in the channel during non-flood conditions.

There were also no waves (wind waves, swell waves or tsunami) included in the model simulations.

3.5 Key objectives assessment

3.5.1 Tidal range results

To assess whether each option geometry would satisfy the 2008 target tidal range in the lake, model outputs for water level between the entrance and Lake Illawarra were extracted along the transect shown in Figure 3.7. This has been compared to the observed tidal range in 2008 based on data at four permanent MHL water level gauges. Further information on the methods used to extract tidal ranges can be found in Appendix C.

Figure 3.8 shows the average high and low tide water level along the transect for the following three scenarios:

Grey lines indicate the observed average high and low tide water levels for 30 June 2008 to 27 July 2008. The 2008 target tidal range (0.07 m) for assessing the management options, is the difference between the high and low tide levels at Koonawarra Bay. Note that the measured 2008 water levels between the four observed gauges have been drawn as straight lines but would not be linear in reality. Note also that on the left side of the x-axis of Figure 3.8, the distance between Lake Illawarra (Koonawarra Bay) and Cudgeree Bay is distorted (e.g. it includes the dashed line shown on the inset in Figure 3.7).

Black lines indicate the modelled base case average high and low tide water levels, established with the 2021 bathymetry driven with the 2008 ocean tides. At the three permanent MHL water gauges inside the estuary, it is clear that the average high tide levels are higher and the low tide levels are lower with the 2021 bathymetry compared to what was measured in 2008 when the entrance channel was significantly less eroded.

Blue lines indicate the modelled water levels for a structure geometry, in this example it is option 1H (bridge weir): 0.1 m AHD weir all the way across. It can be seen that this option meets the 0.07 m tidal range in the lake, however high and low tide elevations in the lake are increased compared to the base case. That is, the mean water level in the lake would be raised by approximately 0.2 m compared to what it is today. Also, downstream of the weir, the tidal range is increased (relative to the base case). That is, implementing the structure would raise high tide levels and lower low tide levels between the structure and the ocean. While the magnitude of change varies, the mean water level in the lake and the tidal range downstream of the structures are both increased for all options which met the target lake tidal range. The impact of these tidal level changes on infrastructure around the lake and the entrance channel requires further consideration prior to implementation.

Figures showing the average high and low tide water levels between the ocean and Lake Illawarra for each structure geometry modelled (including the same 2008 observations and modelled base case) are provided in Appendix C.

Table 3.2 summarises the average high tide level, low tide level and tidal range in Lake Illawarra at Koonawarra Bay for the 2008 observations, modelled base case and all modelled structure geometries over the period from 30 June 2008 to 27 July 2008. Weirs all the way across (no channel) beneath Windang Bridge with elevations of 0.1, 0.25 and 0.5 m AHD met the target tidal range in the lake of 0.07 m. While there were no model scenarios which specifically addressed the presence of adjustable gate structures in conjunction with the weir beneath the bridge, it is assumed to be capable of achieving the same outcomes provided the gates are predominantly maintained in a closed position.



Figure 3.7 Locations where water level data was extracted from the numerical model along transect between the entrance and Lake Illawarra

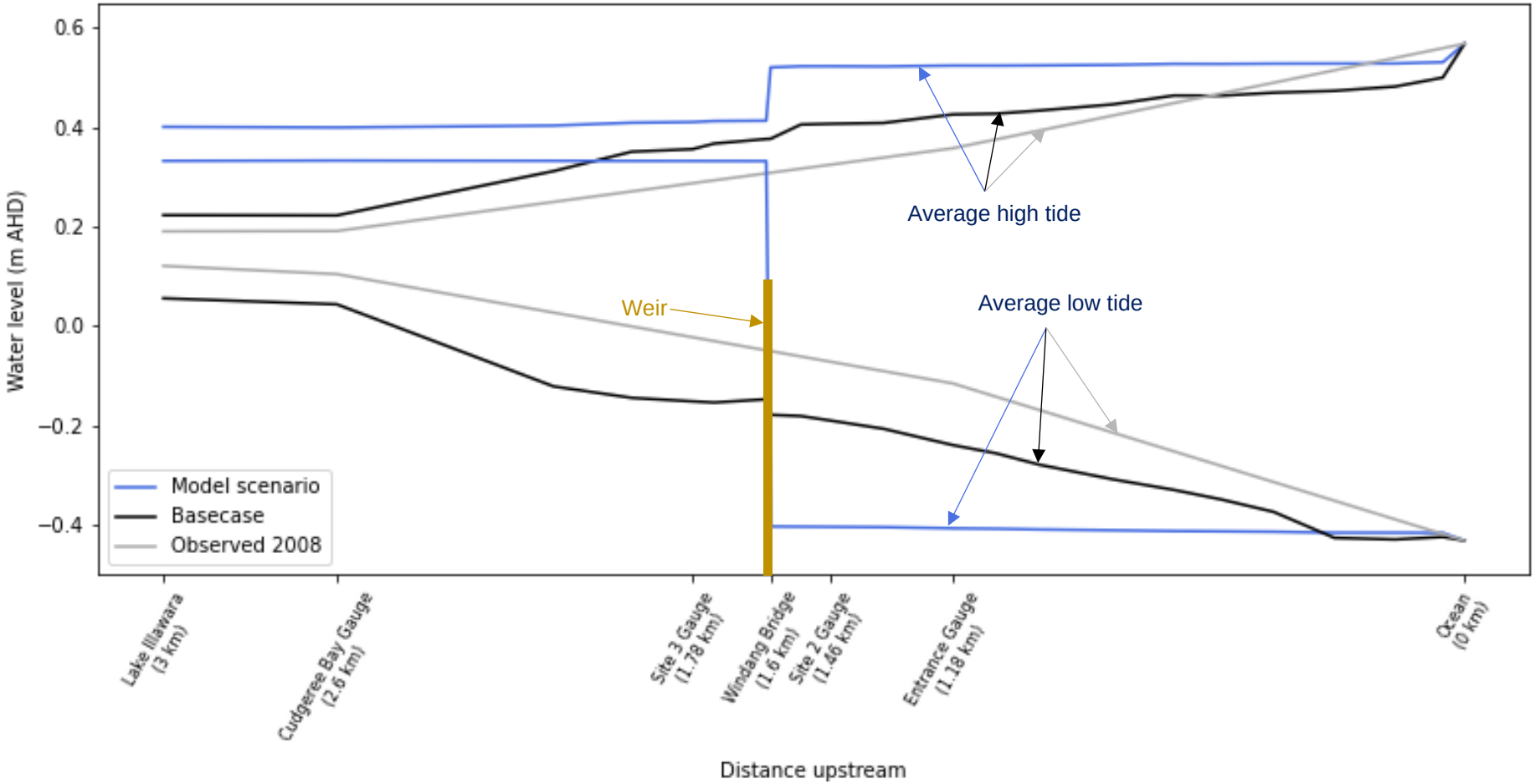


Figure 3.8 Average high and low tide water levels (30/06/2008 – 27/08/2008) along the channel for the observed water levels in 2008 (grey), the modelled base case (2021 entrance geometry, black) and modelled Option 1H (bridge weir, blue): 0.1 m AHD weir all the way across (no channel)

Table 3.2 Modelled management option tidal ranges compared to target tidal range (bold levels indicated the target tidal range was achieved)

Management option and structure geometry	Tidal conditions in Lake Illawarra (Koonawarra Bay)*		
	Avg. High Tide Level (m AHD)	Avg. Low Tide Level (m AHD)	Avg. Tidal Range (m)
2008 observations (target tidal range)	**0.19**	**0.12**	**0.07**
Base case	0.24	0.06	0.18
1. Rock weir beneath Windang Bridge			
1A: -0.5 m AHD weir with 1×100 m wide channel at -2.5 m AHD	0.24	0.07	0.17
1B: -0.5 m AHD weir with 2×50 m wide channel at -2.5 m AHD	0.23	0.07	0.17
1C: -0.5 m AHD weir with 1×50 m wide channel at -2.5 m AHD	0.24	0.08	0.16
1D: -0.5 m AHD weir with 1×25 m wide channel at -2.5 m AHD	0.25	0.10	0.15
1E: 0 m AHD weir with 1×50 m wide channel at -2.5 m AHD	0.28	0.16	0.12
1F: -0.5 m AHD weir all the way across (no channel)	0.27	0.14	0.13
1G: 0 m AHD weir all the way across (no channel)	0.38	0.29	0.09
1H: 0.1 m AHD weir all the way across (no channel)	**0.42**	**0.34**	**0.07**
1I: 0.25 m AHD weir all the way across (no channel)	**0.48**	**0.43**	**0.05**
1J: 0.5 m AHD weir all the way across (no channel)	**0.60**	**0.58**	**0.01**
3. Rock weirs at the western end of the entrance across all three channels			
3A: Central channel: -0.5 m AHD weir with 50 m wide channel	0.23	0.07	0.16
3B: -0.5 m AHD weirs across all three channels	0.27	0.15	0.12
4. Staggered groyne field			
4A: Three 100 m long groynes	0.20	0.07	0.13
4A: Three 100 m long groynes (with local bed scour)	0.24	0.05	0.18
4B: Three 100 m long groynes (with armoured bed)	**0.22**	**0.15**	**0.07**
4B: Three 100 m long groynes (with armoured bed & local bed scour)	**0.22**	**0.15**	**0.07**

* Note that 5 days of tides (9-14 July 2008) have been omitted from the averaging period for the 2008 observations, modelled base case and all modelled options as data from the water level gauge at Koonawarra Bay was unavailable during this time.

None of the model scenarios tested for the western weirs achieved the target tidal range. However, comparison of model 1F (weir beneath Windang Bridge at elevation of -0.5 m AHD) and model 3B (western weirs at elevation of -0.5 m AHD) indicates that the western weirs perform a similar hydraulic function as the weir underneath the Windang Bridge. It is therefore assumed that the western weirs would be effective at meeting the target tidal range if the crest elevation is approximately 0.1 m AHD, or higher. However, this would need to be confirmed with further modelling.

For the staggered groyne field structures, the sensitivity test with local bed scour for option 4A showed that any improvements in lake tidal range immediately following construction would revert back towards the base case lake tidal range with plausible future scour. However, for the groynes with bed armouring (option 4B), plausible future scour upstream of the armouring did not change the lake tidal range which met the 2008 target. For the two staggered groyne field simulations without local bed scour, it is noteworthy that the average tidal range with bed armouring (0.07 m) was smaller than without it (0.13 m). This demonstrates that the bed armouring would not only prevent erosion but contribute to reduction of the lake tidal range through head loss by friction and reduced cross-sectional area.

3.5.2 Bed shear results

To assess the extent to which each option geometry would potentially reduce the present rate of erosion at both the channel bed and foreshore, bed shear output from the model was used as an indicator for likely erosion.

Details of how bed shear has been calculated can be found in Appendix D. A bed shear greater than approximately 1 N/m^2 is likely to result in sediment mobilisation (for these sized sands) and potential erosion (e.g. higher bed shear can be inferred to equal a higher potential rate of erosion). Note that while this method predicts sediment mobilisation and has been used to infer areas of high erosion potential, it does not directly predict erosion (i.e. net lowering of channel bed elevation). Peak flood tide velocities would mobilise sediment towards the lake and peak ebb tide velocities would transport it back towards the ocean, although the volumes are expected to be different due to an asymmetry between the flood and ebb tides. Most importantly, the bed shear method also does not include sediment replenishment from the ocean or other parts of the estuary system.

Figure 3.9 shows the approximate maximum bed shear stress over the period 30 June 2008 to 27 July 2008 for the base case. Any coloured areas in the figure indicate likely sediment mobilisation whenever this maximum bed shear time step (15 minute duration) occurs during the 28 day simulation. Darker coloured areas can be inferred to have higher potential erosion rates.

Figure 3.10 shows the approximate maximum bed shear stress for the same period with implementation of option 1H (bridge weir): 0.1 m AHD weir all the way across (no channel). By comparing this with the base case (Figure 3.9), it can be seen that the extent and severity of erosion is significantly reduced for this structure geometry. It is also important to recognise that erosion is reduced both downstream (which may not be immediately intuitive) and upstream of the structure as a result of velocity reductions on both sides. Reduced erosion upstream and downstream of the structures occurs for all options which met the target lake tidal range.

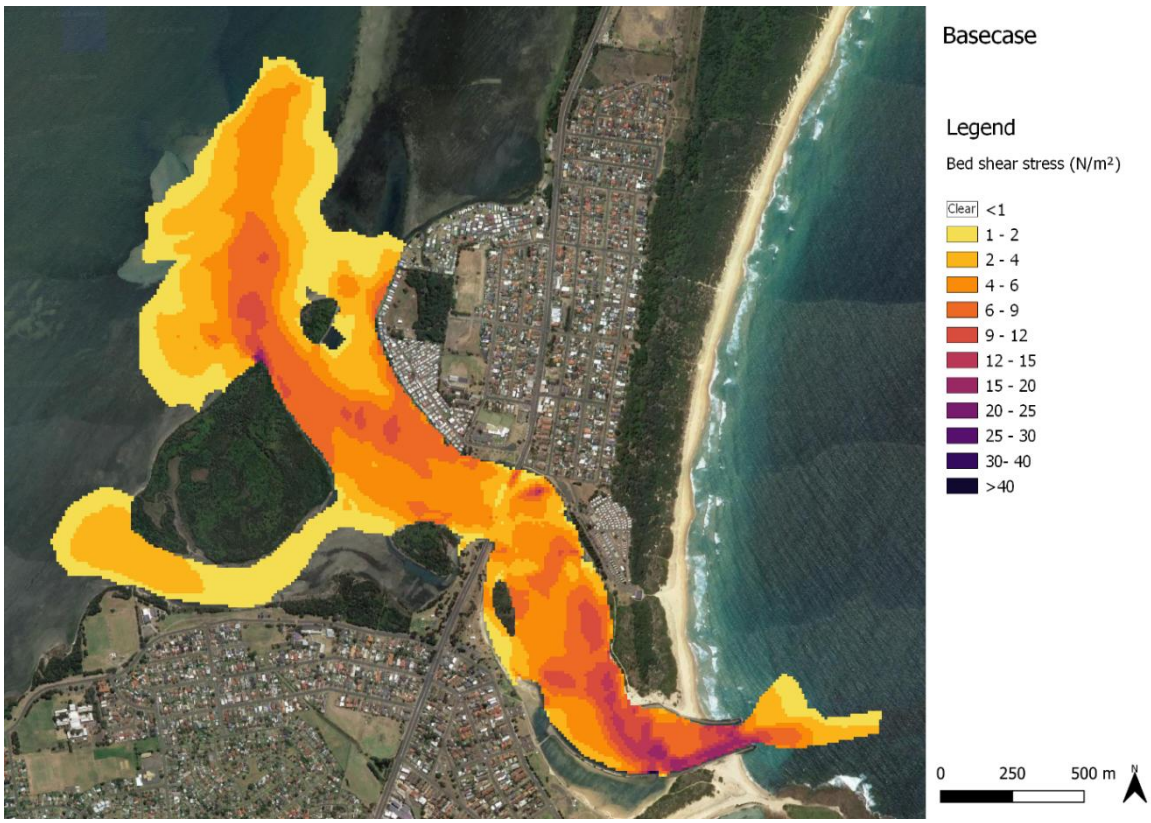


Figure 3.9 Approximate maximum bed shear for modelled base case scenario (2021 channel geometry)

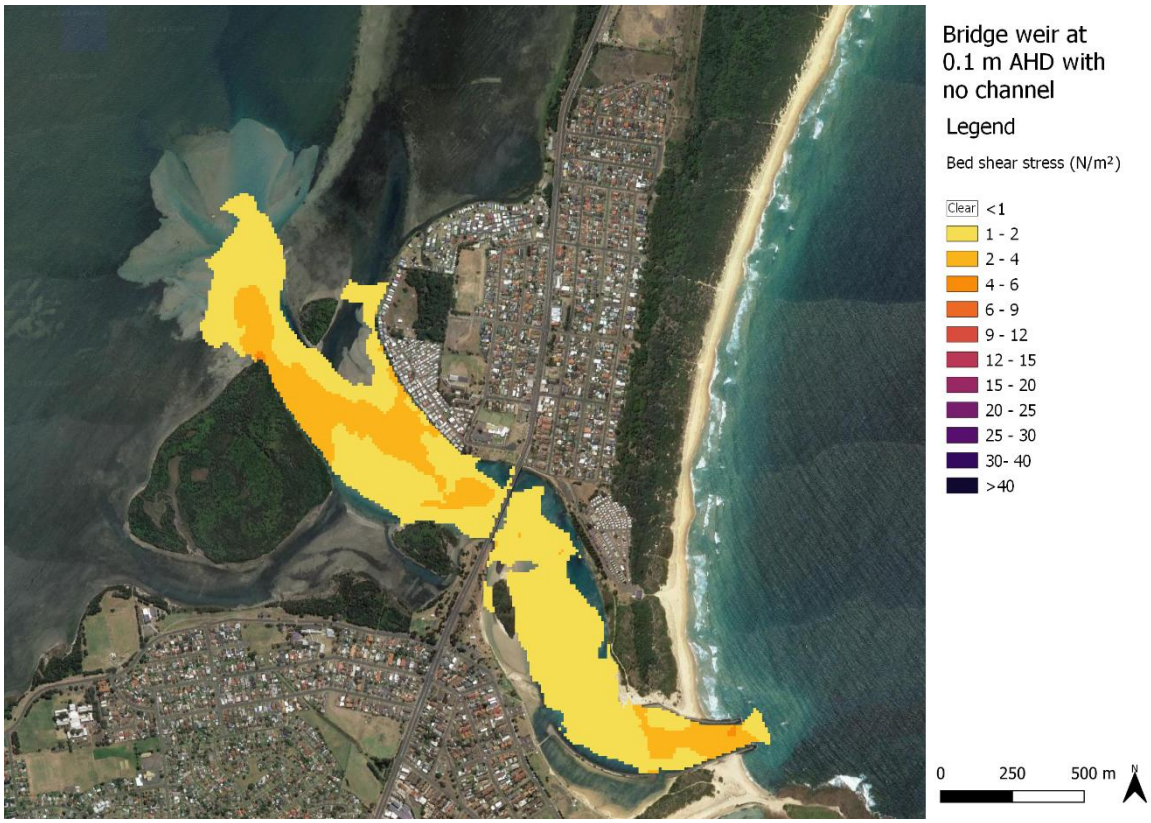


Figure 3.10 Approximate maximum bed shear for modelled Option 1H (bridge weir): 0.1 m AHD weir all the way across (no channel)

Figures showing the approximate maximum bed shear stress for each structure geometry modelled are provided in Appendix D. Structure geometries which had the largest reduction in lake tidal range also had the highest reduction in erosion, which supports the assumption that achieving the target tidal range will also achieve reductions in foreshore erosion. The highest weirs all the way across (0.5 m AHD) had no likely sediment mobilisation in the entrance channel. Other structure geometries had very little erosion reduction (compared to the base case) and although localised erosion increases in the vicinity of abrupt flow changes (e.g. within a groyne field or adjacent to a channel in a weir).

