Merimbula Lake entrance sediment study

WRL TR 2022/27, March 2023

By Y Doherty, J T Carley, B M Miller and C D Drummond

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1 Introduction

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney was engaged by Bega Valley Shire Council to investigate the sediment dynamics and coastal processes that drive morphological change at the Merimbula Lake entrance bar. The goal of this study was to assist with long term management of the Merimbula Lake entrance bar by developing a conceptual understanding of the Merimbula Bay and Merimbula Lake estuary systems by considering the interaction of estuarine and oceanic elements.

This study utilised a data intensive method combining multiple sources of remote sensing imagery with environmental drivers such as rainfall, ocean water levels, tidal cycle and wave climate to derive a comprehensive analysis of the beaches, shoals and channels within the project area. Analysis included synthesis of morphological features extracted from a comprehensive catalogue of aerial images between 1948 to present day consisting of historical aerial photos, satellite imagery, and aerial photogrammetry surveys.

The primary purpose of the study was to:

- More accurately define sediment transport pathways
- Investigate the likely range of movement of key morphological features
- Investigate the long-term trends of key features
- Improve understanding of key environmental drivers for morphological changes such as the 2020 erosion of the entrance bar sand spit
- Inform the feasibility and viability of potential management options

1.1 Site description

The Merimbula Lake estuary system is located adjacent to the township of Merimbula within the Bega Valley Shire Council Local Government Area on the Sapphire Coast of NSW. Approximately 360 km south of Sydney, the Merimbula Lake estuary system is a small-sized system with a catchment area of 26 km^2 and two tributary creeks; Boggy Creek and Bald Hill Creek (MHL, 2003). Located at the complex morphological interface between this tide-dominated estuarine system and a wave dominated semi-open coast location is the Merimbula Lake entrance bar (refer Figure 1). An untrained estuary entrance, the Merimbula Lake entrance bar is a dynamic feature with no known history of closure and a typical channel width of 100-200 m with a channel depth of approximate 2 m. The ebb tide shoal immediately offshore of the site significantly dissipates incident wave energy which periodically reduces navigability of the channel into the estuary at low tides.

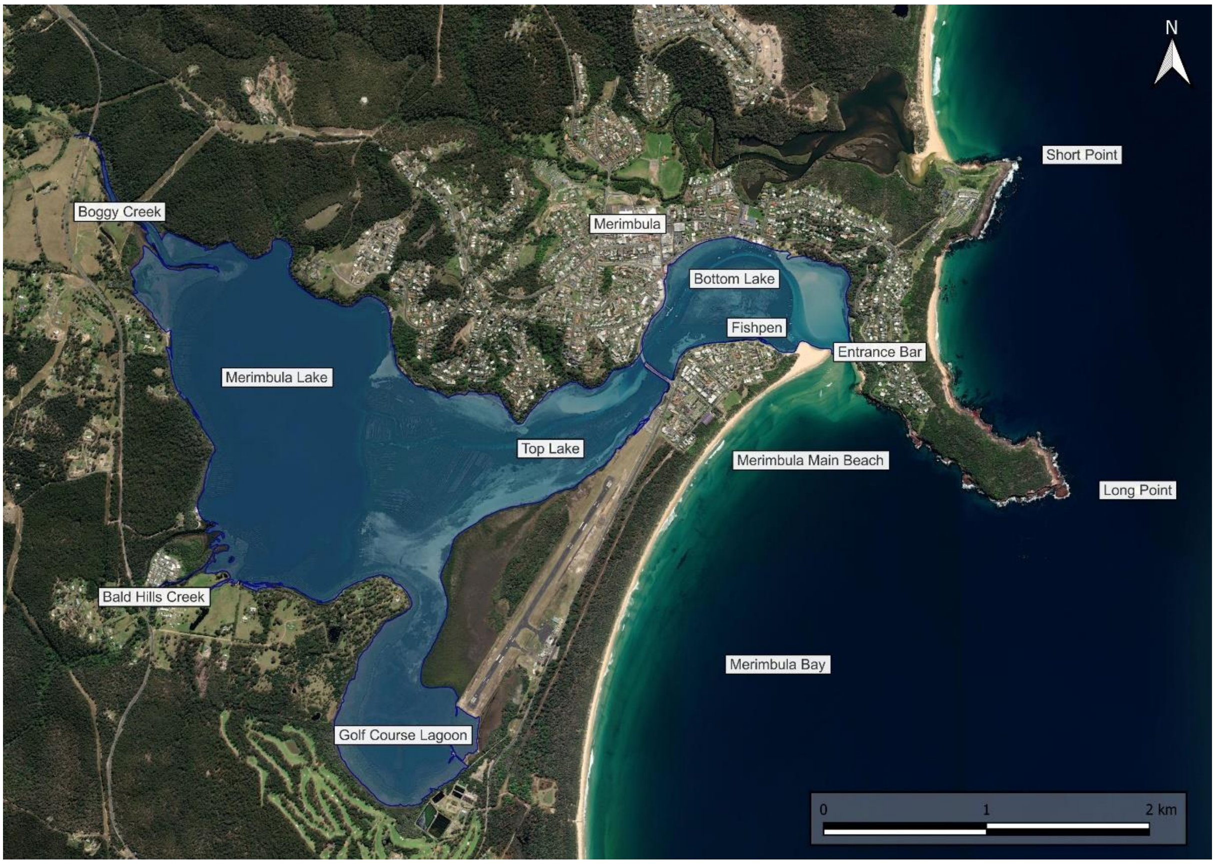

Figure 1 Merimbula Lake estuary system

Figure 2 Merimbula Lake entrance bar

2 Merimbula Lake entrance bar morphology

To more accurately define sediment transport pathways of the Merimbula Lake entrance bar, a data driven approach has been applied at the site to better understand the complex interactions between environmental forcing factors and system change. In order to track morphological changes through time, long-term imagery of the site was collated from a number of sources including historical aerial imagery, satellite data collection programs and the NSW beach profile database. An overview of data collection dates and available images is outlined in Table 1. Further details can be found in Appendix A1.

Table 1 Available Imagery of Merimbula Lake entrance bar

Dates	Number of Images	Source	Pixel Size
1948-2014	16	Aerial imagery	<1 m
1962-2020	16	NSW Beach Profile Database	N/A
1987-present	>1000	Satellite images	10-30 m
2005-2014	6	Maxar	<1 m
2018-2019	2	Nearmap	<1 m
2019-present	84	PlanetScope	3 m

Historical images were georeferenced using a number of control points including recognisable features such as street intersections or building footprints. This catalogue of imagery was used to investigate the long term variability of the sand spit at the Merimbula Lake entrance bar in the context of changes to other key morphological features of the system including channel alignment, ebb tide shoal area and shoreline variability along Merimbula Bay. Morphological change through time and bathymetry was then correlated to environmental driving forces to provide a more complete picture of sediment transport pathways in the system. A summary of environmental forcing factors including wave climate, rainfall data, water level and tidal measurements is provided in Appendix A2.

2.1 Long-term variability of the entrance bar

Taking advantage of the long-term (1987 to present) archive of bi-monthly satellite imagery at the site, an automated machine learning shoreline extraction toolkit was utilised to digitise shoreline position and entrance bar sand spit location through time (refer Appendix A1.1 for further details). By extracting a timeseries of shoreline position at transects along Merimbula Bay and the entrance bar spit, it is possible to view the prolonged 2019-2020 erosion of the sand spit in the context of its long term shoreline position. This method further enables insight into the long term range, stability and trends in morphology of the spit over time.

Based on results from the satellite derived shorelines and contextualised with additional historic imagery, the Merimbula Lake entrance bar spit exhibits a dynamic morphology through time with periodic variations in spit length, width and orientation. Despite this large degree of variability, the cycles of spit erosion and recovery are generally short lived, within a consistent spatial boundary, and recover within a 6 month window. Outside of these times, and as observed in the majority of aerial images, the entrance bar spit is a clear east to west morphological feature approximately 175 m across and 75 m wide. A timeseries of shoreline position along a transect on the entrance bar sand spit is shown in Figure 4, with the full range of sand spit variability based on satellite derived shorelines shown in Figure 3.

