WAMBERAL TERMINAL COASTAL PROTECTION ASSESSMENT

Stage 2 – Coastal Protection Amenity Assessment

December 2021

Prepared for:
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Cover Photograph: Terrigal Lagoon looking north to Wamberal Beach 21 January 2021. Photo by Juddssnaps via Wamberal CoastSnap Station.

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Foreword

In May 2020 NSW government's professional specialist advisor, Manly Hydraulics Laboratory (MHL) in association with the Water Research Laboratory (WRL) of UNSW Sydney and Balmoral Group Australia (BGA) were commissioned by Central Coast Council to undertake the *Wamberal Terminal Coastal Protection Assessment*. The assessment outcomes are being delivered via a series of reports for the following stages of work:

1. Review of previous studies
2. **Coastal protection amenity assessment (this report)**
3. Seawall concept design options
4. Sand nourishment investigation
5. Provision of coastal monitoring (online webpage)
6. Cost benefit analysis and distributional analysis of options

This report provides the outcomes of Stage 2 of the Wamberal Terminal Coastal Protection Assessment, namely the amenity assessment of seawall concept design options for Wamberal Beach. The report assesses and evaluates impacts of seawall concept design options (from Stage 3 works) on beach amenity including quantifying impacts on available dry beach width for beach users as well as evaluating interactions with natural beach processes, cross-shore encroachment impacts and other potential amenity implications.

This report is issued as Final and is classified as publicly available.

Executive Summary

Over the past 50 years development along the foredune of Wamberal Beach has had a history of damage and loss due to coastal erosion events. Managing risks to public safety and built assets, pressures on coastal ecosystems and community uses of the coastal zone make up the priority management issues of the certified Gosford Beaches Coastal Zone Management Plan (CZMP, 2017). Undertaking a review of terminal protection design for Wamberal Beach, coupled with the provision of beach nourishment (in accordance with Section 27 of the Coastal Management Act 2016), was a key recommended action of the CZMP (2017).

This report forms part of a broader series of work, the Wamberal Terminal Coastal Protection Assessment, recently undertaken to progress the key recommended management actions for Wamberal Beach from the Gosford Beaches Coastal Zone Management Plan (2017). The Wamberal Terminal Coastal Protection Assessment includes a detailed review of previous studies (Stage 1), *amenity assessment of coastal protection options (Stage 2 – this Report),* development of seawall concept design options (Stage 3), sand nourishment investigation (Stage 4), implementation of coastal monitoring initiatives (Stage 5) as well as an updated cost-benefit analysis and distributional analysis of management options for Wamberal Beach (Stage 6).

Overwhelming feedback obtained during community consultation (November 2020 and August 2021), highlighted the importance of the natural amenity that Wamberal Beach provides to its users and the broader community. This report provides the outcomes of Stage 2 of the Wamberal Terminal Coastal Protection Assessment, namely an amenity impact assessment of seawall concept design options for Wamberal Beach. The report includes quantifying impacts on available dry beach width for beach users as well as evaluating interactions with natural beach processes, cross-shore encroachment impacts and other potential amenity implications. The report has adopted both quantitative and qualitative approaches to assessing impacts to beach amenity, utilising all available historical beach profile data, dry beach width estimation techniques, as well as a literature review of seawall and beach interactions along the south-east coast of Australia and abroad.

The impact of the five proposed seawall concept designs detailed in the *Stage 3 Seawall Concept Design Report (MHL2780, 2021)* on beach width amenity at Wamberal Beach was quantified and assessed. Findings of the beach amenity assessment for each of the seawall concept options are summarised in Table E.1. In order to assess the relative impact on beach amenity of each option, the present report has not considered beach nourishment which may alleviate amenity impacts. Beach nourishment requirements to maintain beach amenity into the future for each seawall concept option are investigated in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021).*

As part of the present study, all available beach profile data for Wamberal Beach, commencing in 1941 were assembled and analysed. The data encompassed historical aerial photos, satellite shorelines, photogrammetry, WRL quadbike surveys, UNSW Aviation surveys, State Government bathymetric surveys and drone surveys. The intensity of data is sparse in early years and intense in recent decades.

The impacts of each concept design option on available dry beach width for public use were assessed by quantifying the amount of seawall encroachment on the active beach over a representative period of time. This was completed using a beach width model that derived hourly dry beach widths compiled from hourly measured data for ocean water levels and ocean waves through a wave runup model that was interfaced with the most recent 10 year period of frequently measured beach profile data (2010 to 2020 including RTK-GPS, drone and aerial Lidar surveys). Six representative beach profile locations, spread across the 1.4 km study area between the Lagoon entrances, were used to evaluate the impacts of seawall encroachment on available dry beach width for public use.