3.5.3 Summary

Following identification of those management option geometries which meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion (summarised in Table 3.3), their impact on other key management issues is discussed in the following section. Note that given the negative impacts of higher weirs on these other issues, it is acknowledged that a 0.1 m AHD weir would be the preferred candidate option compared to 0.25 m AHD and 0.5 m AHD weirs (which result in a lower lake tidal range). As discussed previously, while the western weirs at an elevation of approximately 0.1 m AHD were not explicitly modelled, it is assumed that these would also be able to achieve the target tidal range given its hydraulic similarity to the weir beneath Windang Bridge.

Table 3.3 Summary of modelled management options which achieved target tidal range

Management option	Structure geometry
1. Rock weir beneath Windang Bridge	1H: 0.1 m AHD weir all the way across (no channel) 1I: 0.25 m AHD weir all the way across (no channel) 1J: 0.5 m AHD weir all the way across (no channel)
4. Staggered groyne field	4B: Three 100 m long groynes (with armoured bed)

3.6 Assessment of impacts on other key management issues

3.6.1 Navigability/safety results

All modelled weir options without a channel have a crest level which is too high to allow boat access across them. They present safety concerns for boating and recreation due to high velocities and turbulence. Managing access over the weir options may especially be an issue during spring high tides when the weir is most submerged and poorly visible.

A specific assessment was completed to consider the safety of the staggered groyne field with armoured bed (Option 4B) and whether it is possible to maintain boat access through it.

The following series of figures have been prepared to demonstrate that dangerous boating conditions are likely to occur if Option 4B is implemented:

- Figure 3.11: Time series of velocity at a critical location for base case and option 4B
- Figure 3.12: Velocity contours at peak flood tide (high tide) for base case and option 4B
- Figure 3.13: Velocity contours at peak ebb tide (low tide) for base case and option 4B
- Figure 3.14: Water surface elevation at peak ebb tide (low tide) for base case and option 4B (plan view)
- Figure 3.15: Water surface elevation at peak ebb tide (low tide) for base case and option 4B (side view)
- Figure 3.16: Water depth contours at peak ebb tide (low tide) for base case and option 4B

For option 4B (groyne field), as shown in Figure 3.11, Figure 3.12 and Figure 3.13, relative to the base case, the peak flood tide velocity off the head of groyne 1 is increased from approximately 1.5 m/s to almost 3 m/s and the peak ebb tide velocity is increased from approximately 1.5 m/s to almost 2.5 m/s. Figure 3.14 illustrates that the water surface elevation change at peak ebb tide (low tide) is dramatic; there is a drop of approximately 0.9 m from groyne 1 (lake side) to groyne 3 (ocean side) in a relatively short distance (325 m) compared to the gradual water level change (approximately 0.4 m drop) of the base case. A complementary concept sketch presenting a side view of the water surface profile at this location for the base case and option 4B (groyne field) at peak ebb tide (low tide) is shown in Figure 3.15. This same water level change can also be seen in the average low tide water level plot shown in Appendix C Figure C-14. Finally, Figure 3.16 (bottom) shows that there is a large area off the head of groyne 1 which would be very shallow (less than 1 m water depth) on a spring low tide.

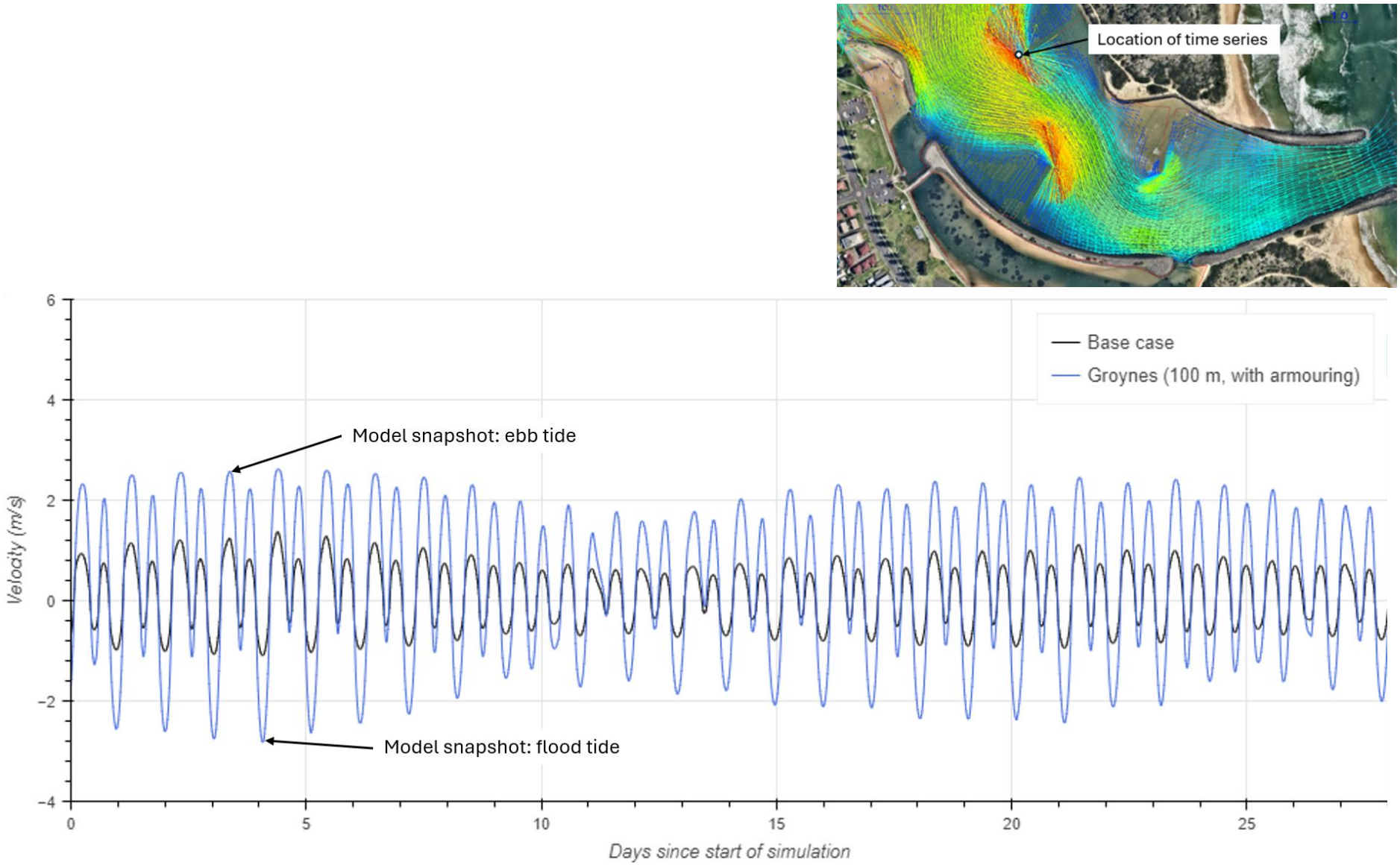


Figure 3.11 Time series of velocity for base case and Option 4B (groyne field) off the head of groyne 1 (location of time series shown in upper right)

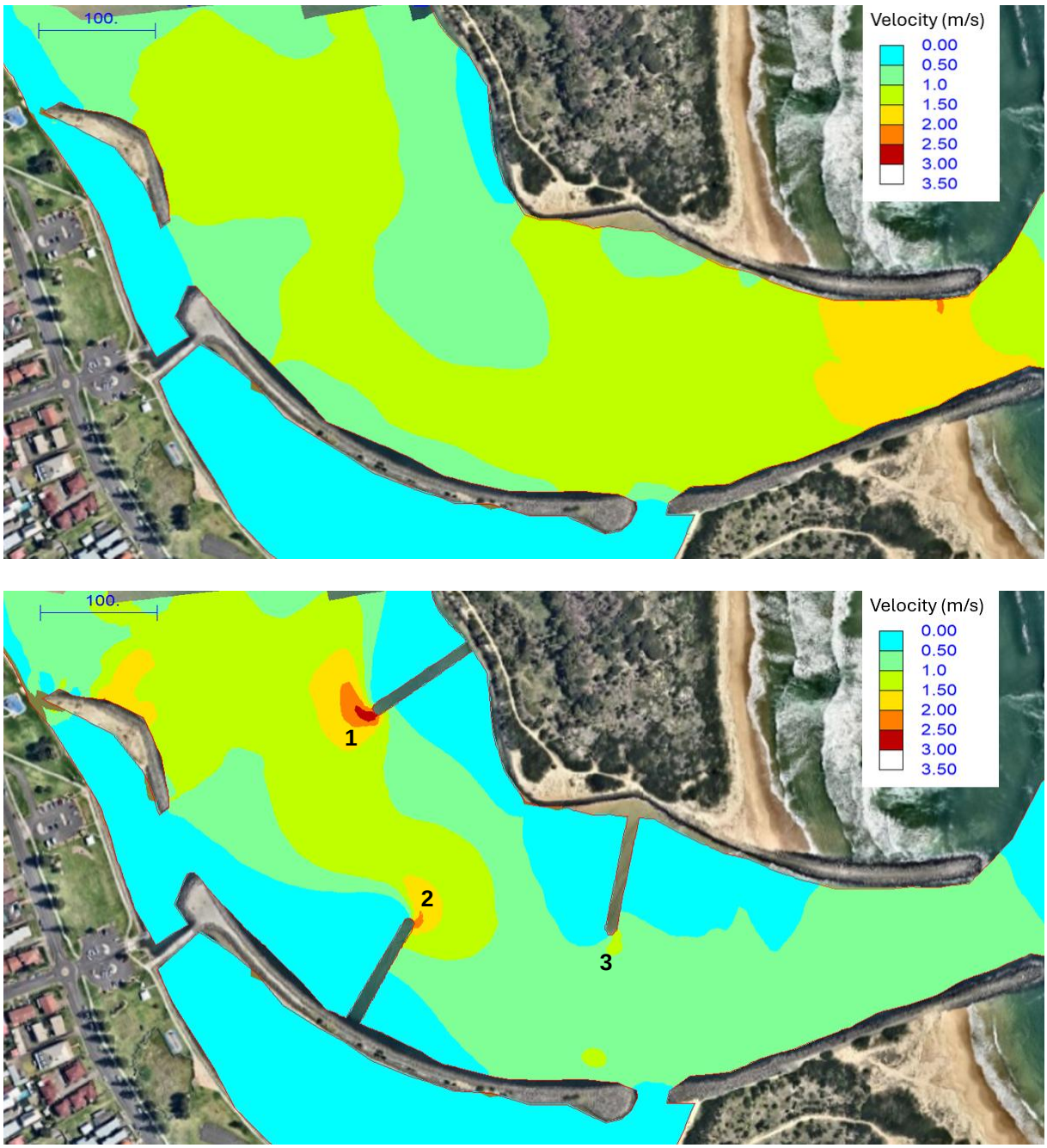


Figure 3.12 Velocity contours at peak flood tide (high tide) for base case (top) and Option 4B (groyne field; bottom). Dry areas are shown in brown

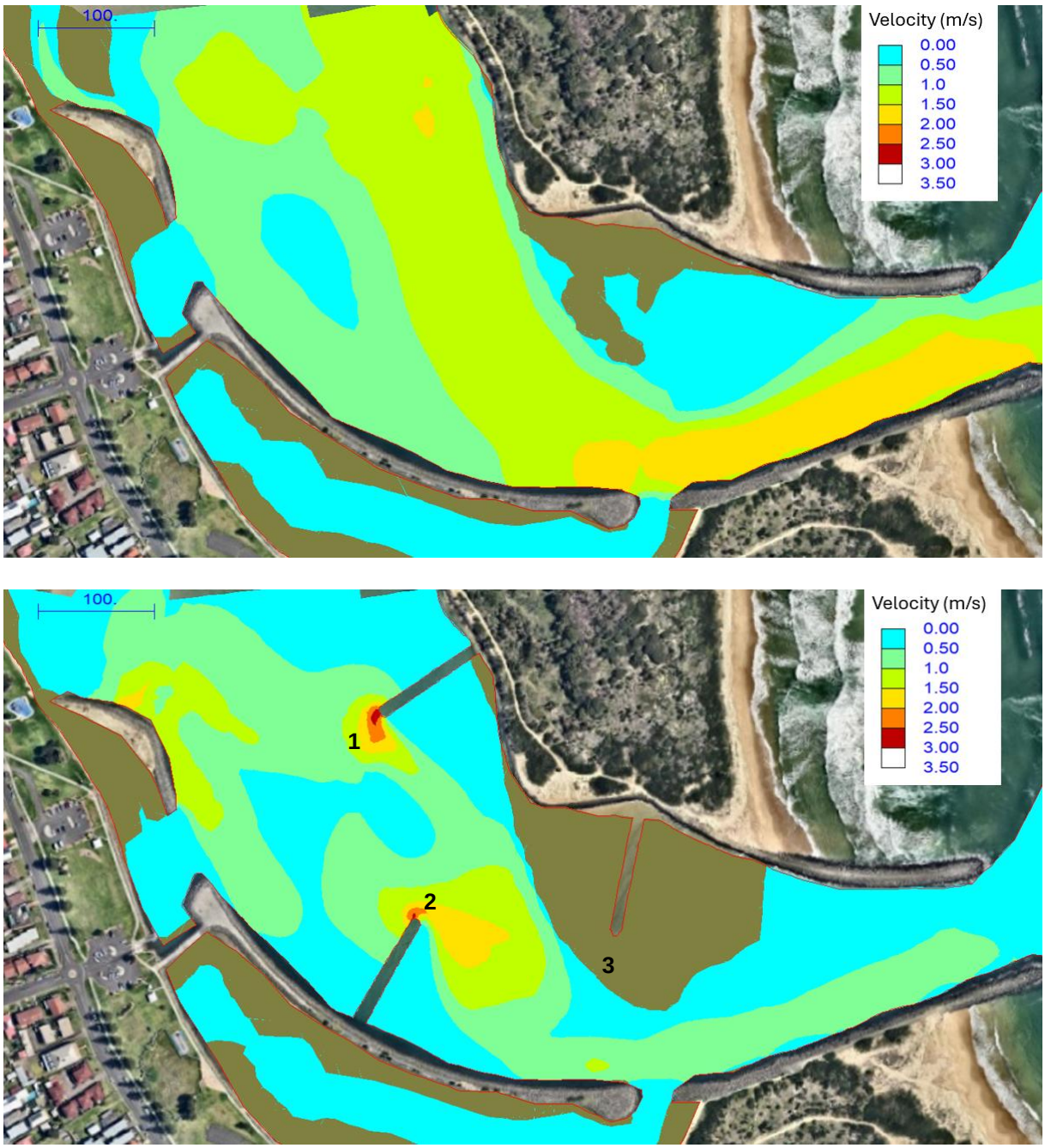


Figure 3.13 Velocity contours at peak ebb tide (low tide) for base case (top) and Option 4B (groyne field; bottom). Dry areas are shown in brown

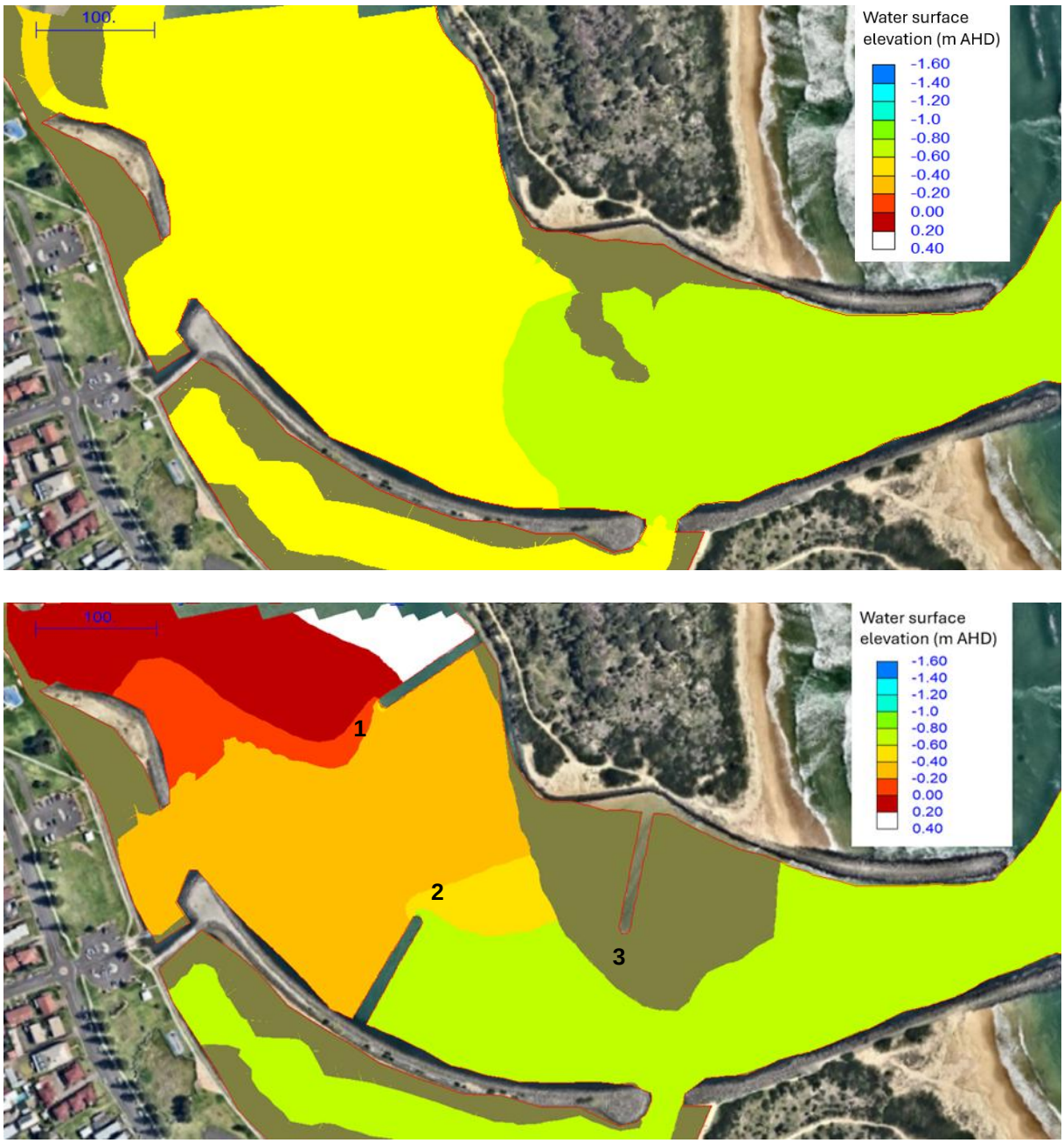


Figure 3.14 Water surface elevation at peak ebb tide (low tide) for base case (top) and Option 4B (groyne field; bottom). Dry areas are shown in brown