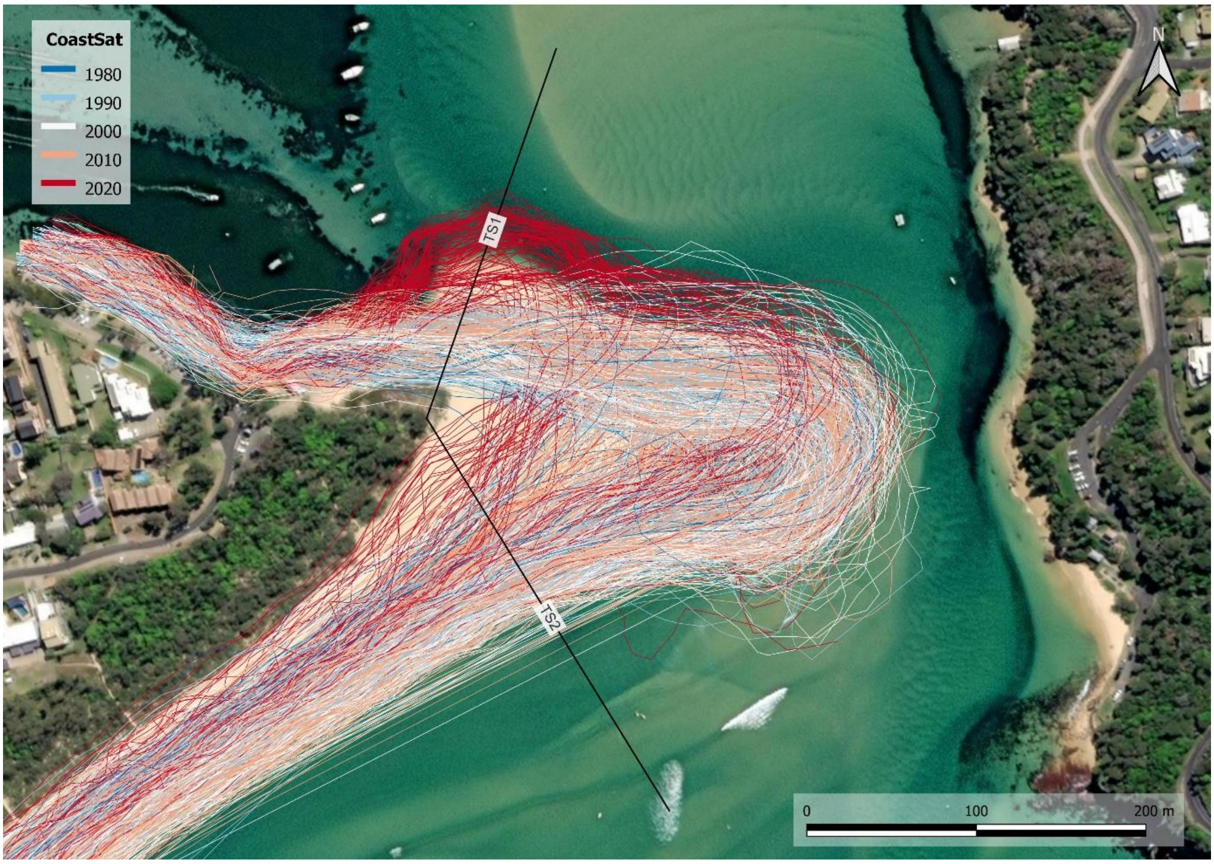

Figure 3 Long-term range of the entrance bar sand spit

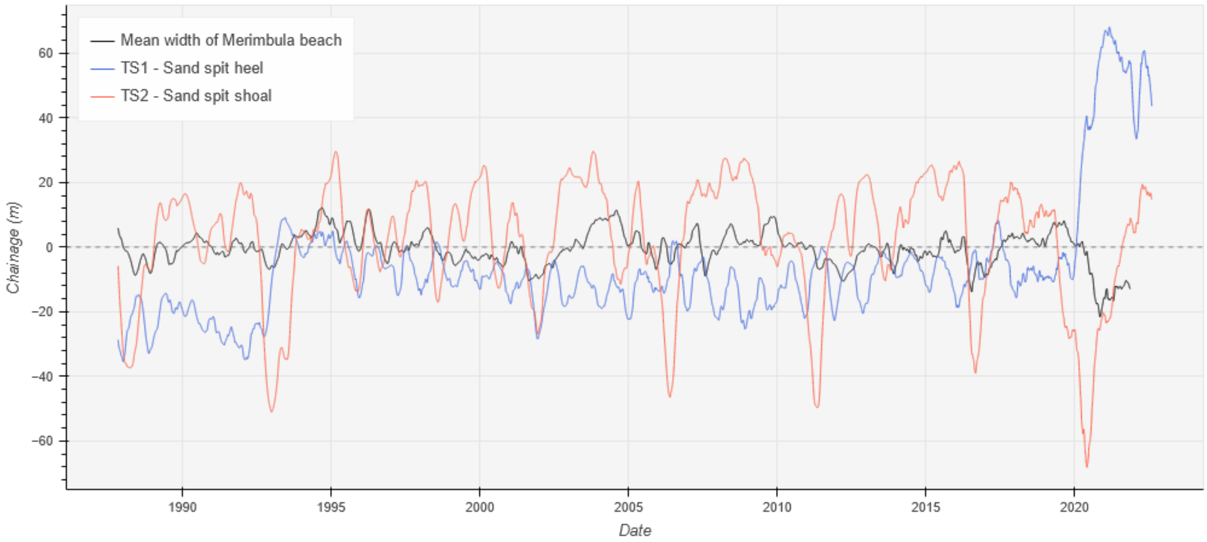

Figure 4 Long-term shoreline variability of the entrance bar sand spit (3 month rolling average)

As shown in Figure 4, the entrance bar sand spit has a cyclic history of shoal blowout with no apparent long term trend in frequency, duration or severity. Generally returning to its long term position from eroded states within a 6 month window, the sand spit is largely a stable morphological feature in a state of dynamic equilibrium between forcing oceanic wave conditions and returning tidal flows. Consistent with the satellite derived shoreline observations, the catalogue of aerial imagery and beach profiles from 1948 onwards show a stable sand spit with a historic footprint similar to that of the present day position.

Several images capturing the sand spit in an eroded state were observed in the historic data catalogue (1962, 1971 and 1979), and are consistent with the findings outlined above. These eroded states were short lived with the spit recovering by the following year.

Based on visual observations of satellite and historic imagery, the alignment of the primary channel in the bottom estuary is largely consistent through time. Closer to the sand spit and entrance bar, channel alignment is more variable and responds to changes in sand spit morphology. During eroded states of the sand spit, sediment is deposited seaward onto the entrance bar, and upstream into the primary channel temporarily reducing the maximum depth of the estuary entrance system. This sediment transport results in a reduction in channel navigability and presents a hazard for boat users, particularly during low tides. During these periods, channel alignment adjacent to the sand spit migrates northward and results in increased tidal flow restrictions. This channel re-alignment in response to changed entrance bar bathymetry was observed to result in a landward deposition of sediment at the 'heel' of the entrance bar spit. This landward deposition and resultant spit width increase was observed in several of the historical images in response to erosion events, and is particularly evident following the 2019-2020 erosion event (see Figure 2 and Figure 3).

2.2 Beach rotation and ENSO

To better understand the Merimbula Lake entrance bar in the context of the broader Merimbula Bay sediment compartment, analysis was undertaken using satellite-derived shorelines to investigate the impact of the El Niño–Southern Oscillation (ENSO) on shoreline position and beach orientation. Utilising an ENSO analysis workflow developed by WRL (Vos et al., 2023), seasonal averages of shoreline position were compared with a multivariate ENSO index for each transect. A summary of findings for the northern end of Merimbula Bay (Merimbula Main Beach) are shown below in Figure 5, with a plot of Beach Orientation Index (BOI) and ENSO Southern Oscillation Index (SOI) in Figure 6. Findings for the southern end of Merimbula Bay (Pambula Beach) are show in Appendix A2.

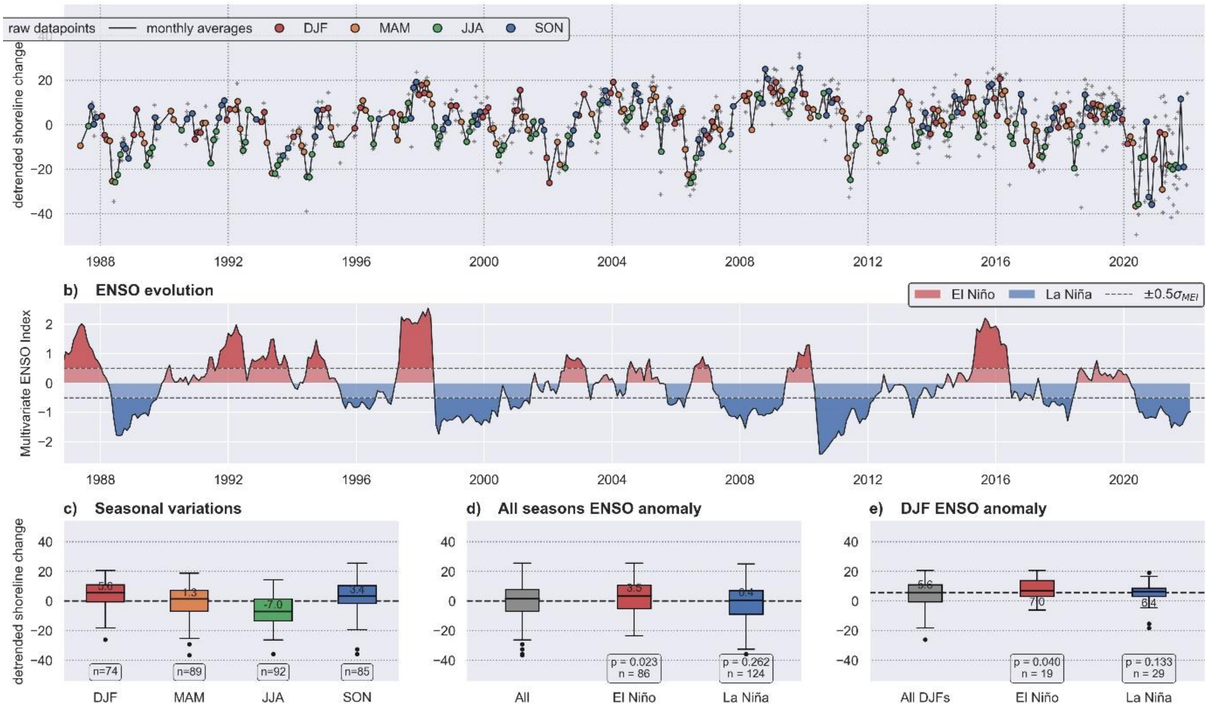

Figure 5 Long term shoreline variability vs ENSO at Merimbula Main Beach (source: Kilian Vos 2023)