Average disruptions to available dry beach width were estimated, that is, the percentage of time (%) when the beach had less than 5 m of dry sand available for public use. Results for each of the proposed seawall concept design options are provided in Table E.1. Values are defined based on R2% (the wave runup level exceeded by 2% of waves) and Rmax (the maximum estimated wave runup level) wave runup statistics.

Rock revetment structures (Options 1 and 2) were found to have a high level of impact on available dry beach width, with an increased amount of time (on average 4x higher than the current situation) below a 5 m width. These options were found to reduce available dry beach width for public amenity, more frequently inhibit alongshore access for beach users and have a relatively higher encroachment on beach processes (Table E.1). Conversely, vertical seawall designs (Options 3 to 5) were found to have a positive impact on the present levels of beach width amenity (resulting in a wider beach relative to existing ad-hoc and emergency rock protection), given their relatively smaller footprints and more landward alignment at the rear crest of the revetment designs with lower encroachment into the active beach (Table E.1). The tiered vertical option would result in minor improvement to the beach width and offers additional preservation and enhancement of alongshore access through the incorporation of a promenade.

The report also undertook a literature review of other aspects of beach amenity and the cross shore and longshore impacts on beach processes of the proposed concept seawall designs for Wamberal Beach. Approximately 91 seawall structures on sandy beaches were catalogued, predominantly in south-east Queensland and NSW. Of these 91 seawall structures, up to 7 have known adverse publicity regarding their impacts on beach amenity. The common feature of these seawalls is an alignment more seaward than that proposed for Wamberal, sometimes on a beach that is receding at a rate more than five times the rate of Wamberal (for example Stockton Beach). Exposed seawalls can cause entry and exit to/from the water to be more hazardous for surfers and swimmers, but direct attribution of any reduction in surf quality to these seawalls is rare (unlike some large breakwaters). This is likely because most surfing is undertaken in deeper water away from the seawall.

The degree of interaction of a seawall with beach processes and sandy beach amenity is highly dependent upon its position within the active beach profile. The proposed vertical seawall designs (Options 3 to 5), with a low degree of encroachment into the active beach will for most of the time be fronted by sand and have minimal impact on coastal processes (Table E.1). A higher degree of impact on coastal processes is expected for revetment Options 1 and 2 which encroach further seaward into the active beach and would be more frequently exposed to waves (Table E.1). The best performing options for sandy beach amenity (Options 3 to 5) will only be impacted by waves on an infrequent basis (ie during major storm events), so will not have frequent cross shore impacts on the beach. These impacts will be akin to iconic beaches such as Manly and Bondi, where whole of embayment seawalls coexist with sandy beaches.

For the vertical seawall designs (Options 3 to 5) any impacts are expected to be limited in extent and duration and are unlikely to affect other developed areas along the beach nor cause longer-term changes to present-day beach and lagoon entrance processes (Table E.1). During major storms there may be slightly higher, albeit temporary, sand volume losses in isolated regions where the seawall is exposed to waves. However, given the proposed alignment at the landward extent of the active beach, natural beach recovery and lagoon entrance infill processes will subsequently rebuild these regions following a storm, with minimal longer-term impact on beach and lagoon entrance morphology. The provision of beach sand nourishment to maintain beach amenity in front of the seawall will further limit this effect (*Stage 4 Sand Nourishment Investigation).*

End effects are reduced for structures aligned further landward in the active beach region. Traditional end effect impacts will not apply as the proposed seawall at Wamberal Beach will be a contiguous structure extending from Terrigal Lagoon to Wamberal Lagoon. Termination of the structure at either end will transition landward of the active beach region, with minimal end erosion effects expected for vertical seawall options (Options 3 to 5). Higher encroachment of the rock revetment structures (Options 1 and 2) in the active beach at the southern end may result in slightly higher sand losses during rare storm erosion events that expose the seawall end to wave action. This region is also governed by dynamic lagoon entrance processes, a rocky backshore to the south and the Ocean View Dr Bridge constriction to the west such that traditional end erosion estimates are not applicable. Specifics of termination design at lagoon ends are subject to detailed design with further design consideration to be given to minimise impacts on coastal and lagoon entrance processes. Review of the former 1998 termination ends is provided in the *Stage 3 Seawall Concept Design Report (MHL2780, 2021).*