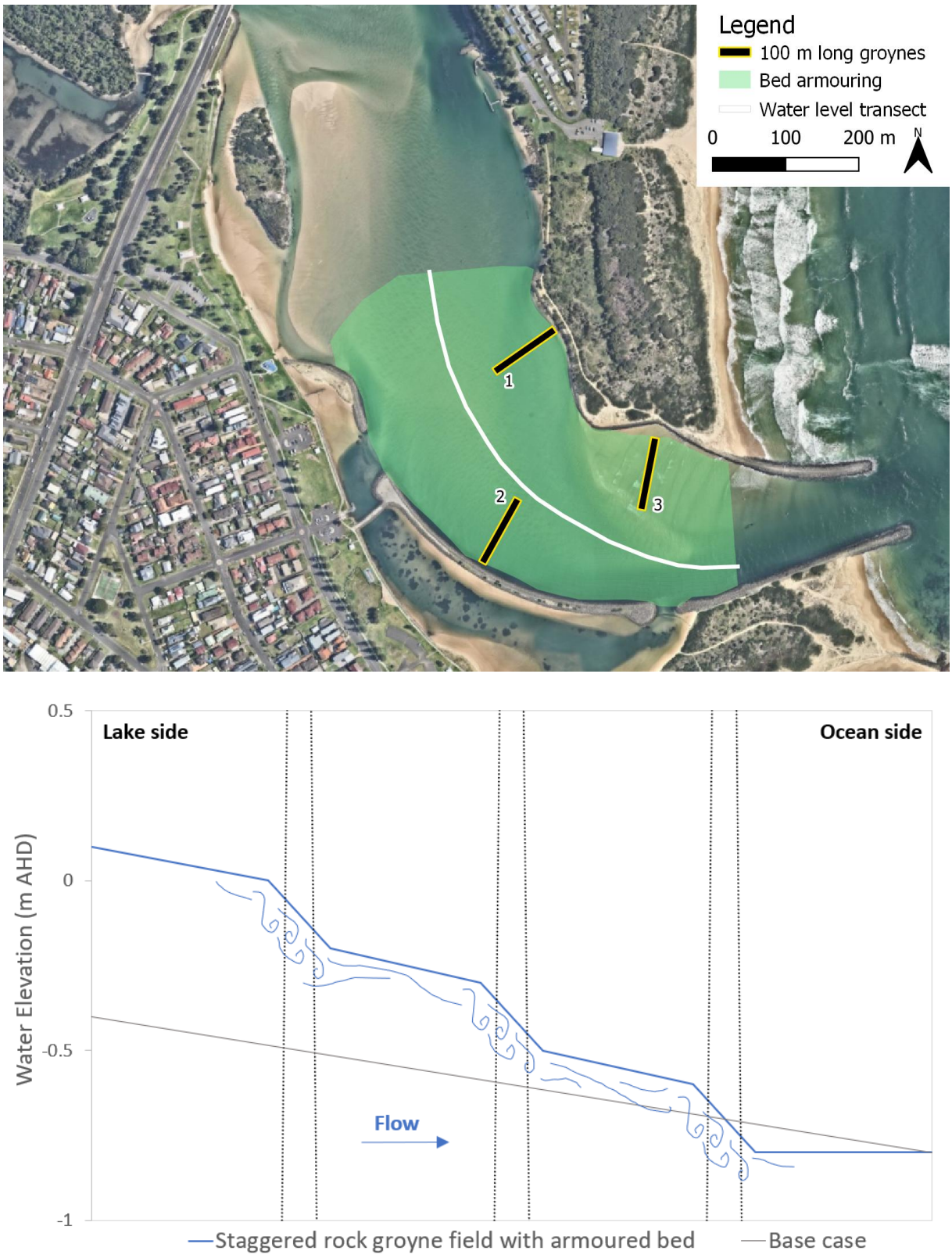


Figure 3.15 Bottom: Modelled sketch of water surface elevations at peak ebb tide (low tide) for base case (grey) and staggered groyne field with armoured bed (blue) (bottom). Top: location of water surface elevation transect

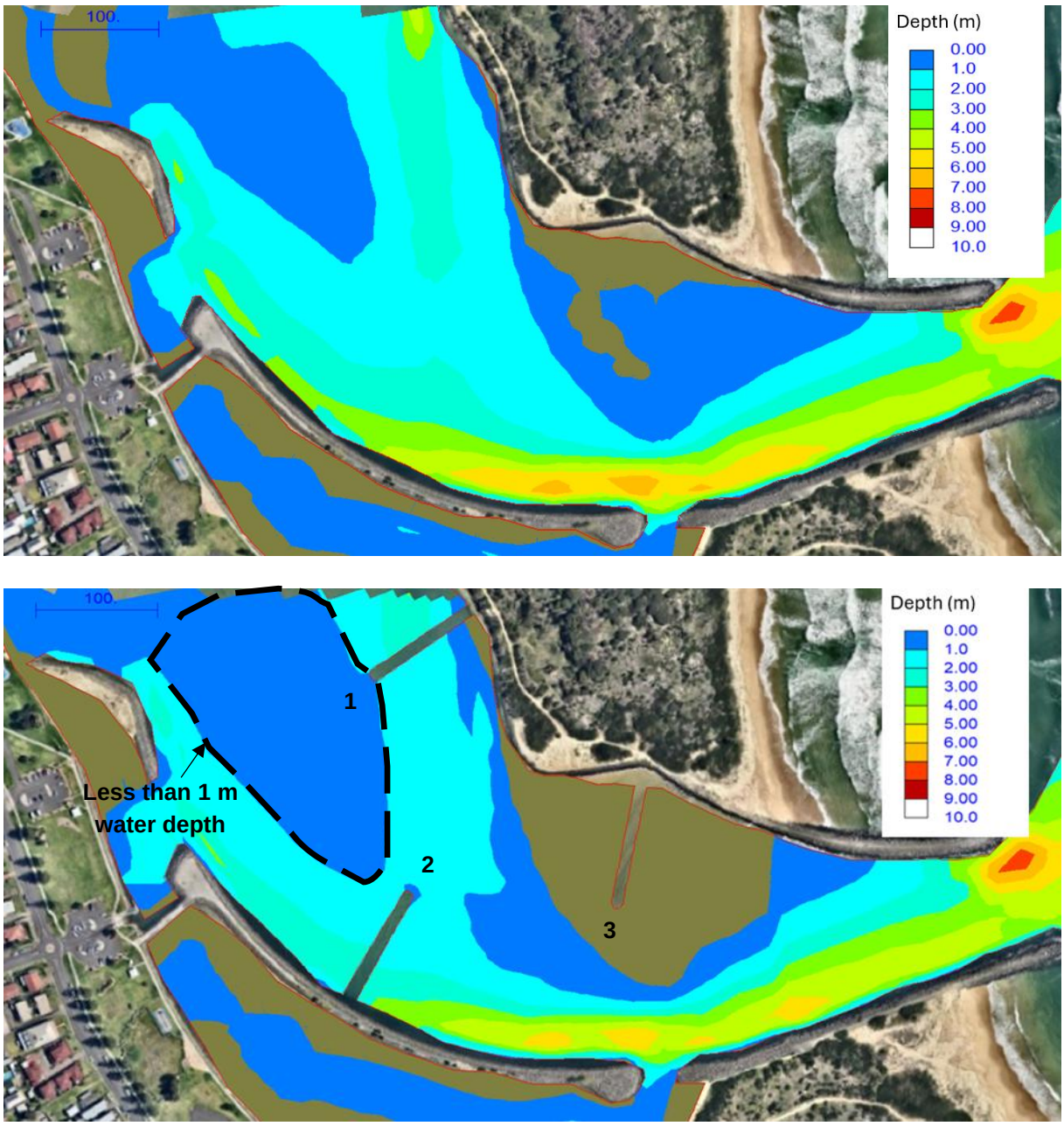


Figure 3.16 Water depth at peak ebb tide (low tide) for base case (top) and Option 4B (groyne field; bottom). Dry areas are shown in brown

While WRL are not boating experts and are not aware of specific criteria for safe boating, we believe that these high tidal velocities and steep water level gradients (which will be present through much of the tidal cycle) would result in dangerous boating conditions for a staggered groyne field. The high velocities and steep water level gradient are also a concern for recreational safety in the channel, which would need to be managed.

In effect, WRL considers that all modelled geometries which met the key hydraulic objectives are not conducive to boat access across them.

3.6.2 Fish passage results

Data from the hydrodynamic model can also be used to compare options against fish passage criteria. However, as these criteria have not been developed for the specific species or targets, WRL made some assessments with the following two rules for options which include weir structures.

1. Fish cannot traverse the weir when the depth averaged velocity over the weir crest is greater than 0.3 m/s in the opposing direction of travel.
2. Fish cannot traverse the weir when the depth over the weir at the centreline is less than 0.5 m.

This criteria has been considered for the weir beneath Windang Bridge with crest elevation of 0.1 m AHD (i.e. the lowest weir structure that met the target tidal range criteria). Example time series of velocity and water depth over the weir crest for option 1H (0.1 m AHD weir beneath Windang Bridge) are shown in Figure 3.17 and tabulated in Table 3.4. The period of time when the velocity and depth threshold rules can be achieved for this option geometry is negligible (0% of the time). This is shown as “passage in either direction” for option 1H (0.1 m AHD weir beneath Windang Bridge) in Table 3.4. The percentage of time that fish could swim with the flow, even if the velocity is greater than the maximum velocity threshold, as long as the minimum water depth is maintained, is denoted as “passage only with the flow”. Finally, the percentage of time that fish passage is not possible based on these rules is denoted as “no passage”. Table 3.4 also shows the same fish passage percentiles if the water depth threshold was reduced to 0.3 or 0.15 m.

Studies presented by fisheries experts to date are generally for fish passage into opposing flows and for flow conditions which do not reverse with the tide. While not directly transferrable to Lake Illawarra, knowledge on fish passage requirements and impacts of weirs on fish populations can be applied to impact assessment in this instance. There is published research work on;

- The movement of eggs and larvae into estuaries
- The movement of adult fish into and out of estuaries
- The impacts of water velocities on fish movements

This information may be useful for assessing the potential impact of changed management of the entrance channel. However, a study that assesses current larvae and adult movement of fish in the entrance channel will assist in a site specific assessment of fish movements in the lake and specific potential impacts from any proposed blockage of fish passage.

As such, these studies may not be as relevant for Lake Illawarra. Rather, studies will be required that assess juveniles and larvae that presently travel with the flow into tidal estuaries and separately assess adult fish which are known to want to swim into the flow. WRL are not fish passage experts, however initial reading and communications with saltwater fisheries experts is that the weir options may have little effect on larvae and juveniles entering the lake but may limit adult fish returning to the ocean.

To aid further assessment by fisheries experts, diagrams presenting the water surface profile over one of the weir options (Option 1H: 0.1 m AHD weir all the way across [no channel]) are presented in Figure 3.18 (low to high ocean tide) and Figure 3.19 (high to low ocean tide), including the plunging flow (turbulence) after the weir. The top panel on both figures shows water level time series on the lake side of the weir and on the ocean side of the weir over a full tidal cycle. Eight dashed lines on this panel represent eight different representative time steps during this tidal cycle. Concept sketches of water levels across the weir at time steps 1-4 are shown in Figure 3.18 and time steps 5-8 are shown in Figure 3.19. An interesting feature is that the plunging, turbulent flows after the weir on the incoming tide are

significantly less than on the outgoing tide (see time steps 1, 2 and 8) because the lake side water level always remains above the weir crest.

No specific assessment of fish passage for the staggered groyne field has been completed. Unlike the weirs, the groynes maintain a channel, which will likely have sufficient depth for fish passage. With reference to Table 3.5, modelling also shows the groynes result in less ebb dominance in the tide, compared to the weirs (that is, the proportion of time the tide is outgoing and incoming flows over a tidal cycle is more evenly distributed). These potential changes are a consideration for both fish passage and net sediment transport. Nonetheless, velocities and turbulence are very high at the heads of each of the groynes, which should be considered.

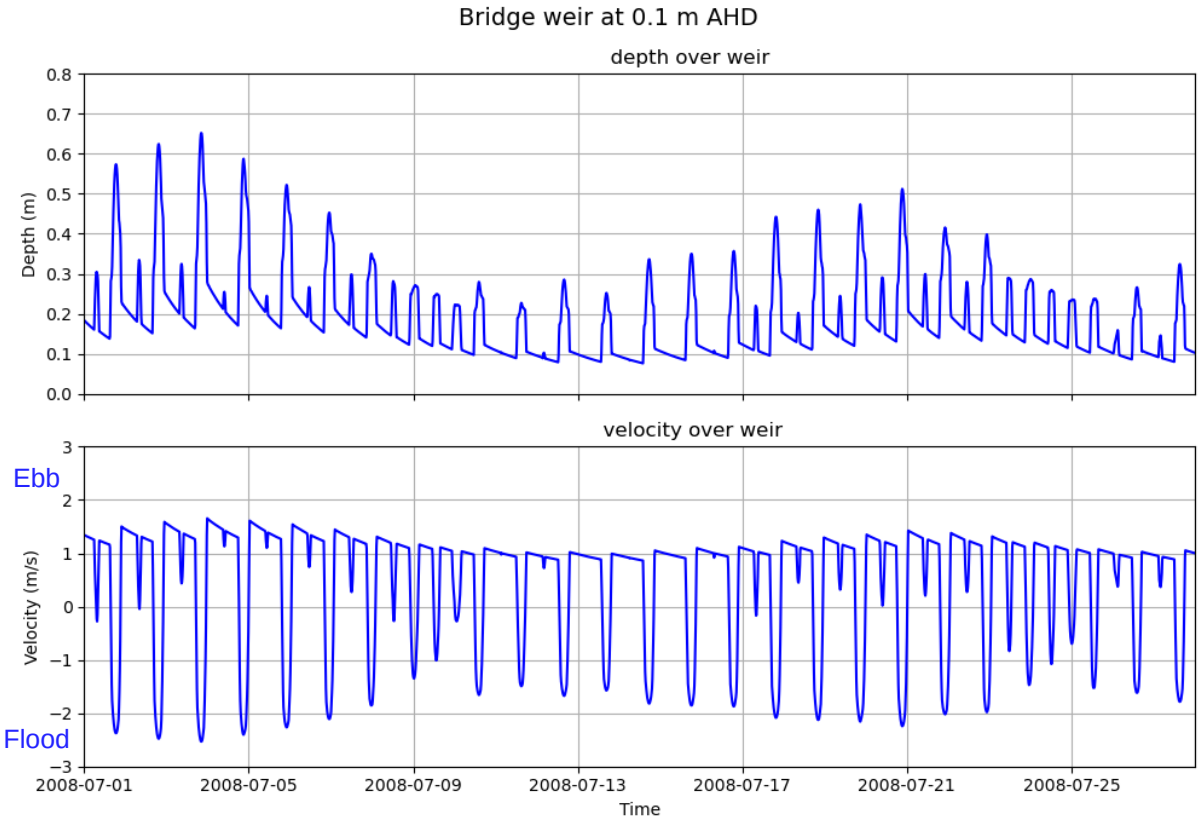


Figure 3.17 Velocity and depth over 0.1 m AHD weir crest: Option 1H (Windang Bridge)

Table 3.4 Percentage of time meeting fish passage requirements: Option 1H (0.1 m AHD weir all the way across (no channel) beneath Windang Bridge) for three different depth requirements

Tide	Passage in either direction (%)	Passage only with the flow (%)	No passage (%)
hydraulic conditions	**velocity < 0.3 m/s, depth > 0.5 m**	**velocity > 0.3 m/s, depth > 0.5 m**	**velocity > 0.3 m/s, depth < 0.5 m**
ebb	0	0	76
flood	0	2	22
hydraulic conditions	**velocity < 0.3 m/s, depth > 0.3 m**	**velocity > 0.3 m/s, depth > 0.3 m**	**velocity > 0.3 m/s, depth < 0.3 m**
ebb	0	2	75
flood	0	12	11
hydraulic conditions	**velocity < 0.3 m/s, depth > 0.15 m**	**velocity > 0.3 m/s, depth > 0.15 m**	**velocity > 0.3 m/s, depth < 0.15 m**
ebb	2	34	40
flood	2	21	0