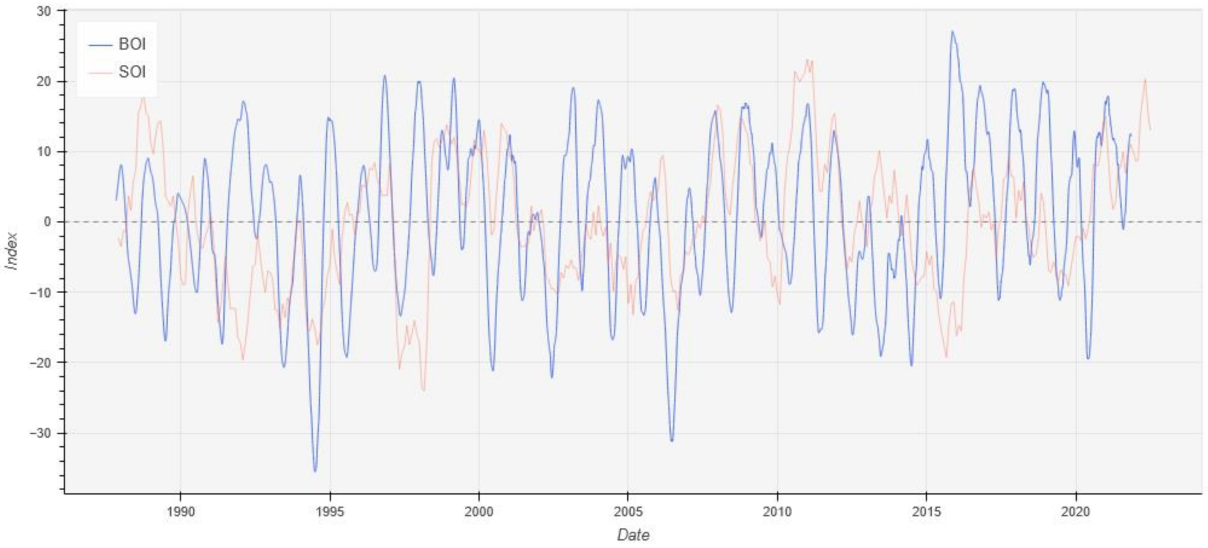

Figure 6 BOI vs SOI for Merimbula Bay (3 month rolling average)

Shown in Figure 5, an El Niño shoreline accretion anomaly of 3 m is observed for the northern end of Merimbula Bay, with no statistically significant finding for La Niña. Conversely, the southern end of Merimbula Bay exhibits an observed La Niña erosion anomaly of 4 m, with no significant El Niño variability evident (refer Appendix A2). In the context of seasonal shoreline variability, ENSO is a relatively minor environmental driver and contributes less to shoreline variability than the annual cycles of accretion and erosion (± 5 - 7 m) and significantly less than discrete storm events (10 - 20 m +). Visible in Figure 6, a seasonal orientation signal is evident along Merimbula Bay with positive BOI values observed in summer, and negative BOI values in winter. Measuring the difference in shoreline position between northern and southern transects, a positive BOI relates to a clockwise rotation. Observing the typical scales of rotation for Merimbula Bay, a positive summer BOI of 10 translates to a 0.1 degree clockwise rotation and roughly corresponds to a 10 m cross-shore difference between northern and southern transects. This difference in shoreline position is relative to the long term mean for each transect and is independent of the state of the beach as a whole, which may exhibit an overall eroded or accreted position.

2.3 Merimbula Lake tidal flows

To understand the primary drivers of entrance bar morphology at the site, the findings and timeline from Section 2.1 were compared against environmental forcing factors from long term measurements of wave conditions, water level, tidal fluctuations and rainfall. Plots and analysis of this data can be found in Appendix A3. Based on gauging studies of tidal flow in the Merimbula Lake estuary system conducted by the Manly Hydraulics Laboratory (MHL) in 1978 and 2003, estimated tidal flows are summarised in Table 2.

Table 2 Merimbula Lake tidal flows

Tide	Measurement	Location	MHL (1978)	MHL (2003)
Flood	Peak inflow	Entrance	160 m^3/s	174 m^3/s
Ebb	Peak outflow	Entrance	175 m^3/s	137 m^3/s
Flood	Peak velocity	Bridge	1.31 m/s	1.24 m/s
Ebb	Peak velocity	Bridge	1.58 m/s	1.21 m/s
Flood	Peak velocity	Entrance	0.45 m/s	N/A
Ebb	Peak velocity	Entrance	0.82 m/s	N/A
Flood	Inflow volume	Bridge	1,860,000 m^3	2,050,000 m^3
Ebb	Discharge volume	Bridge	N/A	2,310,000 m^3

Based on information presented in the 1978 MHL gauging study, Webb, McKeown & Associates undertook an estuary processes study of the Merimbula Lake system (WMA, 1995). Assuming a reasonable set of mixing conditions for the tidal prism, WMA estimated an average tidal volume exchange with the lake of 790,000 m^3 each tidal cycle. Performing a high level analysis of potential flood conditions in the system, WMA estimated a peak flood discharge of 270 m^3/s under a 1% flood event conditions. Relative to the average ebb tide outflow discharge of 137-175 m^3/s (refer Table 2), flood conditions likely only have a minor impact on entrance bar morphology due to both the small magnitude and infrequency of such events.

2.4 Sediment pathway conceptual model

As outlined by WMA (1995), sediment transport in the Merimbula Lake entrance bar is balanced in a circulation cell immediately upstream of the bar. Relatively stable and in a state of dynamic equilibrium, ocean sediment is circulated throughout the tidal cycle. With sediment pushed northward along Merimbula Beach towards the entrance bar by the prevailing south-easterly swell conditions, deposition occurs offshore on the entrance bar shoal. Balancing this influx of ocean sediment, the outgoing ebb tide velocity adjacent to the entrance bar is greater than the incoming flood tide velocity (refer Table 2) and results in increased scour during the ebb phase of the tidal cycle. This complex balance of onshore wave driven sediment transport and return via tidal driven scour results in the observed long term equilibrium wedge shaped sand spit. At the northerly end of an embayed beach, wave energy at the Merimbula Lake entrance bar is sheltered from easterly and northerly swells by Long Point, and from southerly swells by Haycock point to the south. This nearshore attenuation of wave height and direction within Merimbula Bay is shown in Appendix A3.1.

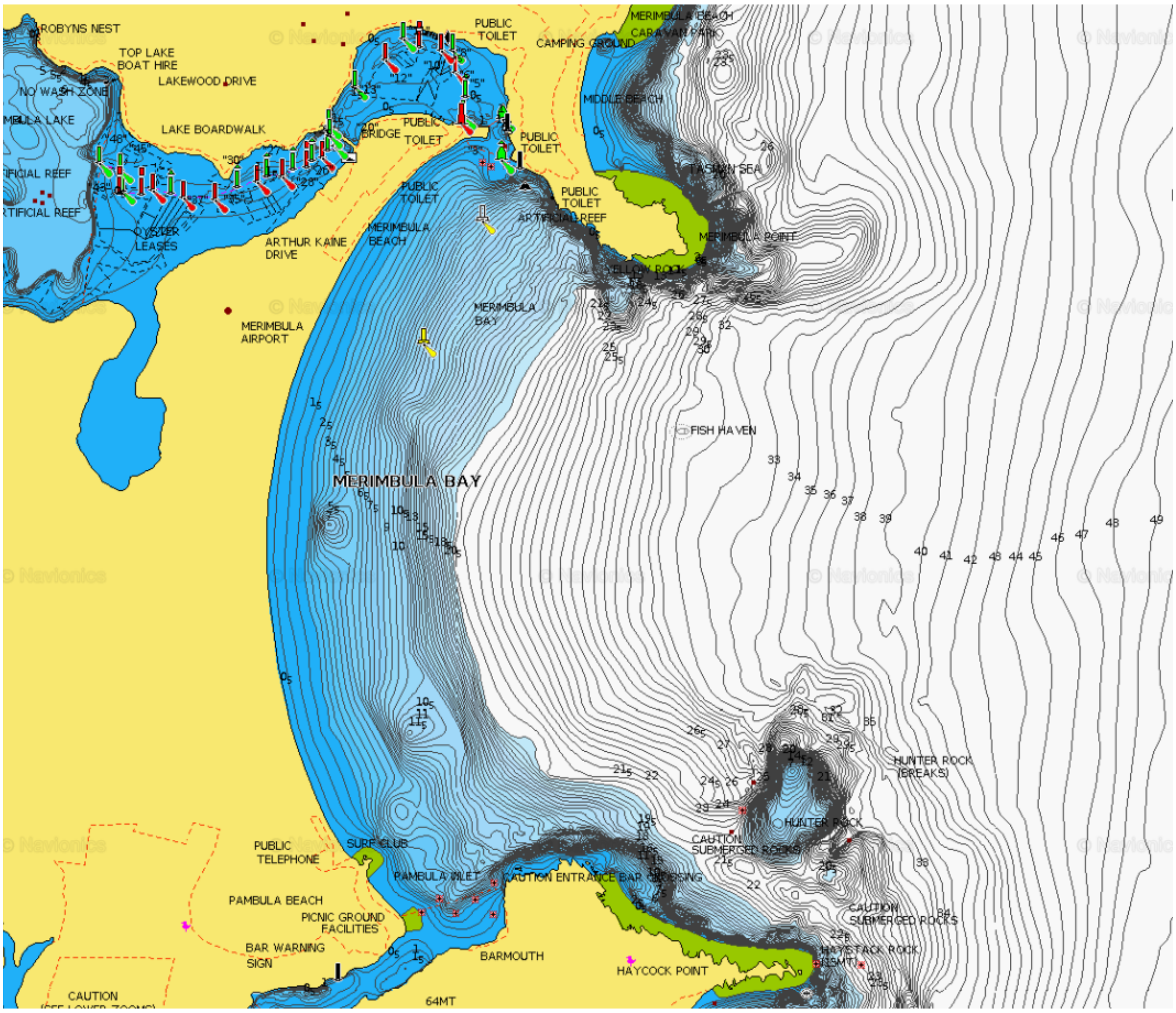

Figure 7 Bathymetry of Merimbula Bay (source: NAVONICS, 2022)

During large wave events from South to Easterly directions, wave refraction around Long Point redirects wave energy towards the entrance bar. Based on the timeseries of shoreline position along the entrance bar spit (refer Figure 4) and compared with a timeseries of offshore wave climate (refer Appendix A3.1), the primary driver of sand spit erosion and shoal blowout appears to be large storm wave events. With the increased water levels associated with storm surge, direct wave attack on the entrance sand spit during storm events pushes sediment into the estuary and into the primary tidal channel. Reducing channel depth, the resulting changes to entrance bar bathymetry temporarily alter the tidal hydrodynamics of the system. Resulting in a northerly channel alignment and deposition of sand on the landward sand spit 'heel', this eroded spit state and shallow bathymetry restrict tidal flow over the entrance bar and reduce the tidal range observed in Merimbula Lake (refer Appendix A3.2). As wave conditions return to normal, tidal forcing conditions push the channel alignment back to its long term equilibrium state and return the deposited oceanic sediment back to the entrance bar shoal. During this 6 month recovery period, channel navigability is impacted as the channel alignment migrates to its long term position and sand is returned offshore reducing entrance bar shoal depth.