Other aspects of beach amenity were assessed and summarised in Table E.1 including post-storm ad-hoc protection debris on the beach, visual amenity, foreshore access and safety impacts. Overall vertical seawall options (Options 3 to 5) are expected to have relatively low to beneficial impacts on present levels of amenity at Wamberal Beach. The large vertical drop for seawall options 3 and 4, particularly after storms, would likely pose public safety risks and visual amenity issues. This is mitigated for the tiered vertical seawall with promenade option (Option 5) which is expected to also provide added public foreshore amenity. Rock revetment options (Options 1 and 2) will likely have a moderate to high adverse impact on beach amenity. Beach nourishment requirements to restore and maintain beach amenity into the future for each seawall concept option are investigated in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021).*

Design specifications to further improve foreshore amenity are to be considered in detailed design and may include (depending on the adopted option) refined crest/promenade levels, landscape design (including privacy considerations), viewing platforms, designated beach access points, lighting, shower facilities and vertical seawall finishes/artworks.

Table E.1: Summary of beach amenity impacts of proposed seawall options for Wamberal Beach

Seawall Concept Option	Percentage of time with less than 5 m available dry beach width (%) [a]	Encroachment into active beach and cross-shore impact	Available dry beach width impact	End erosion impact	Surf amenity impact	Post-storm ad-hoc protection debris on beach	Visual amenity impacts	Foreshore access impacts	Safety impacts	Overall beach amenity impact assessment
Existing beach (including present ad-hoc rock protection)	*1.4% to 3.3%*	*Average of ~5 to 12 days per year when beach is less than 5 m.* *Higher encroachment of ad-hoc protection in central region of beach.*	*Infrequent disruptions following major storms with narrow beach conditions.*	*Potential end effects at gaps in ad-hoc protection.*	*No adverse impacts identified.*	*Emergency works 1974 to present, rock rubble fill, brickwork, concrete, rubber tyres, old septic tanks, failed timber structures, etc. Exposed and dislodged with storms.*	*Poor after storms when existing ad-hoc material exposed. Large unstable dune scarp.*	*Alongshore access inhibited after storms with large unstable dune scarp at access points.*	*Dangerous narrow beach conditions and access points after storms. Risks trying to traverse ad-hoc protection encroaching into shoreline. Large unstable dune scarp.*	*As present – undesirable conditions particularly after storms*
Impacts relative to existing beach amenity										
Option 1: Basalt Rock Revetment	6.8% to 9.5%	Adverse – Average of 24 to 34 days per year when beach is less than 5 m. Higher encroachment	Adverse – More frequent conditions with narrow beach	Potential for minor added erosion when end of seawall is exposed to waves [b]	No adverse impact expected	Beneficial – Existing ad-hoc material removed during seawall construction	Moderate – Presence of large rock structure where not buried [d]	Adverse – Alongshore access inhibited more frequently	Moderate – safety risks at narrow beach sections	Moderate to high adverse impact
Option 2: Sandstone Rock Revetment	8.7% to 12.8%	Adverse – Average of 32 to 47 days per year when beach is less than 5 m Higher encroachment.								Moderate to high adverse impact
Option 3: Vertical Seawall	0.2% to 0.6%	Beneficial – Average of 1 to 2 days per year when beach is less than 5 m. Reduced encroachment	Beneficial – Reduction in conditions with narrow beach	Minimal end effects expected due to landward alignment [b]			Moderate – Large vertical relief visually imposing where not buried [d]	Beneficial – wider beach to improve alongshore access	Moderate – safety risks associated with vertical relief [d]	Low to beneficial impact
Option 4: Vertical Seawall with Rock Toe:	0.2% to 0.6%	Beneficial – Average of 1 to 2 days per year when beach is less than 5 m Reduced encroachment								Low to beneficial impact
Option 5: Tiered Vertical Seawall with Promenade	1.1% to 2.6%	Slightly Beneficial – Average of 4 to 9 days per year when beach is less than 5 m Reduced encroachment	Beneficial – Slight reduction in conditions with narrow beach + provision of promenade access				Beneficial – reduced vertical relief + opportunities for enhanced foreshore landscaping [d, e]	Beneficial – slightly wider beach to improve alongshore access + provision of promenade access	Beneficial – safer alongshore access after storms + reduced vertical relief. [d]	Low to beneficial impact [f]

[a] Values defined by R2% (the wave runup exceeded by 2% of waves) and Rmax (the maximum estimated wave runup) and averaged along the length of the beach between lagoon entrances.