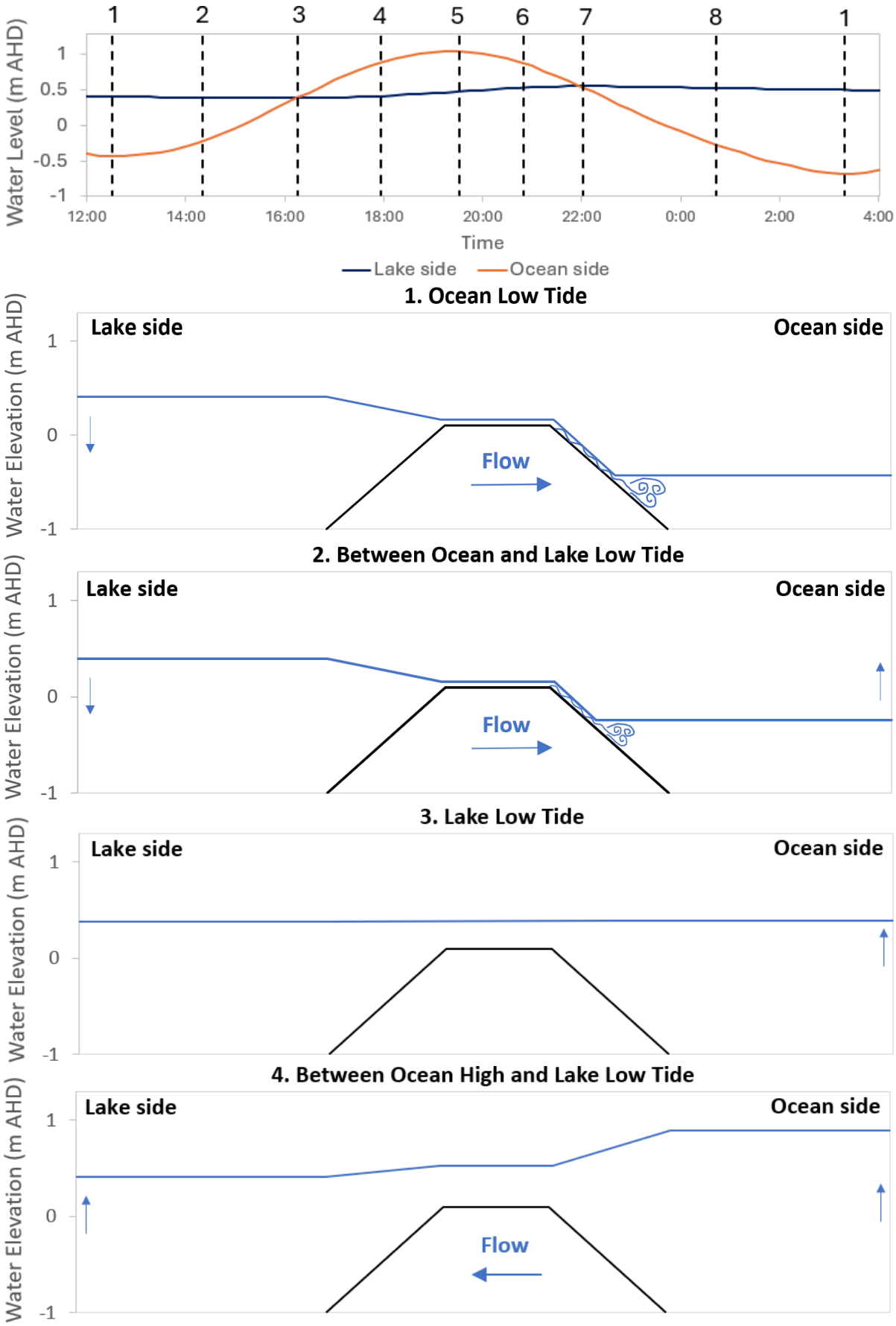


Figure 3.18 Modelled sketches of water levels across a weir beneath Windang Bridge [Option 1H: 0.1 m AHD weir all the way across (no channel)] (low to high ocean tide)

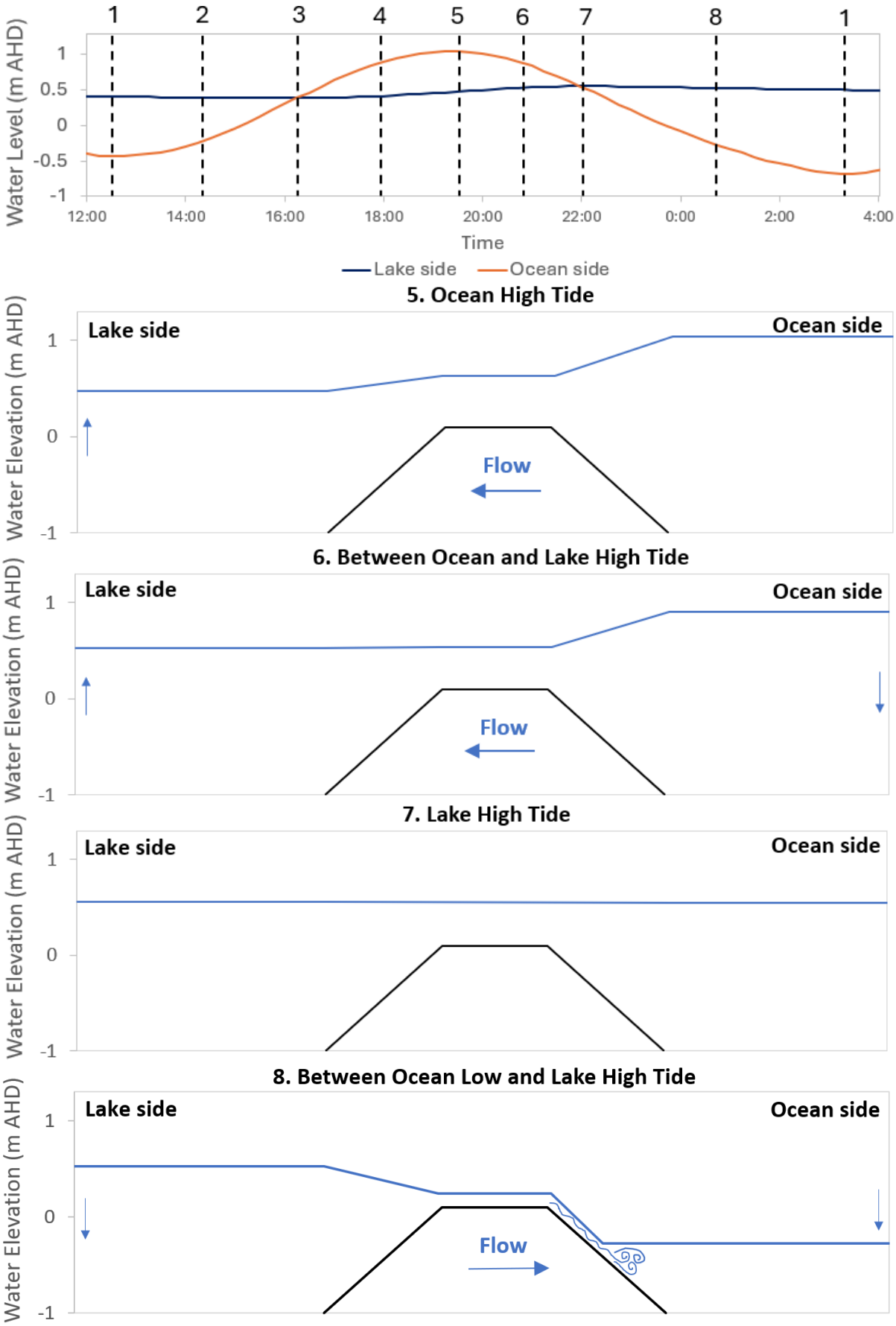


Figure 3.19 Modelled sketches of water levels across a weir beneath Windang Bridge [Option 1H: 0.1 m AHD weir all the way across (no channel)] (high to low ocean tide)

Table 3.5 Percentage of time with outgoing (ebb) and incoming (flood) flows

Management option and structure geometry	Outgoing (ebb) flows (%)	Incoming (flood) flows (%)
Base case		
No structure	57	43
1. Rock weir beneath Windang Bridge		
1H: 0.1 m AHD weir all the way across (no channel)	77	23
4. Staggered groyne field		
4B: Three 100 m long groynes (with armoured bed)	60	40

3.7 Management options with refined geometry

The numerical modelling has been utilised to determine the refined geometry of the five management options based on what would be capable of meeting the key management objective of the reduced tidal range (0.07 m) and reduce foreshore erosion. The following five options were considered in the options assessment in the following sections:

Option 1: Rock weir near Windang Bridge with a crest at 0.1 m AHD
Justification: Explicitly modelled (model 1H), and model results showed that the target tidal can be achieved with the crest at an elevation of 0.1 m AHD. While higher crest elevations also meet the key management objective, this is the lowest crest level that does so.

Option 2: Rock weir near Windang Bridge with a crest at 0.1 m AHD, with additional gate structures to manage flood impacts
Justification: While this was not explicitly modelled, it is functionally similar to model 1H when the gate structures are not in operation (e.g. non-flood periods), and so was assumed to be able to achieve the target tidal range. Flood drainage is expected to be faster than model 1H, depending on the invert and operation of the gate structures.

Option 3: **Rock weirs at the western end of the entrance channel across all three channels with crest elevations of 0.1 m AHD**
Justification: While this was not explicitly modelled, it is functionally similar to model 1H, and so was assumed to be able to achieve the target tidal range, although this should be confirmed. Flood drainage may be slightly faster than model 1H as the total weir length is likely to be longer than modelled.

Option 4: **Staggered groyne field with an armoured bed**
Justification: Explicitly modelled (model 4B), and model results show that the target tidal range (the same as 2008) can be achieved.

Option 5: **Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)**
Justification: No modelling available, however the historical observations demonstrate that this will reduce the tidal range to within the target.

4 Assessment of base case (business as usual)

4.1 Preamble

The following sections of this report provide a qualitative assessment of each of the five refined management options, compared to the base case (business as usual). The base case, along with the five identified options, were discussed in detail with a multi-agency project team at a workshop on 28 June 2024 and subsequent follow-up correspondence. The multi-agency project team included representatives from:

- Wollongong City Council
- Shellharbour City Council
- Transport for NSW
- Department of Primary Industries and Regional Development – Fisheries
- Department of Climate Change, Energy, Environment and Water
- Department of Planning, Housing and Infrastructure – Crown Lands
- Illawarra Local Aboriginal Land Council
- University of Wollongong
- University of New South Wales – Water Research Laboratory

Descriptions of the base case for each of the criteria are provided in this section. Since the base case is the benchmark against which each of the options is compared, the overall rating for the base case against each criteria is “no change”. **Under the base case, many of the negative impacts associated with entrance instability in Lake Illawarra will continue to worsen over time.** In other words, “no change” from the base case means that existing issues will be exacerbated into the future until hydraulic conditions reach an equilibrium state over the next century.

For each of the quantitative and qualitative management objectives and criteria (described in Section 2), the multi-agency project team agreed whether implementing an option would result in a deterioration or improvement for each of the ten objectives/criteria. Definitions of improvement, no change or deterioration compared to the base case for each criteria are provided in this section. Where possible, this was supported by the numerical modelling results.

For the purposes of this assessment, colours were also used to indicate the direction of change and the level of certainty in the change compared to the base case as summarised in Table 4.1. Where there was no consensus in the direction of change, further studies or consultation have been recommended.

Table 4.1 Definitions and colouring for criteria ratings

Colour	Description
Improvement	There is a strong consensus among the multi-agency group that implementing an option will result in an improvement in a criteria with significant certainty, often supported by modelling or observations.
Improvement*/ Improvement#	The multi-agency group agreed that implementing an option will likely result in an improvement in a criteria, however more information is required to confirm this direction of change.
Further study/ consultation required	A consensus was not reached by the multi-agency project team, and further information is required to determine whether implementing an option would improve or deteriorate a certain criteria.
Deterioration*/ Deterioration#	The multi-agency group agreed that implementing an option will likely result in a deterioration in a criteria, however more information is required to confirm this direction of change. Alternatively, implementing the option would cause a deterioration, however this could be readily managed through additional mitigation measures.
Deterioration	There is a strong consensus among the multi-agency group that implementing an option will result in a deterioration in a criteria with significant certainty, often supported by modelling or observations.

4.2 Objectives and criteria

4.2.1 Lake tidal range

The tidal range in Lake Illawarra is assumed to continue to be increasing every year (the mean range at Koonawarra Bay has tripled since 2007-08) until it is approximately the same as the ocean. This theoretical long-term maximum would be approximately 0.8 m larger than the mean lake tidal range for the base case. Nuisance inundation of assets is expected with progressively higher high tides. Exposure of greater mud flat areas is expected with lower low tides, which may reduce amenity for the local community associated with increased odours.

Comparing options to the base case

As discussed in Section 2.2, the adopted quantitative objective for the management options was that the existing lake tidal range be reduced to match (or be less than) the 2008 conditions. For this criteria, improvement from the base case is specifically linked to achieving this objective.

Improvement: The tidal range is reduced to match (or be less than) the 2008 conditions (0.07 m).

No change: The tidal range continues to increase at the same rate, compared to the base case.

Deterioration: The tidal range increases at a faster rate than the base case.

As the chosen options were refined until this criteria was met, all options discussed meet the criteria for improvement.

4.2.2 Foreshore erosion

The ongoing rate of erosion of the channel bed and both foreshores has been assumed to continue until a theoretical long-term equilibrium cross-sectional area is reached (approximately 7.5 times the cross-sectional measured in December 2021) (MHL, 2012, MHL, 2023 and Tucker et al., 2023a). Without further protection, this would undermine a range of assets including Windang Bridge, revetments, natural banks, the Windang groynes, boat ramps, First Nations archaeological sites and the training walls.

Comparing options to the base case

Improvement: The channel is in a form that is stable or accreting and does not significantly threaten assets (although some localised foreshore protection maybe required).

No change: Erosion continues to occur and the threat to assets remains.

Deterioration: Erosion becomes faster than it currently is, and assets are threatened sooner.

Similar to the tidal range criteria, managing foreshore erosion was a key management objective for the options discussed in this study. As a result, all options presented in this report have an improvement rating for foreshore erosion in the Lake Illawarra entrance channel as a result.

4.2.3 Water quality in the lake

Based on monthly chlorophyll-a and turbidity samples, water quality in Lake Illawarra was most recently rated very good at 6/11 sites, good at 3/11 sites and fair at 2/11 sites in 2022-23 (WCC, 2023a).

Water quality in Lake Illawarra is influenced by a diverse range of factors including tidal flushing, nutrient and sediment inputs from catchment runoff and internal nutrient cycling processes. Changing catchment management may have a larger impact on water quality than changes to the entrance condition.

However, increasing tidal exchange will improve the water quality in the lake, assuming the current nutrient and sediment loads remains unchanged. The volume of tidal flushing compared to the lake volume is relatively small (approximately 5% on neap tides and 15% on spring tides) although, it is increasing over time due to ongoing erosion and the increasing tidal range.

The presence of marine water in the entrance channel currently also provides high amenity.

Comparing options to the base case

As the entrance channel is the focus of this study, tidal exchange is being used as a surrogate for water quality. However, it is acknowledged that reductions in tidal exchange could occur concurrently with improved catchment management strategies and result in improvements in water quality.

Improvement: Water quality improves, compared to the base case. For the purpose of this assessment, this was assumed in cases where the rate of increase of tidal exchange increases at a faster rate than the base case.

No change: Water quality remains very good to fair across the lake, and marine water in the channel continues to provide high amenity value, and the rate of tidal exchange continues to increase at the same rate as the base case.

Deterioration: Water quality declines, compared to the base case. For the purpose of this assessment, this was assumed in cases where the tidal exchange decreases.

4.2.4 Recreational safety

High tidal velocities in the entrance channel presently pose a risk to safety for unpowered in-water activities (e.g. swimming, canoeing/kayaking, stand-up paddle boarding). It is assumed that these high tidal velocities will continue to increase every year at the existing rate, which will further increase recreational safety risks.

Comparing options to the base case

Improvement from the base case: The velocities in the whole entrance channel are reduced (associated with a reduction in the tidal range).

No change from the base case: Rate of increase in tidal velocities in the channel does not change, and associated safety risks for recreational use of the channel continue to worsen.

Deterioration from the base case: Tidal velocities increase at a faster rate than the base case, and the recreational safety risks worsen at a faster rate than is currently happening. Alternatively, tidal velocities are reduced throughout most of the entrance channel, but recreational use is unsafe in the immediate vicinity of a new structure due to localised turbulent or high velocity flows.

It is acknowledged that in some cases, mitigation measures could be used to discourage access to the immediate vicinity of a new structure(s) (e.g. weir, groyne, armoured bed) which is unsafe for recreation use due to localised high velocities and/or turbulent flows. This may be sufficient to manage the deterioration of recreational safety for some structures. Where this is the case, it is highlighted in the discussion of each option.

4.2.5 Flooding from rainfall/catchment

The ongoing rate of erosion of the channel bed and both foreshores is improving upstream flood drainage (via hydraulic efficiency). That is, the present rate of change of the hydraulic efficiency of the channel is progressively decreasing peak flood levels in Lake Illawarra and reducing flood drainage times.

Comparing options to the base case

Improvement: Peak water levels within the lake following catchment flooding decrease at a faster rate than currently occurring in the base case.

No change: Peak water levels within the lake following catchment flooding decrease at the same rate as in the base case.

Deterioration: Peak water levels within the lake following catchment flooding decrease at a slower rate than currently occurring in the base case.

While the direction of change in rainfall/catchment flooding for the options is understood, further flood modelling will be required to quantify the changes.

4.2.6 Flooding from coastal storms

It is assumed that the present rate of change of the hydraulic efficiency of the channel is having a negative impact on flooding from coastal storms in Lake Illawarra. That is, peak flood levels in the lake due to coastal storm surge (e.g. the inverse barometer effect and/or regional wind setup) may be increasing over time. However, ongoing scour is likely to have a negligible impact on elevated lake water levels due to longer duration sea level anomalies, such as coastally trapped waves, which typically last between 10 and 25 days (Woodham et al., 2013). In some circumstances, the change in hydraulic efficiency will also reduce flood drainage from a catchment event that coincides with a coastal storm.

Comparing options to the base case

Improvement: The rate of change of the hydraulic efficiency of the channel decreases compared to the base case, and flooding from coastal storms worsens at a slower rate or improves.

No change: The rate of change of the hydraulic efficiency of the channel remains unchanged, and flooding from coastal storms continues to worsen.

Deterioration: The rate of change of the hydraulic efficiency of the channel increases compared to the base case, and flooding from coastal storms worsens at a faster rate.

The rating for flooding from coastal storms has used the criteria above. It is acknowledged that climate change may also exacerbate the impacts of coastal storms into the future. Additional numerical modelling is recommended to quantify the present response of the lake to coastal storm surge.

4.2.7 Fish passage

Fish passage into and out of Lake Illawarra is currently unimpeded by permanent, engineered physical barriers in the entrance channel (subject to existing tidal variations in depth and velocity) but tidal velocities are increasing and are unlikely to stabilise within the next 100 years. Ongoing vegetation changes and the increasing proportion of marine water in the eastern side the lake (near the entrance channel) may change the range of fish species which presently exist in the estuary. Tidal asymmetry (currently ebb tide dominated) will decrease over time as the tidal range in the lake increases.

Comparing options to the base case

Improvement: Existing tidal velocities are reduced to allow fish passage through increased parts of the tidal cycle and greater areas of the entrance channel, without any permanent, engineered physical barriers to fish passage in the entrance channel.

No change: No permanent, engineered physical barriers are in place to prevent fish passage in the entrance channel, although increasing tidal velocities limit fish passage during certain stages of the tide.

Deterioration: Permanent, engineered physical barriers are constructed in the entrance channel which limit fish passage between the lake and the ocean.

Based on the fish passage impact predictions in this report, and advice received from the multi-agency project team, the presence of a permanent, engineered physical barrier has been identified as a deterioration of fish passage to the base case. Prior to entrance training, Lake Illawarra was naturally an ICOLL that intermittently opened and closed and sustained commercial and recreational fisheries for some time. In ICOLLs, fish are known to stay in the system, and grow during closed periods, resulting in benefits for fisheries' productivity. Further studies on fish passage and recruitment will assist in a quantitative assessment of impacts to fish populations and abundances. As such, the criteria above should be viewed as indicative only.