Figure 8 Merimbula Lake entrance bar sediment transport conceptual model

2.5 2020 entrance bar spit erosion

Based on observations of the Merimbula Lake entrance bar sand spit outlined in Section 2.1, the sustained period of sand spit erosion and recovery in 2019-2020 was the largest event recorded over the 35 year satellite imagery record. Based on satellite imagery and observed tidal range in bottom Merimbula Lake, the peak eroded state during this period occurred between May and July 2020. Consulting the NSW Beach Profile Database (http://www.nswbpd.wrl.unsw.edu.au), measurements of shoreline geomorphology for this period coincide with the peak eroded state and data is available at transects along Merimbula Main Beach for 19 June 2020. Comparing the cross-shore width of the sand spit for this date with historical profiles pre-dating satellite imagery, two additional significant erosive events were noted in July 1962 and June 1972. The magnitude of the erosion on these dates however was smaller than that of the June 2020 event.

With erosion of the entrance bar sand spit first evident in the records from June 2019, the spit width reduced and remained stable in a mildly eroded state from September 2019 until the start of 2020. In the first 6 months of 2020, a series of large wave events further eroded the sand spit width to its smallest length on record. Recovering over the following 6 months, the sand spit returned to its long term average position by February 2021. Investigating the long term wave climate for the region, it was noted that the period from mid-2018 to mid-2019 recorded a prolonged period of the smallest average wave height on record with significant wave height 20cm less than its long term average (see Figure 9).

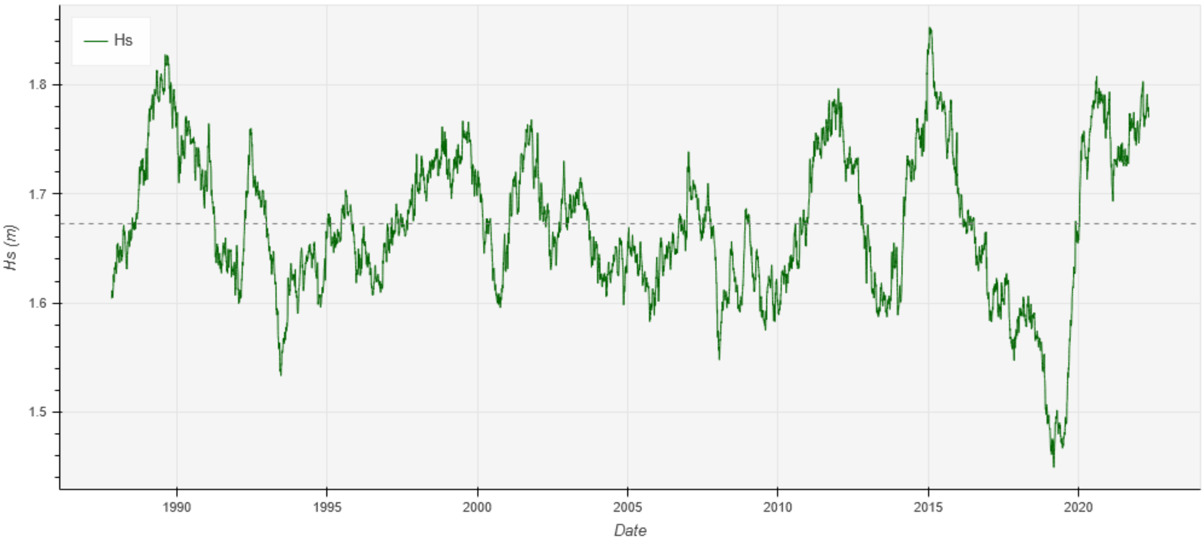

Figure 9 Eden wave buoy significant wave height (annual rolling average)

Contrary to previous periods of entrance sand bar spit erosion which were driven by large storm events, the prolonged period of reduced wave climate may have altered the sediment transport processes along Merimbula Bay and impacted the balanced forcing conditions holding the sand spit in a state of dynamic equilibrium. When the storm events in mid-2020 hit the sand spit, the eroded antecedent conditions resulted in a record erosive event. It was also noted during this period that Merimbula Bay as a whole was in the most eroded state observed over the bi-monthly 35 year satellite imagery record (refer Appendix A2).

3 Conclusions and management options

Based on the findings presented in Section 2, the Merimbula Lake entrance bar is a relatively stable morphological feature in a state of dynamic equilibrium in the complex interface between forcing wave driven sediment transport and restorative estuarine tidal hydrodynamics. The entrance spit has a history of periodic erosion in response to large wave events with a recovery period in the order of 6 months. No long term trends or significant seasonal erosion drivers were observed. Following the record 2020 erosion event, the system re-established the primary navigation channel and entrance bar sand spit without human intervention. In the context of this long term stability and restorative tidal forcing, it is unlikely that any council action is required to stabilise the entrance bar in the near future. For a more comprehensive picture of sediment transport processes in the system, an in-situ bathymetric survey program could be undertaken following the next major sand spit erosion event. This data would help quantify rates of sediment transport during the recovery phase and aid in better understanding the magnitude and mechanism of restorative environmental drivers.

If temporary impacts to channel navigability and wave propagation into the bottom estuary are unacceptable hazards, there are a range of potential long-term management options available for council. A brief summary of these is presented below. Before implementation of any of these strategies, it is advised a more comprehensive options assessment be undertaken with the implementation of a hydrodynamic sediment transport model to better understand the feasibility and viability of proposed management options. This process should further consider the impact and potential changes to sediment dynamics associated with rising sea levels and a changing wave climate.

Do nothing (with monitoring) – recommended option

A do nothing approach would see the entrance sand spit erode and recover periodically as it has in the past. During erosive periods, channel navigability would be impacted by the deposition of sediment and present a maritime hazard during low tides and large swell. A temporary reduction in sand spit width may increase wave propagation into the bottom estuary during periods of large southerly swell, however, the severity and impacts of this would require further study. Based on the long-term stability and history of sand spit recovery without intervention at the site, this is the recommended option as any impacts would likely be short lived and recover within 6 months.

Dune vegetation

Dune revegetation along the estuary bar sand spit may provide some level of protection against storm erosion during small storm events at a low cost. Based on the history of large erosive events at the site, it is unlikely that dune vegetation would provide adequate protection in the event of large scale, or back-to-back storm events.

Dredging and sand nourishment

Dredging of the primary channel to define geometry following periods of entrance bar erosion may reduce the dampened lake tidal cycle and encourage a faster recovery to long term equilibrium position. Dredged channel sands could be placed on the entrance bar spit to further expediate the recovery process. A full hydrodynamic model coupled with wave drivers would be required to ensure adequate understanding of the consequences of dredging to prevent rapid deposition of sand back into the channel. This option may prove expensive and benefits will depend on the local demand for ongoing maintenance of a navigable channel.

Estuary bar protection works

Protective engineering structures along the estuary bar sand spit in the form of rock armour units, kyowa/geotextile bags or entrance training structures may offer protection against erosion during large storm events. These structures would be costly but allow for more continuous usage of the estuary navigation channel. The implementation of hard engineering structures may disrupt existing sediment transport processes and estuarine hydrodynamics in the system, noting that boulder and concrete structures supplement the natural rock on the northern foreshore. In the case of breakwaters and training walls, the removal of entrance bar shoals reduces tidal friction and results in increased tidal conveyance into the estuary. Increasing estuary tidal range and the volume of water entering the system, these changes result in higher channel velocities and may trigger an unstable scouring mode as the system reaches a new state of equilibrium as has occurred on Wallis Lake, Lake Macquarie, Lake Illawarra and Lake Wagonga (Nielsen et al., 2016). Potential implications of these alterations to tidal sediment flux and system hydrodynamics include:

- Altered channel bathymetry, increased channel scour and channel bank foreshore erosion
- Elevated risk of inundation for low lying areas and increased exposure to storm surge, sea level rise and other extreme events
- Altered sediment cycles and wave transformation patterns impacting littoral drift and the broader Merimbula Bay sediment compartment
- Ecological impacts on seagrass, mangrove, saltmarsh and wetland habitat arising from altered tidal regime
- Potential for hazardous navigation and recreation conditions due to increased channel velocities and remaining offshore entrance bars
- Alterations to flood drainage characteristics of the system

To minimise the impacts of unintended consequences on the system and to ensure structural stability, an extensive feasibility study would be required prior to detailed design. This study would need to address the potential issues highlighted above and address the high degree of uncertainty associated with altering a complex dynamic system.

4 References

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Department of Public Works NSW (1978), Merimbula Lake Entrance – Tidal Discharge Measurements, Manly Hydraulics Laboratory, Report MHL259

Nielsen, A. F. & Gordon, A. D. (2016), Breakwaters and Training Walls – The Good, the Bad and the Ugly, NSW Coastal Conference 2016.

Vos, K., Harley, M.D., Turner, I.L. et al. (2023), Pacific shoreline erosion and accretion patterns controlled by El Niño/Southern Oscillation, *Nature Geoscience.* 16, 140–146 https://doi.org/10.1038/s41561-022-01117-8

Webb, McKeown & Associates (WMA) (1995), Merimbula Lake and Back Lake Estuary Processes Study, Report prepared for Bega Valley Council.

Appendix A

A1 Remote sensing data

A1.1 Satellite imagery

Automated shoreline extraction

Generic documentation of the methods used for automated shoreline extraction from satellites can be found at http://coastsat.wrl.unsw.edu.au/.

Estuary timeseries of Merimbula Lake entrance bar since 2016 have been provided to Council as an animated video.