4.2.8 Flora and fauna

The three main communities of estuarine vegetation that occur in the lake (saltmarsh, seagrass, and mangroves) provide essential habitat, food supply and nutrient cycling (BMT, 2020b). These are being used as a proxy for ecological health in the lake. Valued commercial and recreational fish species (e.g. bream, flathead, blue swimmer crabs and prawns) within the lake have been found to derive most of their nutrients from seagrass and saltmarsh habitats, the percentage contribution of each habitat type to the diet of these species varies across different locations in the lake (Gaston et al., 2019). The presence of these fish species further supports fish assemblages and other wildlife.

There is a relationship between the health of estuarine flora and fauna and the tidal range within the lake. Increasing or decreasing the tidal range in Lake Illawarra would have differing effects on the abundances of different species. Some flora and fauna would be expected to flourish with a higher tidal range, while others would decline, and vice versa for a lower tidal range.

Since the entrance was permanently opened in 2007, mangroves (one of the three key vegetation types) have significantly expanded in the lake which has been linked with the associated increasing tidal regime (Regina, 2016; Wiecek et al., 2016; Williams and Wiecek, 2017). As the tidal range in the lake increases and mangroves continue to expand landwards and encroach on areas currently occupied by saltmarsh, expansion of the saltmarsh landward may be constrained by development in some areas.

Seagrass is also important for supporting fish within the lake, as it provides a food source and shelter for different fish during different stages of their life cycles (BMT, 2020b). However, since the entrance was trained, seagrasses on the flood tide delta in the lake have been smothered by sand and seagrasses in the entrance channel have been lost due to increased flow velocities and scour (Wiecek et al., 2016).

Lower low tide water levels in the lake have resulted in the exposure of more mudflats. This may have improved habitat for bird species that feed in intertidal areas, although may have reduced habitat for bird species which feed on small fish commonly found in shallow, slow moving waters.

Comparing options to the base case

The multi-agency project team provided substantial input into the potential changes of flora and fauna under both the base case (ongoing increases in lake tidal range) and the potential options. For individual species, it is sometimes clear that higher (or lower) tidal ranges provide an improvement or deterioration in condition. For example, the expansion of the flood tide delta from large volumes of sediment movement associated with high tidal velocities has reduced the extent and condition of seagrass and will likely to continue to do so into the future unless velocities are reduced. However, the net changes in flora and fauna are less clear.

The changes in the estuarine flora and fauna as a result of the entrance training has benefited some species at the detriment of others. The interaction between flora and fauna and the tidal range is complex and difficult to predict. Therefore, no assessment on the improvement or deterioration of flora and fauna has been provided in the following sections. Where there is sufficient information, a brief discussion has been provided for each option.

4.2.9 First Nations heritage

The ongoing rate of erosion of the channel bed and both foreshores is threatening to undermine First Nations archaeological sites. The present trend for reduced impacts from rainfall/catchment flooding and likely increased impacts from coastal storms on First Nations archaeological sites is noted.

WRL understands that WCC and SCC will engage and consult with the First Nations community regarding the long-term management options for the Lake Illawarra entrance channel.

The views and values of the First Nations community on the condition of Lake Illawarra reflect their long standing cultural and spiritual connection to the area. While threats to Aboriginal sites are a significant issue, the changes to the lake entrance from its natural condition has had other impacts on the cultural values associated with the lake including ongoing care of Country by First Nations communities and cultural activities undertaken in the area. For example, changes to fish species found in the lake means that traditional food sources may no longer be available.

Comparing options to the base case
More consultation will be required to determine if there is an overall improvement or deterioration compared to the base case for each option. However, commentary on the potential benefits and risks of each management option on the First Nations community are discussed qualitatively, with further engagement recommended.

4.2.10 Boating access

Water craft can presently access the ocean (during safe tidal conditions) and lake from boat ramps downstream of Windang Bridge. Vessels launched from boat ramps in Lake Illawarra also have access to the ocean.

High tidal velocities in the entrance channel presently pose a safety risk for powered water craft. It is assumed that these high tidal velocities will continue to increase every year at the existing rate until the channel becomes hydraulically stable (this may take over a century), which will make boating more difficult and further reduce safety.

Comparing options to the base case
Improvement: Water craft continue to access the ocean and lake from boat ramps downstream of Windang Bridge and tidal channel velocities are reduced to manage safety risks.

No change: Water craft continue to access the ocean and lake from boat ramps downstream of Windang Bridge. Tidal velocities in the channel continue to increase, posing increasing safety concerns.

Deterioration: Water craft access to the ocean and/or lake is restricted by physical barriers or unsafe navigability. Or tidal velocities increase at a faster rate than the base case.

Construction of an additional boat ramp upstream of a new structure(s) (e.g. weir, groyne) may be required to facilitate boat access to the lake. While this would not change the deterioration rating for this criteria, it may make an option acceptable to the community.

4.3 Whole of life cost

It is difficult to define the whole of life cost for the base case, which is subject to feedback between ongoing scour processes and any short-term management interventions. Without implementation of a long-term management option, sand will continue to be eroded from the entrance channel and a range of assets will be progressively undermined as the cross-sectional area of the channel increases.

Upfront capital cost
The base case is not associated with any upfront capital works.

Planned ongoing costs
Under the base case, the entrance channel and lake are being managed reactively and planned ongoing costs associated with the channel are minimal. However, reactive management of the channel would be required which is discussed in the following sub-section.

Potential mitigation activities
It is likely that there will be interventions required to reactively mitigate issues associated with the uncontrolled erosion of the entrance channel. These are difficult to forecast in both timing and magnitude. However, mitigation activities may include infrastructure decommissioning and localised management of erosion discussed further below.

Decommissioning of infrastructure
For example, as a direct result of ongoing erosion in the entrance channel, the Pine Trees boardwalk located at the Windang foreshore progressively collapsed over years and was subsequently removed in October 2022 (Tucker et el., 2023b). A children's playground located leeward of the boardwalk was then removed in April 2024 following further erosion exacerbated by a significant storm event (WCC, 2024). This type of infrastructure not only costs money to decommission, but a valuable community asset is lost.

In October 2022, power poles on Picnic Island were also removed by Endeavour Energy as a direct result of ongoing erosion in the entrance channel.

Localised management of erosion
It is unlikely that all assets will be allowed to be undermined in the base case. Some engineered solutions may be required to manage erosion, which has already occurred in the past. This would include requirements to upgrade existing foreshore assets (such as the training walls and groynes) as the engineered toes become undermined.

For example, some assets, such as the Windang Bridge, may be protected using engineering interventions like the placement of rock which has been occurring since 2019. Similarly, foreshore assets could be protected through the construction of revetments, or other similar engineered structures. A recent study on potential options for managing erosion over an alongshore extent of 150 m along the Windang foreshore for a 20 year design life estimated this would require between $0.8M – $6.8M to construct (Tucker et al., 2023b), depending on the material and design chosen.

Other alternative interventions might include sand nourishment. Between 2008 and 2022, approximately 900,000 m^3 of sand has been eroded from the entrance channel (Tucker et al., 2023a). Depending on the source (e.g. offshore), it would likely cost in the order of $20M to $50M to replace this volume via sand nourishment. See Appendix E for further details on key assumptions and inputs for preliminary capital cost estimates in this report. Depending on whether nourishment returned the entrance to an accretionary state, or not, either dredging on periodic nourishment may still be required.

5 Assessment of Option 1: Rock weir near Windang Bridge

5.1 Description

Option 1 considers a rock weir across the span of the channel near Windang Bridge. The crest of the weir is assumed to be at 0.1 m AHD, as this was the lowest crest height predicted by numerical modelling capable of achieving the target tidal range. The weir would be drowned during incoming ocean high tides (ocean water level greater than 0.1 m AHD), and a weir with water flowing over it during ocean low tides (ocean water level less than 0.1 m AHD), similar to the example shown at Coquet River, Amble, UK in Figure 5.1.



Figure 5.1 Example photo of an estuarine weir with water flowing over it during ebb tide at Coquet River, Amble, UK (the ocean is to the right). This weir is located approximately 2.1 km upstream of entrance training walls at the ocean. This photo provides an illustrative example of this type of structure for indicative purposes only.

5.2 Objectives and criteria

5.2.1 Lake tidal range

Constructing a weir near Windang Bridge (0.1 m AHD crest level) would achieve the 2008 target tidal range in the lake, however the mean water level in the lake would be raised by approximately 0.2 m compared to what it is today (high and low tide elevations in the lake increased compared to the base case). This is demonstrated by the numerical modelling discussed in Section 3.5.1. Note that this higher mean water level in the lake is approximately the same as prior to the construction of entrance training walls in 2007.

Immediately downstream of the weir, the tidal range would be increased (relative to the base case). That is, implementing the structure would raise high tide levels and lower low tide levels between the structure and the ocean. The change would be greatest just downstream of Windang Bridge, resulting in the following:

- Average high tide elevation raised by 0.14 m
- Average low tide elevation lowered by 0.22 m
- Average tidal range increased by 0.37 m

The changes to tidal range downstream of the bridge would occur immediately following construction of the weir and would remain stable (excluding the impact of sea level rise). The impact of these tidal level changes on infrastructure around the lake and the entrance channel requires further consideration should this option progress further.

Overall criteria rating: **Improvement**

5.2.2 Foreshore erosion

Constructing this option would significantly reduce the present rate of erosion of the channel bed and both foreshores which is threatening to undermine a range of natural, built and archaeological assets. This is demonstrated by the numerical modelling discussed in Section 3.5.2. The rate of erosion would be reduced both downstream and upstream of the weir due to velocity reductions on both sides.

Overall criteria rating: **Improvement**

5.2.3 Water quality in the lake

This option will reduce tidal exchange, which would result in a negative impact on water quality based on the criteria established. It is important to acknowledge that some tidal exchange will be maintained under this option (similar to the 2008 conditions), and will not result in a return to the pre-training wall conditions (where there was no tidal exchange during closed entrance periods). Some parts of the lake would have negligible change in tidal flushing while the greatest changes would be expected on the eastern side of the lake near the entrance channel. This reduced tidal flushing is associated with the reduced tidal range in the lake. This outcome assumes that catchment and industrial pollutant loads and land use (urbanisation) remains unchanged from the base case. Implementing this option concurrently with improved catchment management may mitigate this risk.

An additional negative impact on amenity is that water in the entrance channel upstream of the weir would change from its existing high proportion of marine water to more brackish water.

Numerical water quality modelling, including consideration of nutrient cycling, is recommended to quantify the changes to water quality in the lake if this option was implemented. Concurrently implementing management of nutrient and sediment sources in the upstream catchment may mitigate some of the impacts to water quality.

Overall criteria rating: **Deterioration***
* Additional controls could be implemented to mitigate deterioration.

5.2.4 Recreational safety

Overall, constructing Option 1 would reduce safety of unpowered in-water activities (e.g. swimming, canoeing/kayaking, stand-up paddle boarding). Although in-water recreational safety would be improved throughout most of the entrance channel (because tidal channel velocities upstream and downstream of Windang Bridge would be reduced), it would not be safe for non-powered water craft or swimmers to cross (or wade along) the weir near the bridge. Mitigation measures would be required to discourage access to the weir; however, this structure would remain unsafe for recreation and mitigation measures would not eliminate the risk entirely.

Overall criteria rating: Deterioration*
* Additional controls could be implemented to mitigate deterioration.

5.2.5 Flooding from rainfall/catchment

Constructing a weir near Windang Bridge (0.1 m AHD crest level) would have a negative impact on upstream flooding in Lake Illawarra. It would increase peak flood levels and increase flood drainage times. Proportionally, these increases are expected to be highest (worst) for more frequent flood events and for flood events which do not coincide with coastal storm events (i.e. an elevated ocean water level).

Formal flood modelling for a range of scenarios is recommended to quantify the changes to upstream flood modelling if this option was implemented. WRL understands that this is presently being undertaken (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

Overall criteria rating: Deterioration#
Additional study is required to confirm that it is a deterioration under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

5.2.6 Flooding from coastal storms

Constructing this option would likely reduce the impacts of most oceanic flooding in Lake Illawarra. It is expected that peak flood levels in the lake, due to coastal storm surge (e.g. the inverse barometer effect and/or regional wind setup), would be reduced. However, this option would have a negligible impact on elevated lake water levels due to longer duration sea level anomalies.

Additional numerical modelling is recommended to quantify the changes to oceanic flooding in the lake if this option was implemented (including consideration of storms of different duration and severity). WRL understands that this is also presently being undertaken (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

Overall criteria rating: Improvement#
Additional study is required to confirm that it is an improvement under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

5.2.7 Fish passage

Implementing this option is considered likely to have an overall negative impact on fish passage and fish migration into and out of Lake Illawarra based on the criteria developed. This is because the velocity over the weir crest is too high and the water depth over the weir is too shallow to allow fish (particularly large fish) to traverse the weir over most of the tidal cycle. That is, a weir at Windang Bridge would create a blockage to the existing two way movement of fish for the majority of the tidal cycle. Flows are particularly turbulent on the outgoing (ebb) tide when water plunges over the weir from the lake side to the ocean side, which may not be suitable for fish passage. Fish accumulations around the weir could be susceptible to predation. Ebb tide dominance will increase compared to the base case, which may impact fish recruitment rates. The lack of connectivity across the weir and the reduced tidal channel velocities may also change the range of fish species and fish abundances which presently exist in the estuary.

It is recommended that a fish passage and fish migration study specific to the Lake Illawarra estuary be undertaken to assess existing conditions and likely changes if a weir is constructed under Windang Bridge.

Overall criteria rating: Deterioration*

* Additional study is required to confirm that it is a net deterioration considering a range of fish species and fish abundances.

5.2.8 Flora and fauna

Constructing a weir near Windang Bridge (0.1 m AHD crest level) will change the flora and fauna in the lake. Some flora and fauna species will benefit from its construction, while it will be to the detriment of others. Examples of probable changes are provided below, however, it is acknowledged that it is presently unknown which other estuarine flora and fauna may decline and which will flourish with a smaller tidal range in Lake Illawarra.

Reducing tidal velocities and the tidal range in the lake may slow the present landward expansion of mangroves (linked to the increasing tidal range). Higher mean tidal water levels may result in some mangrove die off. Higher mean water levels may make saltmarsh more vulnerable to sea level rise as they are more susceptible to mangrove encroachment. Seagrass may recover upstream and downstream of Windang Bridge due to reduced tidal channel velocities. Seagrass distribution in the main body of the lake, which provides important fish habitat, will likely shift landward due to higher mean tide levels and reduce tidal ranges. Existing seagrasses in the eastern side of the lake, near the entrance channel, would no longer be smothered by sand eroded from the entrance channel, and some seagrass recovery may occur in this area.

Changes to low tide water levels will change habitat for birds and fish. There may be a shift towards more brackish fish species (away from marine species), and the loss of intertidal mudflats may result in a decrease in intertidal wader birds (a number of which are listed as threatened species), but this may result in more opportunities for piscivorous birds.

The net change in flora and fauna in Lake Illawarra as a result of this option is difficult to assess. The changes will be complex and interrelated. On this basis, no rating has been provided for this criteria.

Overall criteria rating: Further study required

5.2.9 First Nations heritage

Table 5.1 outlines the potential benefits and drawbacks that implementing this option may have on First Nations archaeological sites. Further engagement would be required to understand the potential suitability of this option from a First Nations perspective.

Table 5.1 Potential impacts on First Nations archaeological sites from Option 1: Rock weir near Windang Bridge

Benefits	Drawbacks
Present rate of erosion is reduced	Option footprint and/or associated construction activities coincide with known sites
Reduced flood impacts from coastal storms (for sites upstream of weir)	Increased flood impacts from rainfall/catchment for sites upstream of weir
Mean water level in the lake is raised to the same level that existed prior to permanent entrance opening	Raised high tide levels may inundate sites downstream of weir

Note that this higher mean water level in the lake is approximately the same as prior to the construction of entrance training walls in 2007.

Overall criteria rating: Further consultation required

5.2.10 Boating access

Constructing a weir near Windang Bridge (0.1 m AHD crest level) would have an overall negative impact on water craft access as it would be a physical barrier across the entrance channel. Powered water craft launched from boat ramps downstream of Windang Bridge would not have access to the lake, but access to the ocean would be maintained. Vessels launched from boat ramps in Lake Illawarra would not have access to the ocean. As discussed in Section 5.2.1, the average low tide elevation downstream of Windang Bridge would be lowered by approximately 0.22 m, which would reduce the navigable area in this section of the entrance channel at low tide.

Although boating access near Windang Bridge would be lost, tidal channel velocities upstream and downstream of Windang Bridge would be reduced, improving ease of boating and safety. Construction of an additional boat ramp upstream of the weir may be required to facilitate boat access to the lake.

Overall criteria rating: Deterioration

5.3 Whole of life cost

Capital cost

The capital cost for a weir near Windang Bridge is estimated to be approximately $20M to $45M. The upper end of this estimated capital cost range for a weir directly beneath Windang Bridge is particularly high due to the challenges of construction in a high velocity region of the entrance channel, as well as constraints on heavy machinery working underneath the bridge (e.g. height restrictions and the need to avoid contact with the piers). If the weir is not constructed beneath Windang Bridge but slightly upstream or downstream of it, the estimated capital cost would likely be towards the lower end of this range. This is because the required rock volume is approximately the same (if the weir is located within 150 m of Windang Bridge) but construction constraints are comparatively reduced.

Planned ongoing costs

Ongoing maintenance and management costs are estimated to be an average of 1% of the capital cost per year (approximately $200,000 to $450,000 per year). This allowance may include such activities as:

- Removal of rubbish/debris collected immediately adjacent to the weir
- Regular condition inspection of the weir from a boat
- Regular condition inspection of the weir from underwater
- Bathymetry survey of the sand levels immediately adjacent to the weir
- Repair of any displaced armour rocks or structural settlement
- Technical engineering design advice for any significant repair works

Potential mitigation activities

There are a number of works that might be required in the implementation and management if this option is pursued. These might include:

- Localised foreshore stabilisation works where existing erosion may have left the foreshore too steep or unstable. This may include the Windang foreshore, which could be managed with targeted nourishment or structure interventions
- Implementation and surveillance of exclusion zones around the weir to manage recreational safety near highly turbulent and high velocity flows
- Construction of an additional boat ramp upstream of Windang Bridge may be required to maintain boat access to the lake
- Additional reactive flood management preparation (e.g. sand bags or re-locating moveable infrastructure) may be required to manage the increase in flood damages

5.4 Potential for staging and adaptability

Since the weir is proposed to be constructed of rock (rather than a concrete monolith) it is relatively adaptable. It would be possible to stage construction, if preferred, to monitor the response of the entrance channel to a weir all the way across the channel that is at a lower elevation than 0.1 m AHD, and then raise it to achieve this elevation during a second construction stage. Similarly, while it would likely be more difficult than initial construction, it would be possible to remove rocks to lower the crest in the future, if required. Both approaches would likely increase the cost to deliver the project.