A-1 Merimbula Lake entrance bar conditions April 2019 (pre spit erosion)

A-2 Merimbula Lake entrance bar conditions July 2020 (peak spit erosion)

A-3 Merimbula Lake entrance bar conditions October 2021 (post spit recovery)

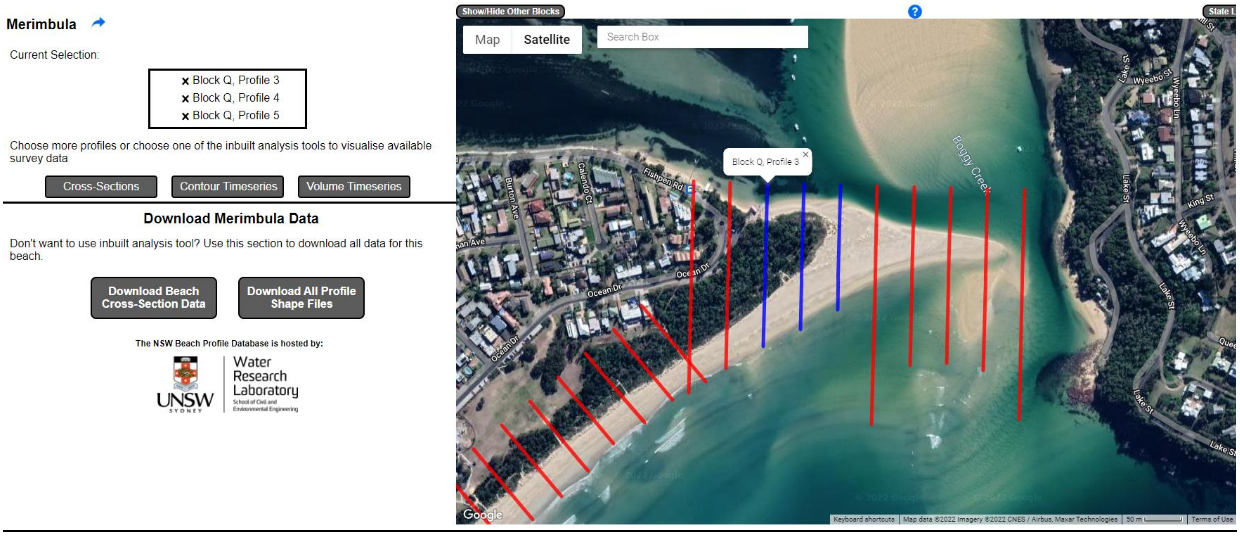
A1.2 Historic aerial imagery

Estuary timeseries of Merimbula Lake entrance bar since 1948

- https://www.youtube.com/watch?v=1Uni5JrWv5U

A1.3 NSW Photogrammetry Beach Profile Database

- http://www.nswbpd.wrl.unsw.edu.au/photogrammetry/nsw/



Merimbula

Current Selection:

✕ Block Q, Profile 3
✕ Block Q, Profile 4
✕ Block Q, Profile 5

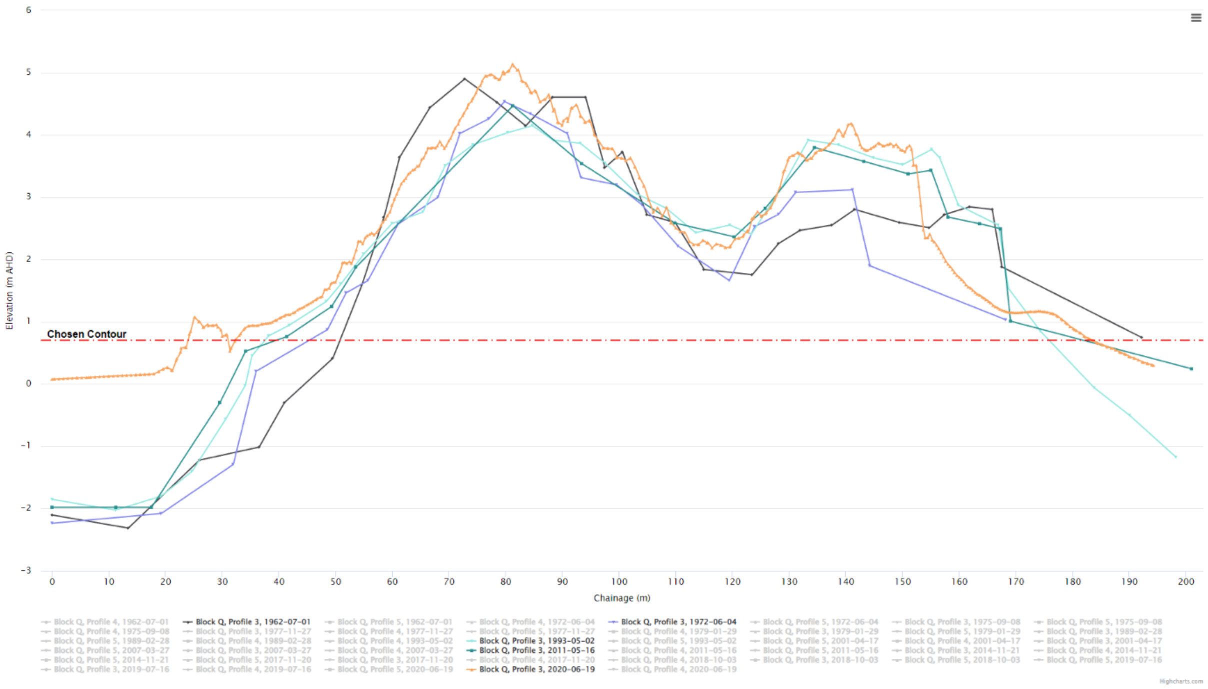
Choose more profiles or choose one of the inbuilt analysis tools to visualise available survey data

Download Merimbula Data

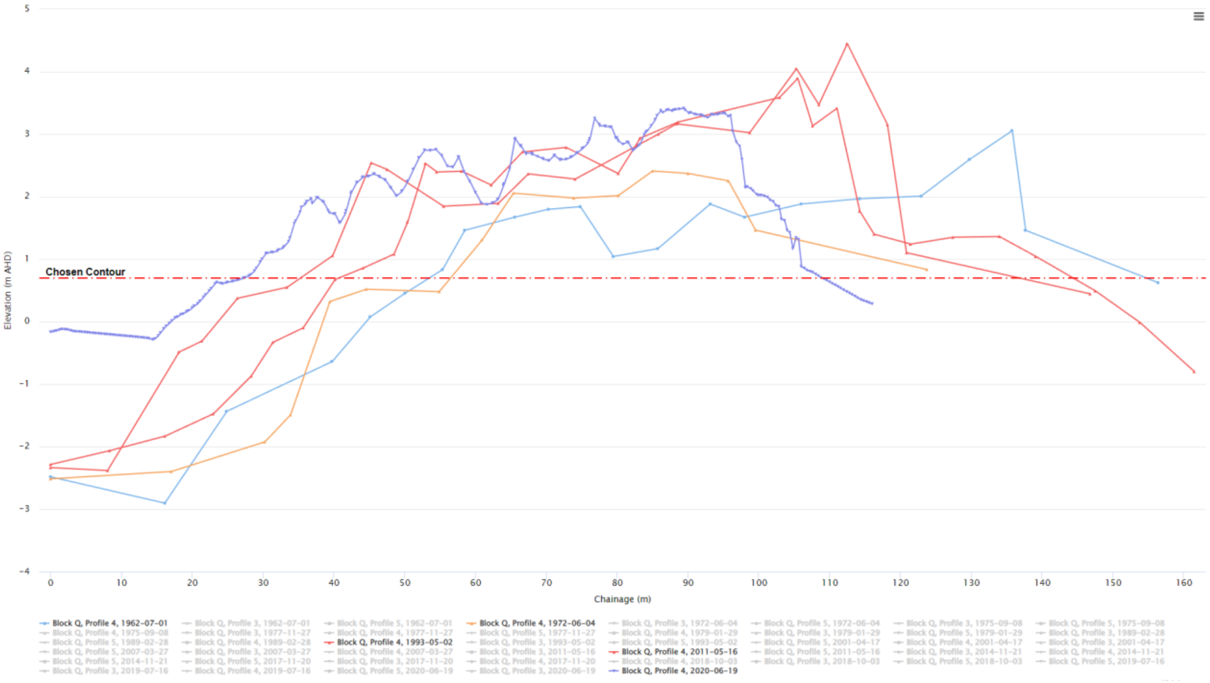
Don't want to use inbuilt analysis tool? Use this section to download all data for this beach.

The NSW Beach Profile Database is hosted by:

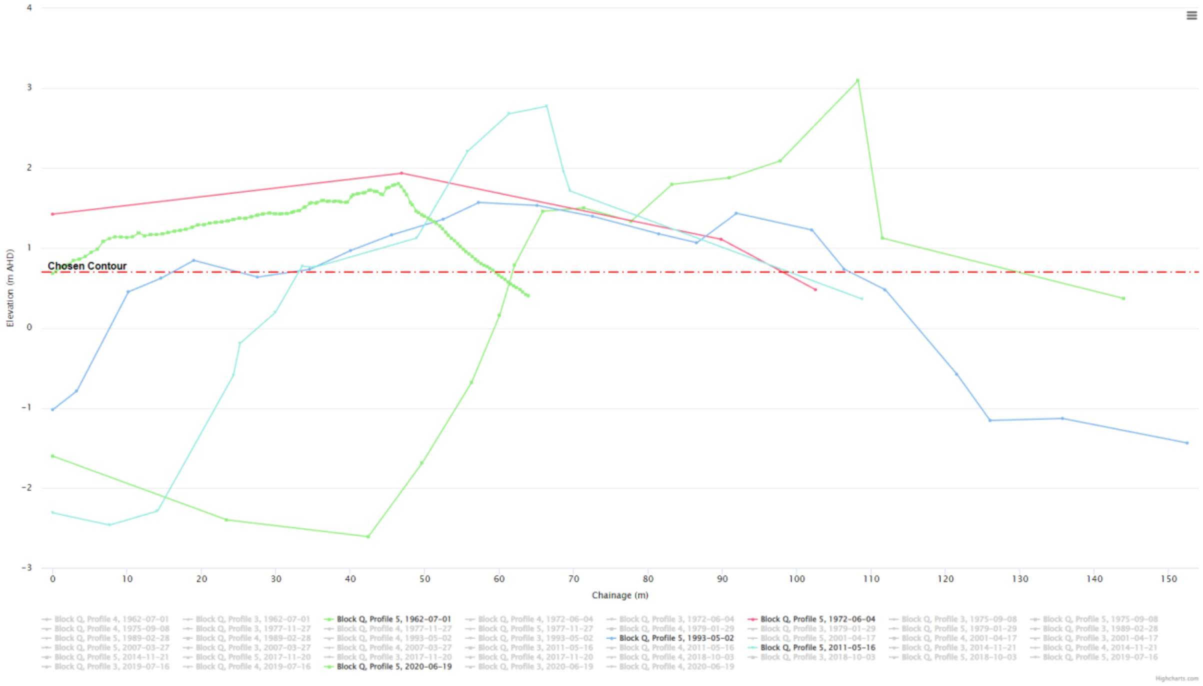
A-4 Extracted transect locations



A-5 Block Q, Profile 3 – Historic eroded sand spit shoreline positions

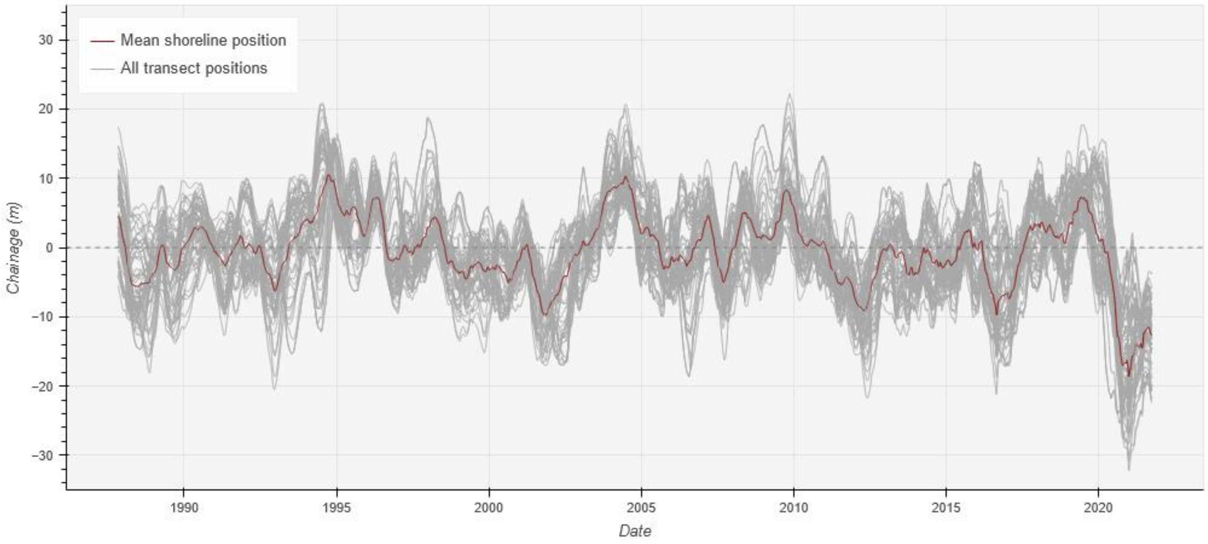


A-6 Block Q, Profile 4 – Historic eroded sand spit shoreline positions

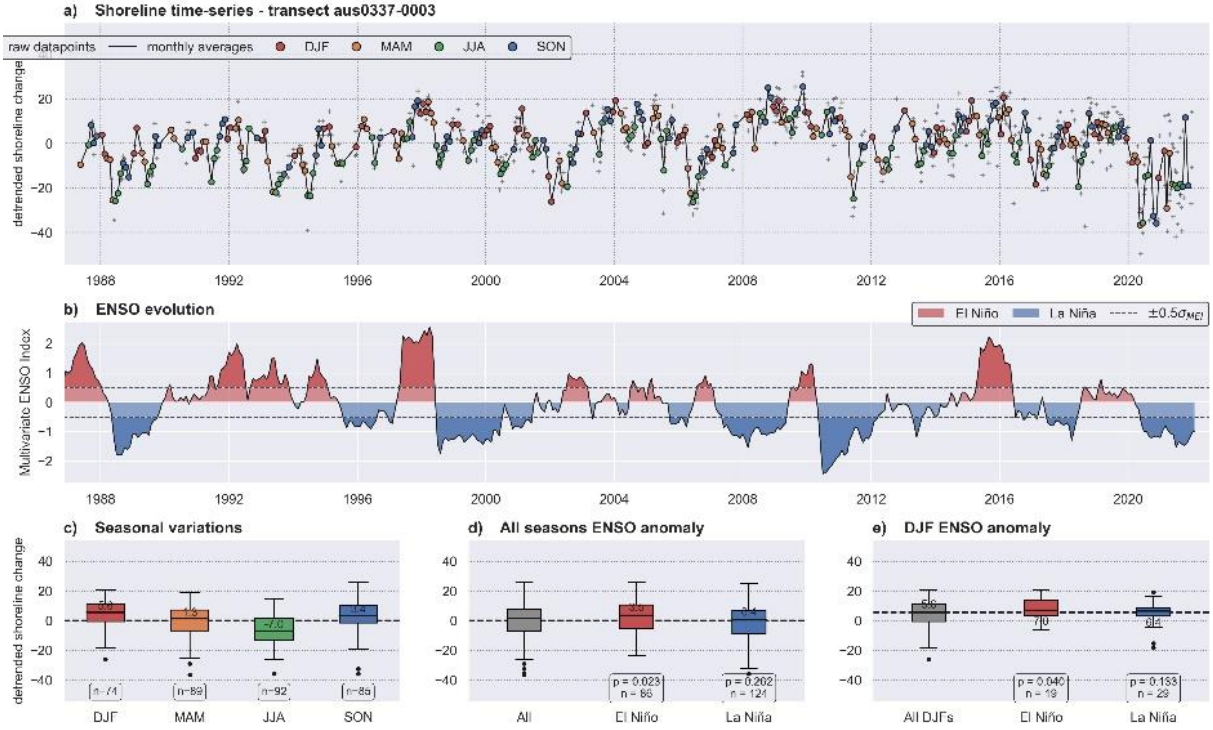


A-7 Block Q, Profile 5 – Historic eroded sand spit shoreline positions

A2 Multi-decadal shoreline variability and ENSO



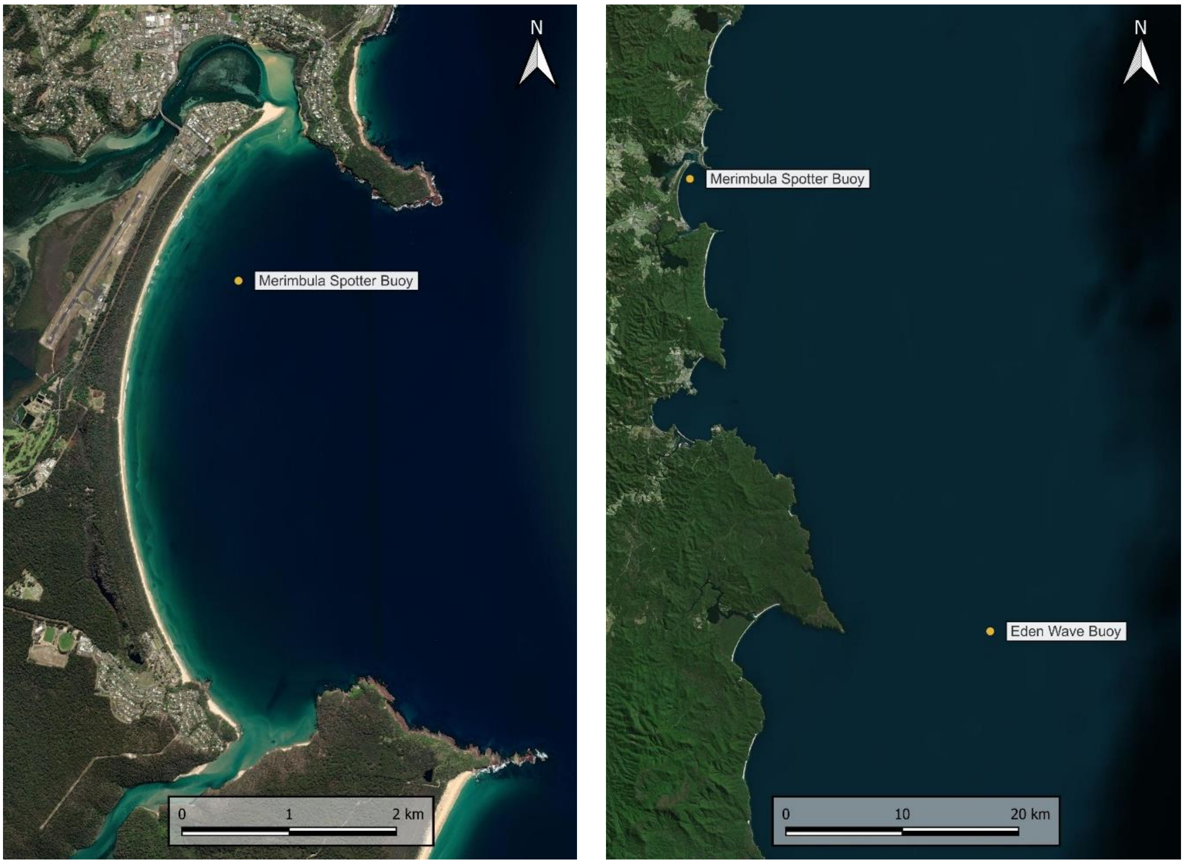
A-8 Long term shoreline variability timeseries as extracted from CoastSat
(6 month rolling average)