Again, since it is a relatively adaptable structure, the weir could be raised above 0.1 m AHD in the future to maintain the target lake tidal range despite projected sea level rise.

5.5 Other risks

There is a risk that the Lake Illawarra entrance channel may switch from the present unstable scour regime to an unstable accretionary mode due to construction of a weir near Windang Bridge (i.e. tending towards a closed entrance channel). This may result in the channel downstream of the weir infilling and eventually, infilling of sediments upstream of the weir.

While the present rate of erosion of the channel bed and both foreshores would generally be reduced, isolated areas of erosion may occur immediately adjacent to the weir which would require further management.

There is a risk that increased velocities (compared to the base case) over the weir crest near Windang Bridge increase stresses on the piers. This risk may be mitigated during detailed design by locating the weir near the bridge (slightly upstream or downstream) rather than directly beneath it. Such a weir would have the same outcomes for reduced erosion and reduced lake tidal range, without the constraints associated with construction under Windang Bridge.

Increased tidal ranges downstream of the weir may have an impact on infrastructure and navigability in this area, which has not been considered in this assessment to date.

Depending on the location of the weir, this option may limit the capacity to perform maintenance on Windang Bridge, which would also warrant further consideration.

5.6 Overall assessment

Constructing a weir near Windang Bridge (0.1 m AHD crest level) would meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion. However, water quality in the lake, upstream flooding, fish passage and boating access would deteriorate overall compared to the base case (Table 5.2). The weir could be located slightly upstream or downstream of Windang Bridge to reduce the risk of increasing stresses on the piers.

Table 5.2 Option 1 assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Option 1: Rock weir near Windang Bridge	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration[#]	Improvement[#]	Deterioration*	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented in conjunction with this option

[#] Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

6 Assessment of Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts

6.1 Description

Option 2 considers a combined structure including a rock weir (similar to Option 1) with adjustable gate structures (example Figure 6.1) to manage flood impacts near Windang Bridge. The specific geometry of the combined structure has not been modelled, however could conceptually involve a rock weir spanning two thirds of the channel and adjustable gate structures on the final third of the channel (approximately 85 m in length). The crest of the combined structure (e.g. when the gate structures are shut) is assumed to be at 0.1 m AHD (the same as Option 1 to achieve the target tidal range). It is assumed that the primary purpose of the gate structures will be to mitigate potential upstream flood impacts, and they would primarily remain shut during non-flood conditions. It has also been assumed that the gate structures are overshot structures.



Figure 6.1 Example photo of adjustable gate structures in a non-tidal freshwater environment at Beavers (Old Man) Creek, Collingullie, NSW (Source: AWMA). This photo provides an illustrative example of this type of structure for indicative purposes only. WRL is not aware of a structure comprising a rock weir and adjustable gate structures within a NSW estuary.

While the gate structures could be operated to increase tidal flushing (compared to Option 1) when required (e.g. during extended dry periods), it is assumed their primary operation would be associated with mitigating upstream flooding so this has not been considered at this stage of the assessment.

6.2 Objectives and criteria

6.2.1 Lake tidal range

Option 2 is assumed to be capable of achieving the same reduction in tidal range as described in Option 1. That is, it will achieve the target tidal range of 0.07 m (the 2008 observed range) provided that the crest of the weir is approximately 0.1 m AHD and the gates are in a closed position.

See Section 5.2.1 for further discussion on potential changes to tidal water levels as a result of this option.

Overall criteria rating: **Improvement**

6.2.2 Foreshore erosion

Option 2 is assumed to be capable of achieving the same reduction foreshore erosion as described in Option 1.

See Section 5.2.2 for further discussion on potential changes to foreshore erosion.

Overall criteria rating: **Improvement**

6.2.3 Water quality in the lake

Option 2 is assumed to have the same issues associated with water quality as discussed in Option 1. A reduction in tidal range will reduce tidal flushing and exchange. As discussed in Section 6.1, while the gate structures could be operated to increase tidal flushing (compared to Option 1) when required, this has not been considered at this stage of the assessment.

Implementing this option concurrently with improved catchment management may mitigate this risk.

See Section 5.2.3 for further discussion on potential changes to water quality.

Overall criteria rating: **Deterioration***
* Additional controls could be implemented to mitigate deterioration.

6.2.4 Recreational safety

Option 2 is assumed to have the same issues associated with recreational safety as discussed in Option 1. High velocity and highly turbulent flow present a risk to unpowered in-water activities at the location of the weir, despite slower velocities throughout the entrance channel. Mitigation measures would be required to discourage access to the weir; however, this structure would remain unsafe for recreation. Increased risks to recreational safety would be expected when the gate structures are opened for flood mitigation purposes, which would need to be appropriately managed.

See Section 5.2.4 for further discussion on potential changes to recreational safety.

Overall criteria rating: **Deterioration***
* Additional controls could be implemented to mitigate deterioration.

6.2.5 Flooding from rainfall/catchment

Flooding from rainfall is the main operational difference between Option 1 and Option 2. The gate structures could be designed in such a way that they can be opened prior to/during a flood event to facilitate faster drainage (through increased hydraulic efficiency). Nonetheless, the gate structures would only allow for increased drainage during the periods of low tide and it is likely to still result in prolonged flood drainage, compared to the base case.

Formal flood modelling for a range of scenarios is recommended to quantify the changes to upstream flood modelling if this option was implemented.

Overall criteria rating: **Deterioration#**
Additional study is required to confirm that it is a deterioration under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

6.2.6 Flooding from coastal storms

When the gates are in a closed position, Option 2 is assumed to have the same improvements to flooding from coastal storms as discussed in Option 1.

Additional numerical modelling is recommended to quantify the changes to oceanic flooding in the lake if this option was implemented (including consideration of storms of different duration and severity).

See Section 5.2.6 for further discussion on potential changes to flooding from coastal storms.

Overall criteria rating: **Improvement#**
Additional study is required to confirm that it is an improvement under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

6.2.7 Fish passage

Despite the gate structures (which have been assumed to be overshot structures for the purpose of this assessment) in Option 2, it is assumed that these structures will be operated primarily to reduce the impacts of flooding. It is therefore assumed that Option 2 is assumed to have the same issues associated with fish passage as discussed in Option 1 due to the presence of a permanent, engineered physical barrier in the entrance channel.

See Section 5.2.7 for further discussion on potential changes to fish passage.

Overall criteria rating: Deterioration*

* Additional study is required to confirm that it is a net deterioration considering a range of fish species and fish abundances.

6.2.8 Flora and fauna

Changes to flora and fauna as a result of implementing Option 2 is likely to be functionally the same as Option 1, assuming the gate structures are only operational to manage flood impacts. Some flora and fauna species will benefit from construction of a weir, while it will be to the detriment of others. The net change in flora and fauna in Lake Illawarra as a result of this option is difficult to assess. The changes will be complex and interrelated. On this basis, no rating has been provided for this criteria.

See Section 5.2.8 for further discussion on potential changes to flora and fauna.

Overall criteria rating: Further study required

6.2.9 First Nations heritage

Option 2 is likely to have broadly similar benefits and drawbacks from a First Nations Perspective to Option 1. There may a slight advantage to Option 2, compared to Option 1, due to the improvement in flood drainage through the use of gate structures. Further engagement would be required to understand the potential suitability of this option from a First Nations perspective.

See Section 5.2.9 for further discussion on potential changes to First Nations Heritage.

Overall criteria rating: Further consultation required

6.2.10 Boating access

Option 2 is assumed to have the same issues associated with water quality as discussed in Option 1. The additional gate structures are assumed to be operational for flood mitigation purposes and do not provide additional boat access, compared to Option 1.

Construction of an additional boat ramp upstream of the weir may be required to facilitate boat access to the lake.

See Section 5.2.10 for further discussion on potential changes to boating access.

Overall criteria rating: Deterioration

6.3 Whole of life cost

Capital cost

The capital cost for the combined weir and adjustable gate structures near Windang Bridge is estimated to be approximately $60M - $105M. The combined structure (this option) is substantially more expensive than the rock weir alone due to the higher complexity of construction required for the gate structures. As with Option 1, the upper end of this estimated capital cost range is for a weir located directly beneath Windang Bridge but a weir constructed slightly upstream or downstream of it would likely be towards the lower end of this range.

Planned ongoing costs

Ongoing maintenance and management costs are estimated to be an average of 1% of the capital cost for the rock weir in addition to 1.5% of the capital cost of the gate structures per year (approximately $800,000 to $1,450,000 per year). In addition to the activities identified for Option 1, this might include regular maintenance checks to ensure the gates are functional, as well as operational staff to ensure the gates operate (even if the gates have automated systems) when required during flood events.

Potential mitigation activities

There are a number of works that might be required in the implementation and management if this option is pursued. These might include:

- Localised foreshore stabilisation works where existing erosion may have left the foreshore too steep or unstable. This may include the Windang foreshore, which could be managed with targeted nourishment or structure interventions
- Implementation and surveillance of exclusion zones around the weir to manage recreational safety near highly turbulent and high velocity flows
- Construction of an additional boat ramp upstream of Windang Bridge may be required to maintain boat access to the lake

6.4 Potential for staging and adaptability

For the purpose of this assessment, it is assumed that the primary purpose of the gate structures would be to mitigate the impact of flooding from rainfall. However, if this option is pursued further, there may be the potential to design the gates that allow for more control and flexibility of flow between the ocean and the lake during day to day tides. This may allow for increased tidal connectivity which may improve both tidal flushing (water quality) and fish passage. This would require careful consideration on design and operational protocol to ensure that any tidal flows do not result in high tidal velocities which could damage the structure or risk the safety of water users. It is anticipated that this would add significant complexity to the design and operation, which would increase the upfront capital cost and ongoing operational costs.

Since the rock weir is a relatively adaptable component of the structure, it could be raised above 0.1 m AHD in the future to maintain the target lake tidal range despite projected sea level rise. If the adjustable gate structures are designed so that they can achieve a higher crest level than 0.1 m AHD if required, this component of the structure would also be adaptable to future sea level rise.

6.5 Other risks

The risks associated with this option are broadly similar to those discussed in Option 1 (see Section 5.5).

An additional risk associated with Option 2 (compared to Option 1) is the operation of the adjustable gate structures. Relying on management of the gate structures during an emergency event (e.g. a flood) is a potential liability risk for the operator of the structure. It may also result in upstream communities becoming complacent to the risks of flooding if the structure fails to operate as expected.

There may be pressure from the community to operate the gate structures to allow boat access. This has not been assessed in this study, but it is considered likely that the resulting high velocity, turbulent flows would be unsuitable for navigation through the gate structures.

6.6 Overall assessment

Constructing a combined structure including a rock weir with adjustable gate structures to manage flood impacts near Windang Bridge (0.1 m AHD crest level) is expected to meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion. However, water quality in the lake, upstream flooding, fish passage and boating access would deteriorate overall compared to the base case (Table 6.1).

Table 6.1 Option 2 assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Option 2: Weir near Windang Bridge with gate structures to manage flood impacts	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration[#]	Improvement[#]	Deterioration*	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented in conjunction with this option.

[#] Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

7 Assessment of Option 3: Rock weirs at western end of the entrance channel across all three channels

7.1 Description

Option 3 considers three rock weir structures at the western end of the entrance channel, between the Shellharbour foreshore and Bevans Island, between Bevans Island and Cudgeree Island and between Cudgeree Island and the Wollongong foreshore (see Figure 3.2). A specific geometry for these structures that is capable of meeting the target tidal range has not been numerically modelled. However, it is hydraulically similar to the weir under the bridge and for the purpose of the assessment it is assumed that with a crest of approximately 0.1 m AHD, the target tidal range is likely to be achieved. Like Option 1, these will be drowned during high tide water levels and weirs with water flowing over them at low tide. This would require a total length of weir of approximately 485 m.

7.2 Objectives and criteria

7.2.1 Lake tidal range

Option 3 is assumed to be capable of achieving the same reduction in tidal range as described in Option 1. That is, it is expected to achieve the target tidal range of 0.07 m in the lake (the 2008 observed range) provided that the crest of the weirs is approximately 0.1 m AHD (to be confirmed with numerical modelling). If this option is pursued further, numerical modelling of the tidal losses is recommended to confirm the crest elevation required to meet the target tidal range.

As the weirs are located further upstream than Option 1, the entire channel which will experience an increase in tidal range compared to the base case (from the weirs to the ocean). The impact of these tidal level changes on infrastructure (particular on residences within Oaklands Village) and navigability in the entrance channel requires further consideration should this option progress further.

See Section 5.2.1 for further discussion on potential changes to tidal water levels as a result of this option.

Overall criteria rating: **Improvement**

7.2.2 Foreshore erosion

Option 3 is assumed to be capable of achieving the same reduction foreshore erosion as described in Option 1.

See Section 5.2.2 for further discussion on potential changes to foreshore erosion.

Overall criteria rating: **Improvement**

7.2.3 Water quality in the lake

Option 3 is assumed to have similar issues associated with water quality as discussed in Option 1. A reduction in tidal range will reduce tidal flushing and exchange, which is associated with a decrease in water quality. The presence of marine water in the entire entrance channel may result in an increase in recreational amenity of the channel compared to Option 1.

See Section 5.2.3 for further discussion on potential changes to water quality.

Overall criteria rating: Deterioration*
* Additional controls could be implemented to mitigate deterioration.

7.2.4 Recreational safety

Option 3 is assumed to have the same issues associated with recreational safety as discussed in Option 1. High velocity and highly turbulent flow present a risk to unpowered in-water activities at the location of the weirs, despite slower velocities throughout the majority of the entrance channel. Mitigation measures would be required to discourage access to the weir; however, these structures would remain unsafe for recreation.

See Section 5.2.4 for further discussion on potential changes to recreational safety.

Overall criteria rating: Deterioration*
* Additional controls could be implemented to mitigate deterioration.

7.2.5 Flooding from rainfall/catchment

Option 3 is assumed to have similar issues associated with flooding from rainfall/catchment as discussed in Option 1. Due to the total combined length of the three weirs, this option may result in faster flood drainage than Option 1 (subject to confirmation with additional formal flood modelling). However, flood drainage will still be worse than the base case.

Formal flood modelling for a range of scenarios is recommended to quantify the changes to upstream flood modelling if this option was implemented.

Overall criteria rating: Deterioration#
Additional study is required to confirm that it is a deterioration under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

7.2.6 Flooding from coastal storms

Option 3 is assumed to have the same improvements to flooding from coastal storms as discussed in Option 1 for the majority of locations, except that there will be a greater area of the entrance channel (downstream of the weirs) with increased tidal range than the base case. In these areas, flooding from coastal storms may get worse.

Additional numerical modelling is recommended to quantify the changes to oceanic flooding in the lake if this option was implemented (including consideration of storms of different duration and severity).

See Section 5.2.6 for further discussion on potential changes to flooding from coastal storms.

Overall criteria rating: Improvement[#]

[#] Additional study is required to confirm that it is an improvement under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

7.2.7 Fish passage

Option 3 is assumed to have the same issues associated with fish passage as discussed in Option 1.

See Section 5.2.7 for further discussion on potential changes to fish passage.

Overall criteria rating: Deterioration*

* Additional study is required to confirm that it is a net deterioration considering a range of fish species and fish abundances.

7.2.8 Flora and fauna

Changes to flora and fauna as a result of implementing Option 3 is likely to be functionally the same as Option 1. Some flora and fauna species will benefit from the construction of a weir, while it will be to the detriment of others. The net change in flora and fauna in Lake Illawarra as a result of this option is difficult to assess. The changes will be complex and interrelated. On this basis, no rating has been provided for this criteria.

See Section 5.2.8 for further discussion on potential changes to flora and fauna.

Overall criteria rating: Further study required

7.2.9 First Nations heritage

Preliminary input from the multi-agency project team indicated that weir structures abutting onto the natural land of Bevans and Cudgeree Island may not be appropriate due to the cultural significance of the islands, although this would require further input from First Nations people. Otherwise, Option 3 is likely to have similar benefits and drawbacks from a First Nations perspective to Option 1.

See Section 5.2.9 for further discussion on potential changes to First Nations Heritage.

Overall criteria rating: Further consultation required

7.2.10 Boating access

Option 3 is assumed to have the same issues associated with boat access as discussed in Option 1.

Construction of an additional boat ramp upstream of the weirs may be required to facilitate boat access to the lake.

See Section 5.2.10 for further discussion on potential changes to boating access.

Overall criteria rating: Deterioration

7.3 Whole of life cost

Capital cost
The capital cost for the three weirs at the western end of the entrance is approximately $15M to $30M (assuming a crest level of 0.1 m AHD and a total weir length of 485 m). While these weirs are not under the bridge, construction and maintenance may need to be completed via a barge due to difficulty of access, which may further increase the costs.

Planned ongoing costs
Ongoing maintenance and management costs are estimated to be an average of 1% of the capital cost per year (approximately $150,000 to $300,000 per year). This allowance may include the same activities as those identified for Option 1.

Potential mitigation activities
There are a number of works that might be required in the implementation and management if this option is pursued. These might include:

- Localised foreshore stabilisation works where existing erosion may have left the foreshore too steep or unstable. This may include the Windang foreshore, which could be managed with targeted nourishment or structure interventions
- Implementation and surveillance of exclusion zones around the weirs to manage recreational safety near highly turbulent and high velocity flows
- Construction of an additional boat ramp upstream of the three weirs may be required to maintain boat access to the lake
- Additional reactive flood management preparation (e.g. sand bags or re-locating moveable infrastructure) may be required to manage the increase in flood damages

7.4 Potential for staging and adaptability

Unlike Options 1 and 2, Option 3 includes three separate structures. These could be constructed in succession to gauge the impact of individual structures. However, this would likely lead to increased tidal velocities in parts of the channel without weirs, which could exacerbate local erosion. Similar to Option 1, if the weirs are made of rock, they are relatively adaptable. It would be possible to stage construction, if preferred, to monitor the response of the entrance channel to a weir all the way across the channel that is at a lower elevation than 0.1 m AHD, and then raise it to achieve this elevation during a second construction stage. Similarly, while it would likely be more difficult than initial construction, it would be possible to remove rocks to lower the crest in the future, if required. Both approaches would likely increase the cost to deliver the project.

Again, since they are relatively adaptable structures, the weirs could be raised above 0.1 m AHD in the future to maintain the target lake tidal range despite projected sea level rise.

7.5 Other risks

The risks associated with this option are broadly similar to those discussed in Option 1 (see Section 5.5). Note that as there will be three weir structures, mitigation measures to manage recreational safety (such as exclusion zones) may be more difficult to enforce and monitor than Option 1.

7.6 Overall assessment

Constructing three weirs at the western end of the entrance channel is expected to meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion. However, water quality in the lake, upstream flooding, fish passage and boating access would deteriorate overall compared to the base case (Table 7.1). Preliminary input suggests that this option may not be suitable from a First Nations' perspective, although further consultation is required.

Table 7.1 Option 3 assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Option 3: Rock weirs at the western end of the channel across all three channels	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration[#]	Improvement[#]	Deterioration*	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented in conjunction with this option.

[#] Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

8 Assessment of Option 4: Staggered groyne field with armoured bed

8.1 Description

Option 4 considers three 100 m long groynes staggered in the lower entrance channel with localised bed armouring in the vicinity of the groynes (see Figure 3.4 for locations). Numerical modelling has shown that this arrangement is capable of achieving the target tidal range in the lake. The groynes would be exposed at all stages of the tide, similar to the existing groynes (Figure 8.1), although they would be higher, wider and substantially longer (the longest existing groyne is approximately 25 m).

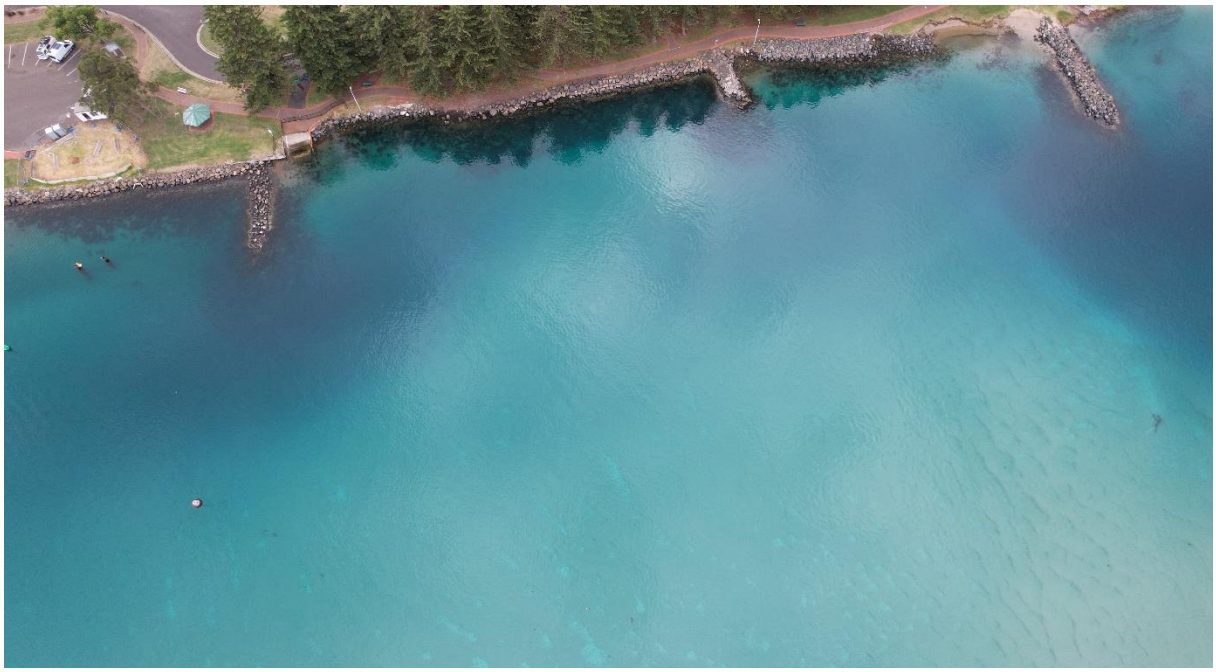


Figure 8.1 Photo of existing groynes along the Windang foreshore (3 March 2023)

8.2 Objectives and criteria

8.2.1 Lake tidal range

Constructing a staggered groyne field at the downstream extent of the entrance would achieve the 2008 target tidal range in the lake. The mean water level in the lake would be marginally higher than today (by 0.04 m), although the reduction in tidal range is largely associated with an increase in the low tide water level (by 0.09 m). This is demonstrated by the numerical modelling discussed in Section 3.5.1.

Downstream of the groynes and bed armouring, the tidal range would be increased slightly (relative to the base case), although the impacts of this are considered minimal given that this is fully within the training walls. However, implementing the groynes and bed armouring would raise high tide levels and lower low tide levels in the Kiyong Beach embayment (in the lee of the southern training wall) by up to 0.05 m.

Overall criteria rating: Improvement

8.2.2 Foreshore erosion

Option 4 is capable of achieving the similar reduction foreshore erosion as described in Option 1. Localised bed armouring is required to ensure scour at the location of the groynes does not occur.

See Section 5.2.2 for further discussion on potential changes to foreshore erosion.

Overall criteria rating: Improvement

8.2.3 Water quality in the lake

Option 4 is assumed to have the similar issues associated with water quality as discussed in Option 1. A reduction in tidal range will reduce tidal flushing and exchange, which is associated with a decrease in water quality.

See Section 5.2.3 for further discussion on potential changes to water quality.

Overall criteria rating: Deterioration*
* Additional controls could be implemented to mitigate deterioration.

8.2.4 Recreational safety

Option 4 is considered to be the most dangerous from a recreational safety perspective of the five options under consideration. Very high velocities (up to 3 m/s) have been modelled during normal tidal conditions near the heads of each of the groynes. Extremely steep water level gradients through the groyne field will further exacerbate risks to unpowered in-water activities in this area, despite slower velocities throughout the majority of the entrance channel.

Flows through the groyne field will also be highly turbulent and possibly hard to predict. While exclusion zones would need to be implemented to manage these risks, the length of the channel covered by the groyne field is significantly larger than the weirs. As the channel is not obstructed over its full width, there may be a push from the community to maintain access through the groyne field. Both of these factors will make exclusion zones harder to enforce. Consideration of the potential risks associated with this option in regard to recreational safety should be explicitly considered prior to pursuing Option 4.

Overall criteria rating: Deterioration

8.2.5 Flooding from rainfall/catchment

Option 4 is assumed to have the similar issues associated with flooding from rainfall/catchment as discussed in Option 1, although there is currently no numerical modelling available to quantify the change. While it is not clear whether flood drainage will be better or worse than Options 1 to 3, flood drainage will be worse than the base case.

Formal flood modelling for a range of scenarios is recommended to quantify the changes to upstream flood modelling if this option was implemented.

Overall criteria rating: Deterioration[#]

[#] Additional study is required to confirm that it is a deterioration under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

8.2.6 Flooding from coastal storms

Option 4 is assumed to have the same improvements to flooding from coastal storms as discussed in Option 1 through decreased hydraulic efficiency.

Additional numerical modelling is recommended to quantify the changes to oceanic flooding in the lake if this option was implemented (including consideration of storms of different duration and severity).

See Section 5.2.6 for further discussion on potential changes to flooding from coastal storms.

Overall criteria rating: Improvement[#]

[#] Additional study is required to confirm that it is an improvement under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

8.2.7 Fish passage

Unlike Options 1 to 3, Option 4 does not physically block the channel and slows the velocities in most parts of the channel. While high velocity and highly turbulent flow will remain an issue at the groyne field itself, this is viewed as an overall improvement in fish passage, compared to the base case as the velocities will not continue to increase into the future and access to the lake for fish passage is maintained across the whole tidal cycle (compared to the weir options which limit connection to the top of the tidal cycle).

It is recommended that a fish passage and fish migration study specific to the Lake Illawarra estuary be undertaken to assess existing conditions and likely changes if a staggered groyne field is pursued further.

Overall criteria rating: Improvement*

* Additional study is required to confirm that it is a net deterioration considering a range of fish species and fish abundances.

8.2.8 Flora and fauna

Option 4 will result in the smallest change in the present day tidal range in the lake. The mean water level in the lake in the lake would be marginally higher than today (by 0.04 m), and the reduction in tidal range is largely associated with an increase in the low tide water level (by 0.09 m) and high tide water levels are only changed by 0.02 m. Unlike the base case, this option will stabilise the tidal range at this level (excluding consideration of climate change). This will slow the expansion of mangroves and reduce the area of mudflats. This will be to the detriment of some species (e.g. intertidal birds) and to the benefit of others (e.g. saltmarsh).

Similar to Options 1 to 3, the net change in flora and fauna compared to the base case in Lake Illawarra as a result of this option is difficult to assess. The changes will be complex and interrelated. On this basis, no rating has been provided for this criteria.

See Section 5.2.8 for further discussion on potential changes to flora and fauna.

Overall criteria rating: Further study required

8.2.9 First Nations heritage

Preliminary input from the multi-agency project team indicated that the staggered groyne field may be viewed negatively by First Nations communities due to the hard engineering structures abutting onto natural foreshores, although this would require further input from First Nations people. Otherwise, Option 4 is likely to have similar benefits and drawbacks from a First Nations perspective to Option 1.

See Section 5.2.9 for further discussion on potential changes to First Nations Heritage.

Overall criteria rating: Further consultation required

8.2.10 Boating access

While the construction of a staggered groyne field does not physically block the channel, numerical modelling results suggest the high velocity turbulent flows through the structures would pose substantial safety risks to vessels. Very high velocities (up to 3 m/s near the head of the groynes) have been modelled during normal tidal conditions. This is approximately double the velocity currently observed in the entrance channel and will occur where the channel is narrow (and so boating manoeuvrability is restricted) due to the presence of the groynes. Extremely steep water level gradients at both high and low tide through the groyne fields will further exacerbate risks to vessel activities in this area, despite slower velocities throughout the entrance channel. Due to these dangerous conditions (previously discussed in Section 3.6.1), boat access through these structures is not recommended if this option is implemented.

Similar to the risks for recreational safety, similar concerns should be considered for boat access. As there is a channel through the groynes, it is likely that there will be community pressure to allow boating through these structures, which presents a risk to community safety. Exclusion zones would be required, which may be difficult to enforce.

Tidal channel velocities upstream of the armoured bed area would be reduced, improving ease of boating and safety in most of the entrance channel. However, the boat ramp at Reddall Reserve would no longer be usable. Construction of an additional boat ramp upstream of the armoured bed area may be required to maintain the same level of boat access to the lake.

Overall criteria rating: Deterioration

8.3 Whole of life cost

Capital cost

The capital cost for the staggered groyne field with the armoured bed is estimated to be approximately $145M to $240M. A substantial volume of rock will be required and construction will be difficult due to the high velocities already experience in this part of the channel. Temporary closure of the channel may be required to facilitate construction.

Planned ongoing costs

Ongoing maintenance and management costs are estimated to be an average of 1% of the capital cost for the groynes in addition to 0.5% of the capital cost of the bed armouring per year (approximately $750,000 to $1,250,000 per year). This allowance may include such activities as:

- Removal of rubbish/debris collected immediately adjacent to the groynes
- Regular condition inspection and survey of the groynes from the crest
- Regular condition inspection of the bed armouring from a boat
- Regular condition inspection of the groynes and bed armouring from underwater
- Bathymetry survey of the bed armouring levels
- Repair of any structural settlement of the groynes or displaced rocks from the groynes or bed armouring
- Technical engineering design advice for any significant repair works

Potential mitigation activities

There are a number of works that might be required in the implementation and management if this option is pursued. These might include:

- Localised foreshore stabilisation works where existing erosion may have left the foreshore too steep or unstable. This may include the Windang foreshore, which could be managed with targeted nourishment or structure interventions
- Implementation and surveillance of exclusion zones around the staggered groyne field and armoured bed to manage recreational safety near highly turbulent and high velocity flows
- Construction of an additional boat ramp upstream of the armoured bed area may be required to maintain boat access to the lake from the Shellharbour side of the channel
- Additional reactive flood management preparation (e.g. sand bags or re-locating moveable infrastructure) may be required to manage the increase in flood damages

8.4 Potential for staging and adaptability

Option 4 includes the construction of three groynes and substantial bed armouring. These could be constructed in succession, although this would likely increase the stress on individual structures in the interim which may increase the likelihood of failure. Similar to other options, as the groynes would likely be made of rock, they are relatively adaptable. Rocks could be removed from the end of the structures to increase the hydraulic efficiency and improve tidal flushing if required in the future. However, this would add additional costs, particularly as the high velocity regions at the end of the groynes will be extremely difficult to work around.

Again, since they are relatively adaptable structures, the rock groynes could be lengthened in the future to maintain the target lake tidal tide range despite projected sea level rise.

8.5 Other risks

The staggered groyne field shares many of the same risks as those discussed in Option 1 (see Section 5.5). In addition to those risks, there is a possibility that the entrance channel would need to be temporarily shut to facilitate construction of the groynes which would require an environmental assessment. This could be achieved through the placement of temporary rock bags in the channel, or similar, but this has not been included in the capital cost estimate.

The risks to recreational and boat safety may also pose a liability risk if an accident occurs. Detailed consideration of these risks should be considered prior to pursuing this option further.

8.6 Overall assessment

Constructing the staggered groyne field at the eastern end of the channel is expected to meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion, while also maintaining fish passage. Water quality in the lake, upstream flooding, boating access and recreational safety would deteriorate overall compared to the base case (Table 8.1). The increased risks to both powered and un-powered water users is a significant concern which would warrant further consideration prior to pursuing this option. Preliminary input suggests that this option may not be suitable from a First Nations' perspective, although further consultation is required.

Table 8.1 Option 4 assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Option 4: Staggered groyne field with armoured bed	Improvement	Improvement	Deterioration*	Deterioration	Deterioration#	Improvement#	Improvement*	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented in conjunction with this option.

Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

9 Assessment of Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)

9.1 Description

Option 5 considers removal of the training walls that were constructed in 2007 (Figure 9.1) in conjunction with large scale nourishment to return the system to its natural condition as an ICOLL (see Figure 9.2). Prior to 2007, Lake Illawarra was an ICOLL that tended to be shut to the ocean more often than it was open. The previous structural intervention was the construction of an inner southern training wall in 2001 (see light blue line in Figure 9.2). Small scale maintenance dredging periodically occurred between 2001 and 2006, although these did not typically keep the entrance open for substantial periods of time. Returning the system to an accretionary state is the aim of this option. While no modelling was completed for this option, observations of pre-training conditions have been used to inform this section.

It is uncertain whether removing the training walls alone would return the entrance to a target historical state within an acceptable timeframe. There is a risk the entrance channel may widen (eroding the Windang peninsula) following the removal of both training walls. To prevent this, large scale sand nourishment would be required in addition to the removal of both training walls to achieve the target historical state in a guaranteed period.

While this Stage 2 assessment has only considered the removal of both training walls, other variations of this option which could be assessed in a future investigation include the removal of only one training wall or the shortening of one or both training walls to increase sand replenishment from the ocean.

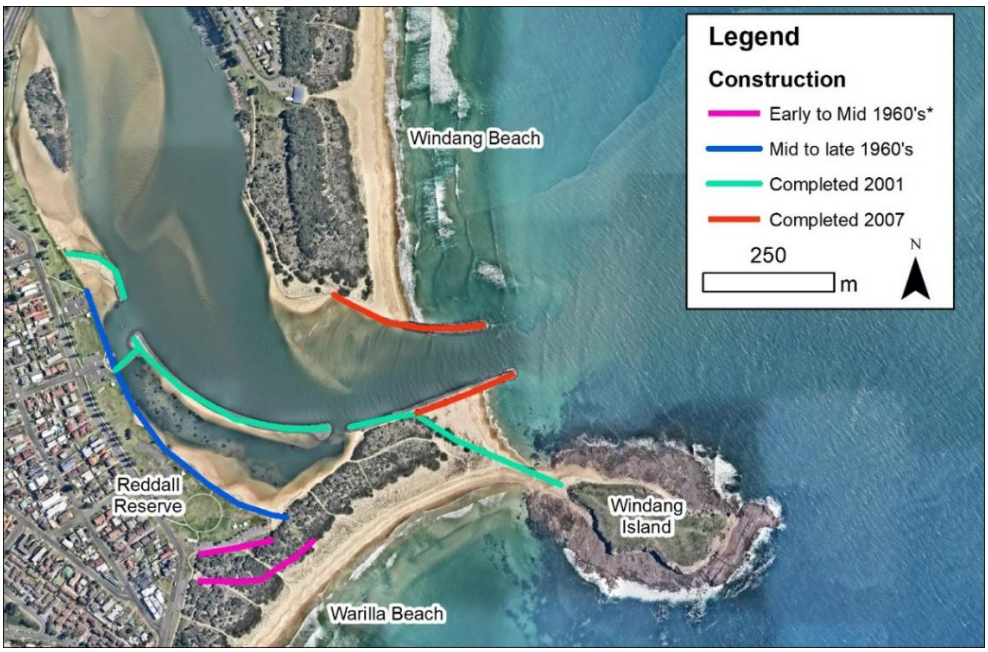


Figure 9.1 Indicative locations of construction works since the 1960s (aerial photo: 30/10/2018)

* Position and length of walls is indicative only and has been estimated from old aerial images.



Figure 9.2 Photographs on Lake Illawarra entrance channel in open (left – 25/05/2001) and closed (right – 31/03/2004) states before construction of the training walls (Source: MHL, 2023)

9.2 Objectives and criteria

9.2.1 Lake tidal range

Returning Lake Illawarra to an ICOLL would achieve the target tidal range (less than 2008). Prior to entrance training, annual average tidal range in the lake was typically 0.01 – 0.03 m, depending on how often the lake was opened (Young et al., 2014). Average water levels in the lake varied year to year, but were typically around 0.3 – 0.4 m AHD.

Overall criteria rating: **Improvement**

9.2.2 Foreshore erosion

The aim of this option would be to revert Lake Illawarra into an accretionary mode (i.e. an ICOLL which shuts even if it is temporarily opened). This will effectively address foreshore erosion within the entrance channel.

However, a drawback of this option is that beach (approximate length 150 m) between the southern training wall and the coastal structure extending to Windang Island (completed in 2001) would likely be realigned and reduced in width because of removal of the southern training wall.

Overall criteria rating: **Improvement**

9.2.3 Water quality in the lake

This option will reduce tidal exchange, which would result in a negative impact on water quality based on the criteria established. It is acknowledged that the water quality in the lake is not only related to tidal flushing (Habitat Innovation & Management 2023), and poor water quality could be further exacerbated by urban and agricultural development in the catchment. This option would result in the lake returning to an ICOLL, which will be shut unless there is intermediate dredging as required to address water quality.