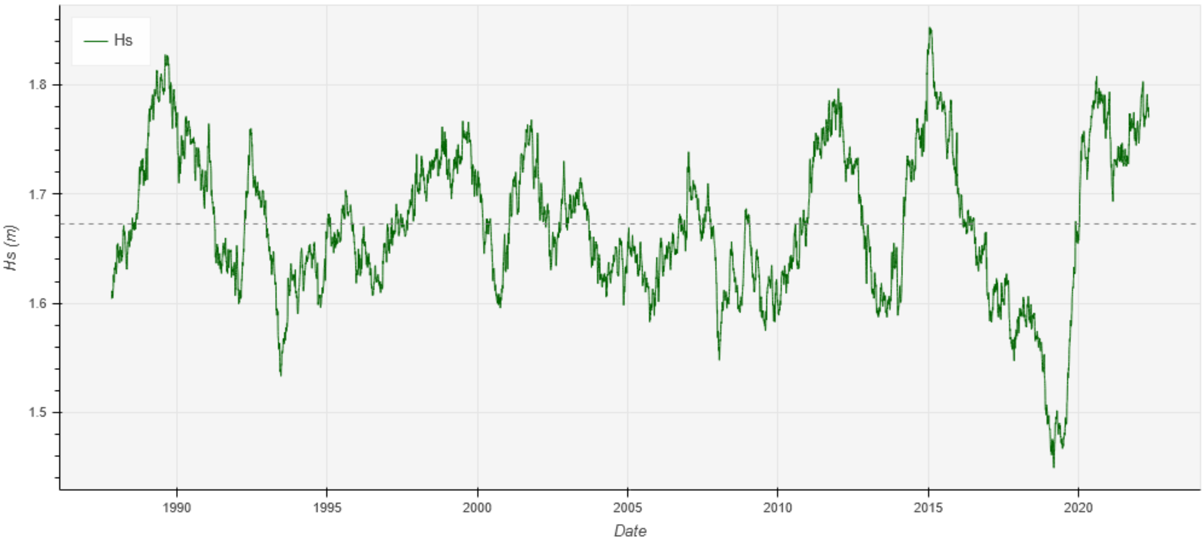
A-9 Long term shoreline variability vs ENSO at Pambula Beach
(source: Kilian Vos 2023)

A3 Morphological drivers

A3.1 Wave data

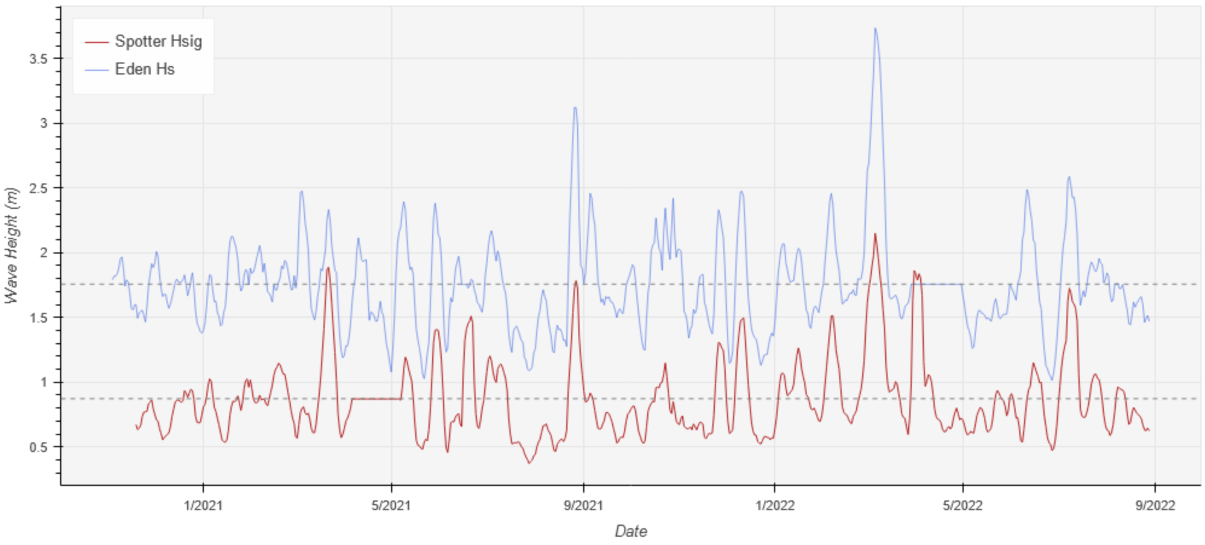


A-10 Eden wave buoy and Merimbula Bay nearshore Spotter buoy locations

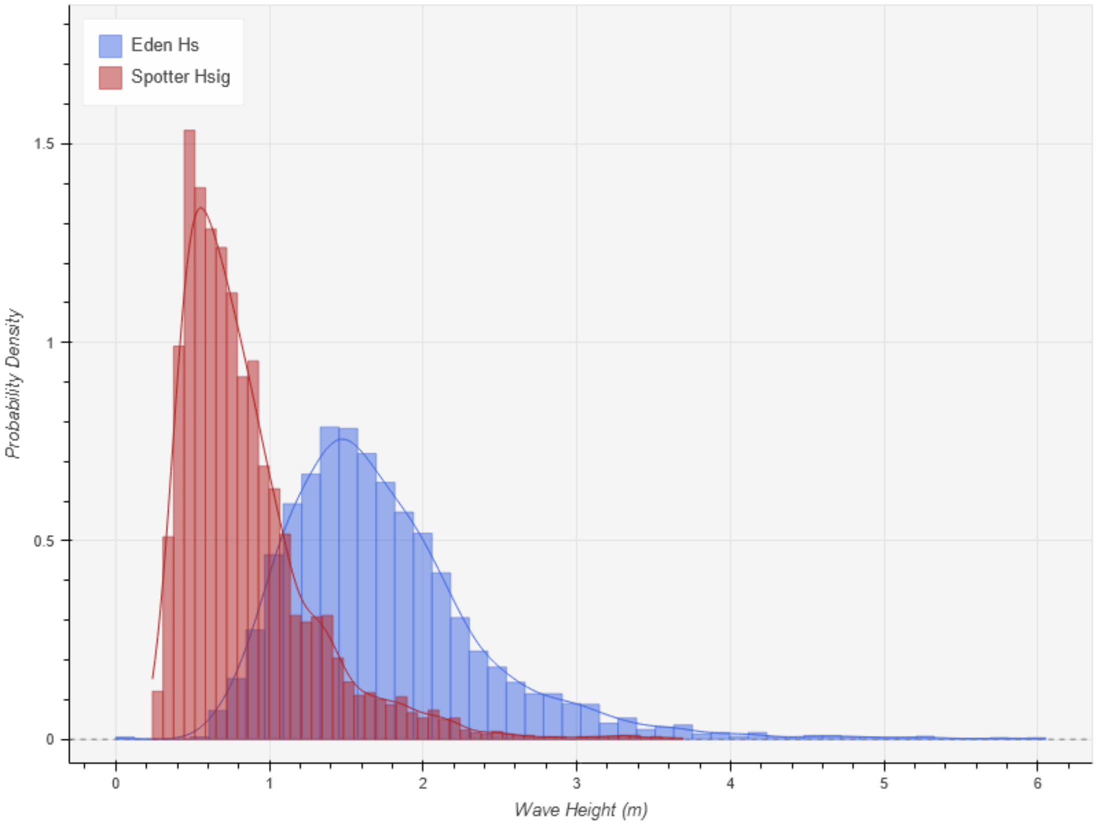


A-11 Significant wave height (annual rolling average) at Eden wave buoy timeseries (Source: MHL, 2022)

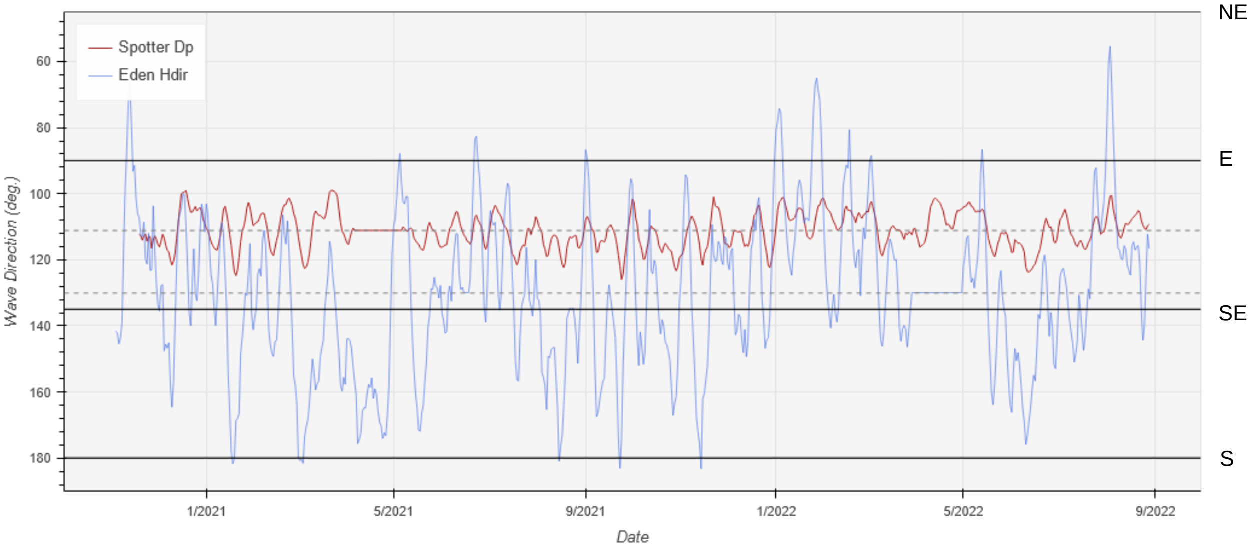
A-12 Wave direction (annual rolling average) at Eden wave buoy timeseries (Source: MHL, 2022)