Issues associated with poor water quality when Lake Illawarra was shut prior to the training walls was a major driver for the initial construction of the training walls. Similarly, this would have an additional negative impact on amenity as the water in the entrance channel would change from its existing high proportion of marine water to more brackish water.

Management of water quality entering the lake would need to be considered to prevent potential unacceptable impacts similar to that experienced prior to the lake being permanently opened. Management of water quality entering the lake would likely require water quality improvement measures in the lake catchment and consideration of water quality triggers in an ICOLL Entrance Management Policy may be required.

Such measures could include investment in or active management of sediment in the entrance channel.

Overall criteria rating: Deterioration*
* Additional controls could be implemented to mitigate deterioration.

9.2.4 Recreational safety

Implementing Option 5 would improve recreational safety of unpowered in-water activities (e.g. swimming, canoeing/kayaking, stand-up paddle boarding) through reduction of the tidal velocities in the entrance channel. As there are no structural barriers in this option, recreational safety will be improved across the whole channel.

Overall criteria rating: Improvement

9.2.5 Flooding from rainfall/catchment

Returning the lake system to an ICOLL would have a negative impact on upstream flooding in Lake Illawarra. It is likely that active management of the entrance channel would be required to facilitate rapid scour during a flood event, which is common in ICOLLs in NSW.

Formal flood modelling for a range of scenarios is recommended to quantify the changes to upstream flood modelling if this option was implemented.

Overall criteria rating: Deterioration#
Additional study is required to confirm that it is a deterioration under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

9.2.6 Flooding from coastal storms

This option would likely reduce the impacts of most oceanic flooding in Lake Illawarra. It is expected that peak flood levels in the lake, due to coastal storm surge (e.g. the inverse barometer effect and/or regional wind setup) and longer duration sea level anomalies, would be reduced.

Additional numerical modelling is recommended to quantify the changes to oceanic flooding in the lake if this option was implemented (including consideration of storms of different duration and severity).

Overall criteria rating: Improvement[#]

[#] Additional study is required to confirm that it is an improvement under a wide range of environmental conditions. This is presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b).

9.2.7 Fish passage

While returning Lake Illawarra to an ICOLL system will intermittently reduce connectivity between the ocean and the lake, the impact on fish passage is not well understood. ICOLL systems, particularly large ICOLLs, can be more productive in fish than permanently open estuaries (DPI Fisheries, n.d.). Based on the input from the multi-agency project team, there is significant uncertainty in how this option would impact fish passage, and a fish passage and fish migration study specific to the Lake Illawarra estuary would be required to understand the implications if this option was pursued.

Overall criteria rating: Further study required

9.2.8 Flora and fauna

Similar to Option 1, it is difficult to determine whether changes to flora and fauna from Option 5 would be an improvement or deterioration. It is assumed that eventually the flora and fauna would return to a similar condition that existed between 2001 and 2006, prior to the construction of the training walls (although it may take some time). For example, this option would prevent the smothering and erosion of seagrass beds in and around the entrance channel in the lake and may promote recovery of some of the lost seagrass areas since the entrance training occurred. Reducing the tidal range will prevent the expansion of mangroves, which may result in stabilisation of saltmarsh communities which have been declining.

Similar to other options, Option 5 will also change habitat for birds and fish. There would likely be a shift towards more brackish fish species (away from marine species), and the loss of intertidal mudflats may result in a decrease in intertidal wader birds (a number of which are listed as threatened species), but this may result in more opportunities for piscivorous birds. Over time, the accumulation of sand in the entrance channel may create suitable habitat for shorebirds and seagrass.

The net change in flora and fauna in Lake Illawarra as a result of this option is difficult to assess. The changes will be complex and interrelated. On this basis, no rating has been provided for this criteria.

Overall criteria rating: Further study required

9.2.9 First Nations heritage

Preliminary input from the multi-agency project team indicated that Option 5 be considered appropriate from a First Nations perspective, as it would conserve cultural heritage values that are at risk from erosion and there is likely to be a preference to returning to a more natural ecological condition. Unlike the other options, there would be no new built infrastructure. However, it is acknowledged that this will worsen upstream flooding, which may impact areas of cultural significance along the lake foreshore. Similarly, the removal of the training walls may require consideration of impacts of heavy machinery if completed from the land.

Further engagement would be required to understand the potential suitability of this option from a First Nations perspective.

Overall criteria rating: Further consultation required

9.2.10 Boating access

Implementing Option 5 would restrict boating access between the lake and ocean, resulting in an overall negative impact on boating access. While the lake would remain accessible from the Windang boat ramp, the lake and channel would no longer be able to be accessed from the ocean. This also means Lake Illawarra would not be available for safe harbour to boats passing by (although other nearby alternatives will remain).

Overall criteria rating: Deterioration

9.3 Whole of life cost

Capital cost

The capital cost to remove the entrance training walls is estimated to be approximately $20M. In addition to removing the training walls, large scale nourishment would also be required. Between 2008 and 2022, approximately 900,000 m^3 of sand has been eroded from the entrance channel (Tucker et al., 2023b). Depending on the source (e.g. offshore), it would likely cost in the order of $20M to $50M to replace this volume via sand nourishment. It is acknowledged that it may not be necessary to replace the entirety of this lost sand volume to get the entrance to close, however further studies would be required to optimise the amount of nourishment required.

The total capital cost to remove the entrance training walls in conjunction with large scale sand nourishment is estimated to be approximately $35M to $70M (rounded to the nearest $5M).

Planned ongoing costs

Ongoing management of the entrance will be required and is estimated to cost $100,000 to $200,000 per year. This will require the development of an ICOLL Entrance Management Policy and will likely include costs for managing entrance breakouts to minimise upstream flood impacts, as well as consideration of ecological impacts (such as impacts on endangered shorebirds nesting sites) of active entrance management. These ongoing costs have not included the concurrent catchment management activities and in-lake water quality management that have been discussed previously as being crucial for maintaining water quality in Lake Illawarra with a closed entrance.

Potential mitigation activities

There are a number of works that might be required in the implementation and management if this option is pursued as outlined in the previous paragraph (i.e. under the “planned ongoing costs” sub-heading).

9.4 Potential for staging and adaptability

The staging of the removal of the training walls would require careful consideration in a future study. This study has only provided a high level, conceptual possibility for the staging which may include:

1. The northern training wall could be shortened, but not completely removed, in the first instance alongside the large scale sand nourishment. This may be effective at allowing some marine sediment to be delivered into the channel while still restricting the rate of sediment accretion. However, the aim of this option must be to force the entrance channel into an accretionary mode (e.g. tending to close following rainfall events) to prevent the channel from returning to the current condition. Keeping a short length of the northern training wall in place may also be advantageous for ensuring that, when a closed entrance condition is opened by flooding from rainfall/catchment, the entrance remains in the existing location (i.e. it does not meander into the Windang peninsula).
2. If the rate of sediment input is insufficient to maintain this accretionary mode, further work will be required to remove the remainder of the wall and/or shorten/remove the southern training wall too. This would be more costly than completing the works in one campaign.

The extent of ongoing management of the entrance is dependent on the goal or goals of these works (e.g. flood mitigation, water quality improvement and/or maintaining boating access to the ocean) and will require adaptation to projected sea level rise.

9.5 Other risks

This option will result in the lake tending towards a closed condition. This will need to be managed with an ICOLL Entrance Management Policy. There is also a risk that without the training walls, the entrance may meander and openings may occur in new locations which may impact sand dunes, cultural sites, beach access and public amenity. Finally, there is a risk that altering the training walls may be perceived to impact nearby surfing breaks. Such changes could be either positive or negative, and could be both at different times or for different user groups.

9.6 Overall assessment

Removing both training walls and using large scale sand nourishment to return Lake Illawarra to an ICOLL would meet the key objectives of the target lake tidal range and reducing foreshore and bed erosion. However, water quality in the lake, upstream flooding and boating access would deteriorate overall compared to the base case (Table 9.1). Preliminary input suggests that this option may be preferable from a First Nations perspective, although further consultation will be required.

Table 9.1 Option 5 assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	Improvement	Improvement	Deterioration*	Improvement	Deterioration[#]	Improvement[#]	Further study required	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented in conjunction with this option.

[#] Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

10 Summary

Reducing the tidal range to the 2008 observed range and therefore reducing foreshore erosion in the Lake Illawarra system is feasible through engineering intervention. This could be achieved through:

- Installation of weirs across the width of the channel. However, the crest would need to be at least 0.1 m AHD to achieve the target tidal range, meaning it will be a weir with water flowing over it at some stages of the tide and drowned at high tide. Three weir options have been considered:
    - **Option 1:** A rock weir near Windang Bridge with a crest height of 0.1 m AHD
    - **Option 2:** A combined rock weir near Windang Bridge with a crest height of 0.1 m AHD with adjustable gate structures to manage flood impacts
    - **Option 3:** Three rock weirs at the western end of the entrance channel with a crest height of 0.1 m AHD
- **Option 4:** Installation of a staggered groyne field near the entrance channel, including localised bed armouring. The groynes would need to substantially block the channel (at least 100 m in length each) to achieve the target tidal water level.
- **Option 5:** Removing both training walls and large scale sand nourishment to return the lake to an ICOLL. This option would require an ICOLL Entrance Management Policy (as the dominant entrance state would be closed without active management), which contrasts with Options 1 to 4 for which sand nourishment may be required for localised foreshore stabilisation works.

While all five options are effective at meeting the target tidal range and reduction in foreshore erosion, there is no single option that improves all ten of the management objectives/criteria for Lake Illawarra. Table 10.2 provides an overview of the options assessment. All five options result in a deterioration in water quality (i.e. tidal flushing), flooding from catchment/rainfall and boating access.

The three options (Options 1 to 3) involving weirs result in permanent engineered barriers across the channel, which will impact fish passage and fish abundances. While the groynes (Option 4) maintain fish passage, there are significant concerns about recreational safety. Option 5, removing both training walls, is the only option which does no deteriorate recreational safety, although these risks may be manageable for other options through the enforcement of exclusion zones around the structures. Returning Lake Illawarra to an ICOLL (Option 5) will result in changes in fish passage, however this is the natural state for this estuary. Further studies are required to assess the impact of removing both training walls on fish passage.

The condition of the entrance channel and subsequent changes in tidal range influences flora and fauna within the lake system. The increase in tidal range since the entrance was trained has increased the extent of some estuarine flora (e.g. mangroves), while decreasing the extent of others (e.g. seagrass, especially in the entrance channel). Changes to the tidal range and connectivity causes shifts in the flora and fauna communities which are complex and interrelated and it is difficult to assess whether any single change is a net improvement or deterioration. More studies would be required to assess the net change in flora and fauna.

Consultation and engagement with First Nations communities will be essential to the long-term success of the management of Lake Illawarra. Preliminary input suggests that hard engineering structure abutting onto natural foreshores (e.g. Cudgeree or Bevans Island) may not be culturally appropriate. A preference for removing both training walls was evident in the preliminary input from the multi-agency

project team. Proactive and early engagement with First Nations communities is recommended following this study.

The cost of implementing each option varies, depending on the size and complexity of the structural intervention and sand nourishment required. Table 10.1 summarises the preliminary estimates of capital and ongoing costs. The staggered groyne field (Option 4) is significantly more expensive than the other options due to the amount of material required. The cost of Option 5 depends largely on the volume and source of sand required to complete the nourishment to ensure the lake returns to an ICOLL system which tends to close during periods of low rainfall.

Table 10.1 Preliminary estimates of capital and ongoing costs (excluding reactive management)

Option	Capital cost	Annual ongoing costs
Option 1: Rock weir near Windang Bridge	$20,000,000 to $45,000,000	$200,000 to $450,000
Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts	$60,000,000 to $105,000,000	$800,000 to $1,450,000
Option 3: Rock weirs at the western end of the channel across all three channels	$15,000,000 to $30,000,000	$150,000 to $300,000
Option 4: Staggered groyne field with armoured bed	$145,000,000 to $240,000,000	$750,000 to $1,250,000
Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	$35,000,000 to $70,000,000	$100,000 to $200,000

This study effectively shows that while there are options to reduce the tidal range in Lake Illawarra, the decision on which option to choose depends on the balance of a number of management objectives. There is no single option which will improve all ten management objectives/criteria, and a compromise between these objectives will need to be reached. It is important that the community and other stakeholders are provided an opportunity to understand, engage and provide input into the ideal balance of these objectives. The gazetted Lake Illawarra Coastal Management Program provides the overarching framework for future decision making as well as coordinated and strategic management of the lake by all responsible stakeholders.

Lake Illawarra is a sensitive and dynamic system with important community and cultural values. Regardless of which option is ultimately selected, ongoing monitoring and adaptive management will continue to be required in conjunction with the implementation of a long-term entrance management option. Some options may also have management implications that need to be considered in developing Open Coast CMP's by both Councils (especially on Windang and Warilla Beaches).

Members of the project control group have not formed a position on the preferred entrance management option as it is to be informed by community feedback, additional detailed studies and the overall Coastal Management Framework.

Table 10.2 Summary options assessment matrix relative to base case scenario

Option	Objectives and criteria									
	Lake tidal range	Foreshore erosion	Water quality in the lake	Recreational safety	Flooding from rainfall/ catchment	Flooding from coastal storms	Fish passage	Flora and fauna	First Nations heritage	Boating access
Base case	No change	No change	No change	No change	No change	No change	No change	No change	No change	No change
Option 1: Rock weir near Windang Bridge	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 2: Rock weir near Windang Bridge with gate structures to manage flood impacts	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 3: Rock weirs at the western end of the channel across all three channels	Improvement	Improvement	Deterioration*	Deterioration*	Deterioration#	Improvement#	Deterioration*	Further study required	Further consultation required	Deterioration
Option 4: Staggered groyne field with armoured bed	Improvement	Improvement	Deterioration*	Deterioration	Deterioration#	Improvement#	Improvement*	Further study required	Further consultation required	Deterioration
Option 5: Remove both training walls and large scale sand nourishment (return to pre-2007 conditions)	Improvement	Improvement	Deterioration*	Improvement	Deterioration#	Improvement#	Further study required	Further study required	Further consultation required	Deterioration

* Assessed with a narrow criteria which may not reflect the direction of change, further studies are recommended and/or there are potential mitigation actions that could be implemented with this option

Presently being assessed (at the time of writing) as part of the *Review of the Lake Illawarra Floodplain Risk Management Study and Plan* (WCC, 2023b)

11 Additional considerations and recommended further studies

11.1 Additional considerations

The purpose of this study was to develop a range of physically feasible options to manage foreshore erosion in the Lake Illawarra entrance channel. There are a range of other considerations which have not been explicitly discussed in this report, including:

- Given the scale of these options and complexity of impacts, the approval process will be complicated and lengthy and would not be guaranteed. Approval pathways and timeframes would vary between options.
- Climate change, including sea level rise, will impact the water and sediment dynamics in Lake Illawarra. Further consideration of climate change will be required prior to implementing any management option.
- Water quality has been considered in this report in reference to the potential for tidal flushing. Water quality in Lake Illawarra is intrinsically linked to catchment runoff, and mitigation of water quality by flushing the lake with oceanic water through the entrance channel has a lesser impact. Concurrent management of increasing nutrient and sediment sources in the upstream catchment, including from new urban developments will likely be required regardless of the future management of the entrance channel. Pollutant removal targets have been determined under the Risk Based Framework Strategic assessment for Lake Illawarra (DCCEEW, 2024) based on residence time under an open entrance condition. Previously determined nutrient removal targets may need to be increased to achieve the same environmental outcomes for water quality.
- Any engineered barriers (such as weirs) in the entrance channel will need to consider fish passage and fish abundances. Further consideration of fishways may be required to mitigate impacts should such structures be implemented.
- Options 1 – 4 involve the construction of new infrastructure which will require ongoing management and maintenance. Funding, ownership and maintenance responsibilities have not been determined in this study but would require consideration before implementation. Further to this, potential negative impacts on existing infrastructure (e.g. Windang Bridge piers) or associated maintenance access to it, due to new infrastructure, should be considered and minimised. The implementation of new infrastructure should not increase the maintenance costs for existing infrastructure.
- While Options 1 and 2 are located near Windang Bridge, a weir with crest lest of approximately 0.1 m AHD, which would achieve the target lake tidal range, could conceivably be constructed anywhere between the western end of Picnic Island (approximately 250 m upstream of Windang Bridge) and the western end of the training walls (subject to also controlling any back channel flows behind Picnic or Berageree Islands). Locating a weir towards the western end of the training walls would maximise the area of the entrance channel directly accessible by water craft from the lake, but these vessels would not have access to the ocean and more brackish water would exist throughout most of the entrance channel. On the other hand, a weir located towards the western end of the Picnic Island would maintain access to the ocean for water craft launched from boat ramps downstream of Windang Bridge and a greater extent of the entrance channel would maintain a high proportion of marine water. However, water craft launched from these boat ramps would not have access to the lake if a weir were located at Picnic Island.

- If large scale sand nourishment (Option 5) is required, sources of sand would need to be identified and approved. If no sand sources are available within a proximity, this could substantially increase potential costs.
- The CMP notes that a “registered Native Title Claim (NC2017/003 South Coast People) covers the entire CMP study area” but that “no determinations regarding the Claim have been made to date”. If engineering works (such as the long-term management options assessed in this report) are “scheduled to take place on a Crown reserve, advice on compliance under these acts will need to be obtained from a Native Title Manager”.
- Some options have implications for the management of the adjacent open coast systems and the broader marine estate, and would require further integration with the appropriate open coast CMP and Marine Estate Management Strategy (MEMS).

11.2 Recommended further studies

It is understood that community and stakeholder engagement and consultation is planned to occur following the publishing of this final draft report. In addition to upcoming community consultation, the following further studies are recommended:

- Investigation into First Nations perspectives, values and opinions into the future of Lake Illawarra
- A fish passage and fish migration study specific to the Lake Illawarra estuary to understand the impact of the current entrance conditions and any potential option to be pursued implications
- Detailed flood studies, including consideration of rainfall/catchment and coastal storms
- Further hydrodynamic modelling to include consideration of sea level rise
- Ecological investigations into changes in flora and fauna (particularly those listed as threatened species) as a result of changes in the tidal regime
- Specific investigation into recreational and boating safety, particularly if Option 4 (staggered groyne field) is pursued further
- Detailed water quality modelling, including nutrient cycling and consideration of catchment loads

Additional studies will also be required once a preferred management option is determined. This will include:

- Detailed costing
- Detailed design, including infrastructure placement
- Business case development
- Investigation into funding pathways, ownership and responsibility
- Approval pathways (including potentially an Environmental Impact Assessment and other legislative requirements)

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