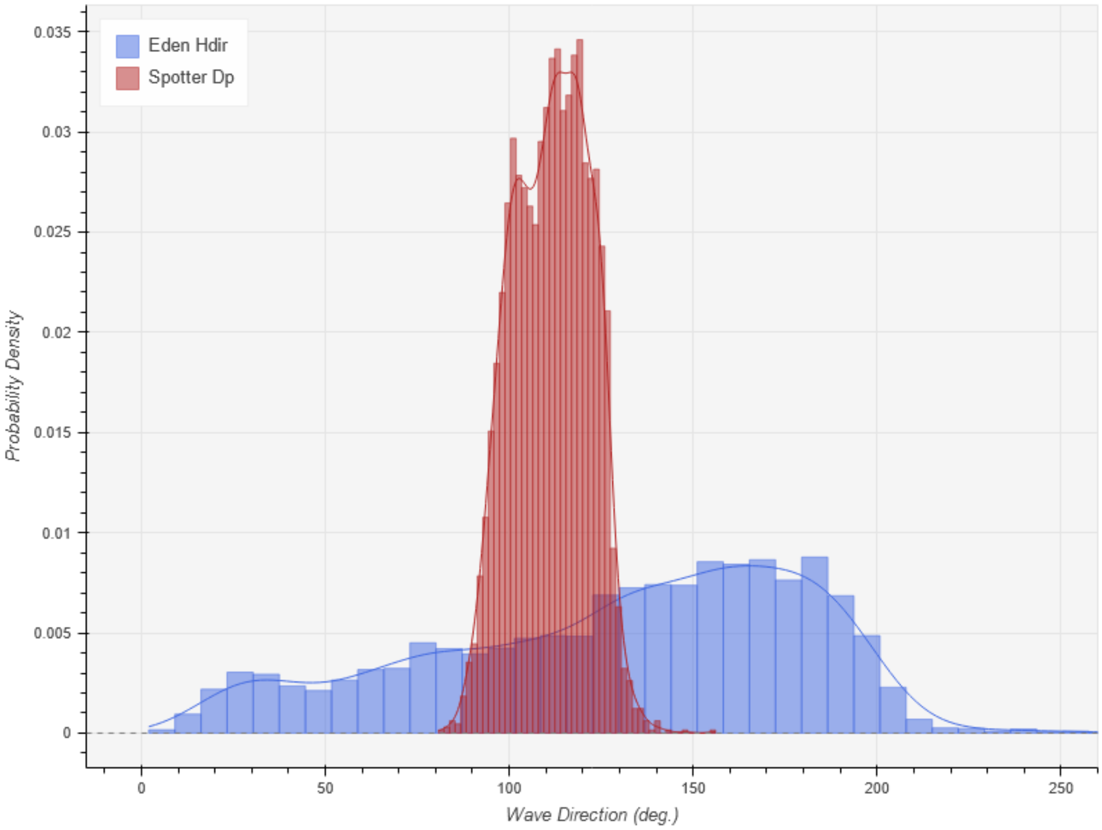
A-13 Significant wave height (7 day rolling average) at Eden wave buoy and Merimbula Bay nearshore Spotter buoy (Source: MHL, 2022; DPE, 2022)



A-14 Significant wave height probability density histogram at Eden wave buoy and Merimbula Bay nearshore Spotter buoy highlighting have height attenuation (Source: MHL, 2022; DPE 2022)

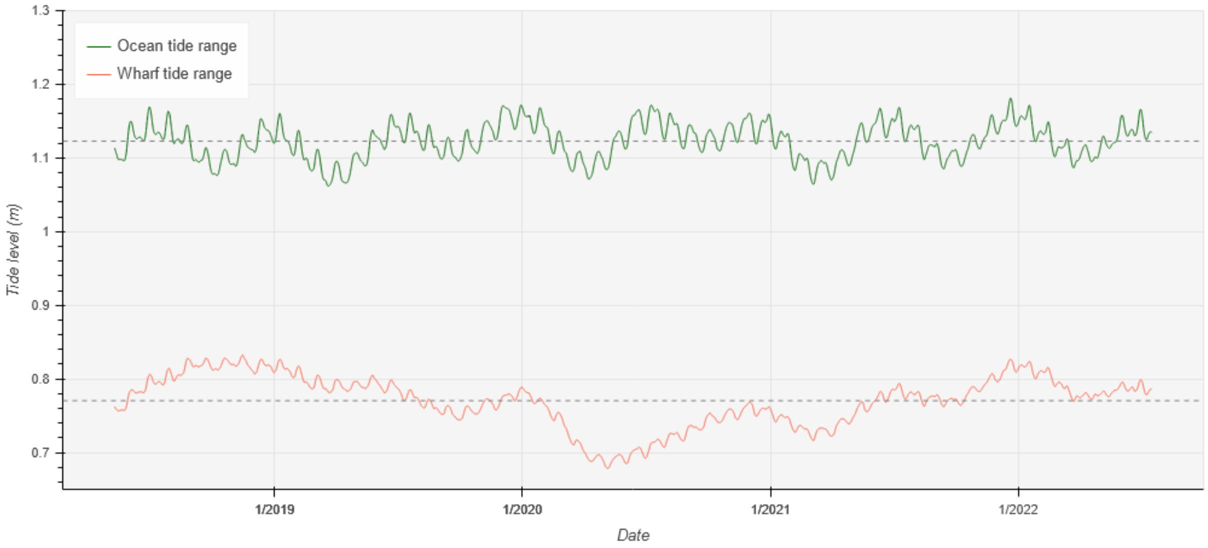


A-15 Wave direction (7 day rolling average) at Eden wave buoy and Merimbula Bay nearshore Spotter buoy (Source: MHL, 2022; DPE, 2022)

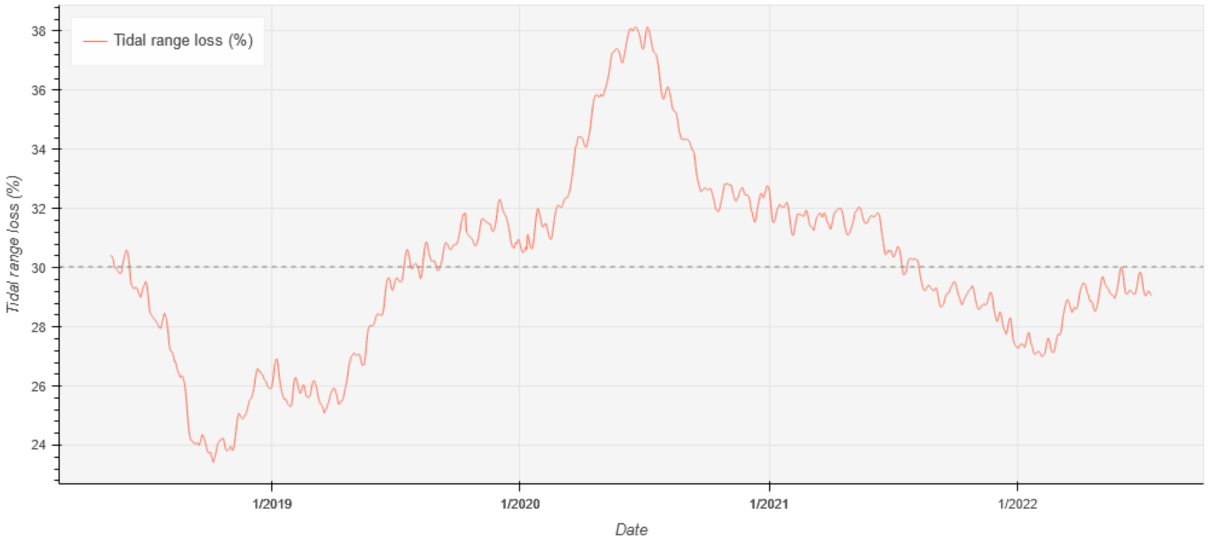


A-16 Wave direction probability density histogram at Eden wave buoy and Merimbula Bay nearshore Spotter buoy highlighting shore-normal direction attenuation (Source: MHL, 2022, DPE, 2022)

A3.2 Water level data

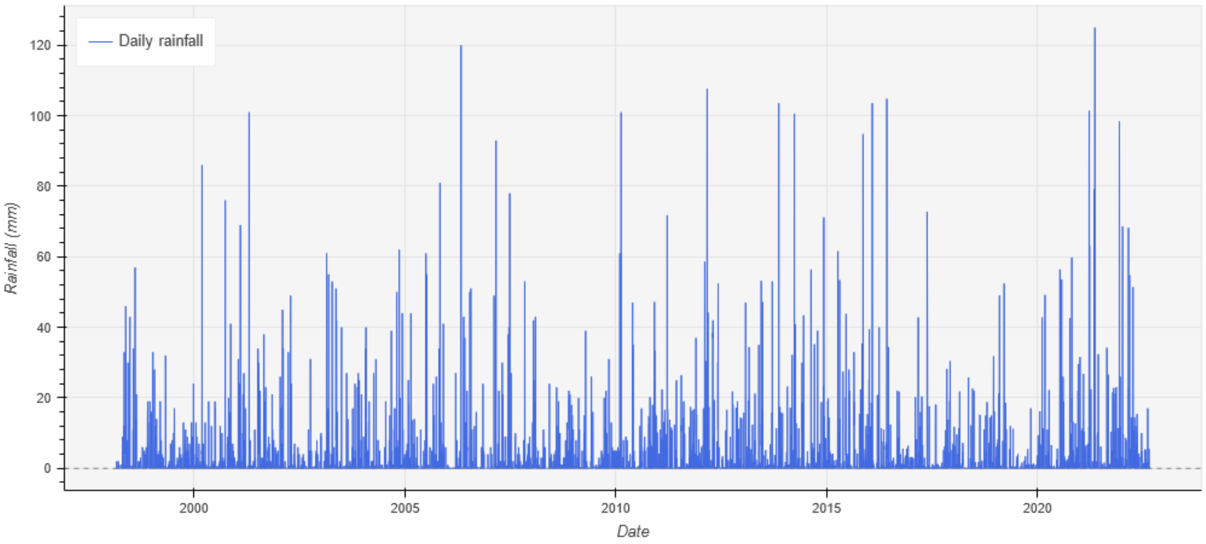


A-17 Oceanic and Merimbula Lake tidal range timeseries (3 month rolling average) (Source: MHL, 2022)



A-18 Tidal head loss between oceanic and Merimbula Lake tidal gauge (3 month rolling average

A3.3 Rainfall data



A-19 Daily rainfall data at Merimbula airport (source: BOM, 2022)