[b] Region of potential end effects are also influenced by lagoon entrance processes, bridge abutments and rocky foreshores. Potential end effects are unlikely to affect other developed areas along the beach. Specifications of termination design at lagoon ends are subject to detailed design.

[c] Does not consider other sources of debris from eroded vegetated dunes and lagoon entrances.

[d] Concept design crest levels to be refined during detailed design. Visual and safety amenity will benefit from removal of ad-hoc protection and unstable dune scarps.

[e] Design considerations to mitigate privacy impacts on beachfront residents are addressed in the *Stage 3 Seawall Concept Design Options (MHL2780, 2021)*.

[f] Also provides broader public amenity value of foreshore promenade.

Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

Wamberal Beach is within the traditional boundaries of Darkinjung (Darkinyung) land, which extends from the Hawkesbury River in the south, Lake Macquarie in the north, the McDonald River and Wollombi up to Mt Yengo in the west and the Pacific Ocean in the east.

Wamberal Beach is a sandy ocean coast shoreline, situated within the Wamberal-Terrigal embayment on the NSW Central Coast as shown in Figure 1.1. A more detailed description of the study site including regional wave climate is provided in the *Stage 1 Report (MHL2778, 2021)*. Over the past 50 years development along the foredune of Wamberal Beach has had a history of damage and loss due to coastal erosion events. Managing risks to public safety and built assets, pressures on coastal ecosystems and community uses of the coastal zone make up the priority management issues of the certified Gosford Beaches Coastal Zone Management Plan (CZMP, 2017) with the primary objective:

> *"to protect and preserve the beach environments, beach amenity, public access and social fabric of the Open Coast and Broken Bay beaches while managing coastal hazard risks to people and the environment".*

Major actions recommended for Wamberal Beach from the CZMP (2017) were the following:

- *"TW11 Terminal protection – Council to action review, design and funding of terminal protection structure for Wamberal."*
- *"TW14 Investigate sources of sand and feasibility of beach nourishment for Wamberal Beach."*
- *"TW15 Beach nourishment coupled with a terminal revetment to increase buffer against storm erosion."*

In 2020 NSW government's professional specialist advisor, Manly Hydraulics Laboratory (MHL) in association with the Water Research Laboratory (WRL) of UNSW Sydney and Balmoral Group Australia (BGA) were commissioned by Central Coast Council to undertake the *Wamberal Terminal Coastal Protection Assessment*. A key outcome of the study is a series of reports for the following stages of work:

1. Review of previous studies
2. **Coastal protection amenity assessment (current report)**
3. Seawall concept design options
4. Sand nourishment investigation
5. Provision of coastal monitoring (online webpage)
6. Cost benefit analysis and distributional analysis of options

This report provides the outcomes of Stage 2 of the Wamberal Terminal Coastal Protection Assessment, namely the amenity assessment of seawall concept design options for Wamberal Beach. This report assesses and evaluates impacts of seawall concept design options (from Stage 3 works) on beach amenity including quantifying impacts on available dry beach width for beach users as well as evaluating interactions with natural beach processes, cross-shore encroachment impacts and other potential amenity implications.

Figure 1.1: Study site location map.

1.2 Stage 2 objectives

Objectives of Stage 2 of the *Wamberal Coastal Protection Assessment* include:

- synthesise available beach width and profile datasets for Wamberal Beach to construct a beach width timeseries for Wamberal Beach.
- provide a beach width impact assessment of five different seawall concept design options (from Stage 3 report) for Wamberal beach to quantify impacts on available dry beach width for beach users
- undertake a review of seawall and beach interactions to assess potential end effects at lagoon entrances, cross-shore encroachment impacts, impacts on surfing amenity and other potential amenity implications of the proposed seawall concept designs at Wamberal Beach.

1.3 Stage 2 overview

The Stage 2 report includes the following:

- Synthesis of historical beach width and profile data for Wamberal Beach including construction of beach width timeseries. (Section 2 and 3)
- Beach width impact assessment of seawall concept design options for Wamberal Beach. (Section 4)
- Review of seawall and beach interactions including potential end effects at lagoon entrances, cross-shore encroachment impacts, impacts on surfing amenity and other potential amenity implications of the proposed seawall concept designs at Wamberal Beach. (Section 5)

2 Data collation

The Water Research Laboratory (WRL) completed a thorough collation of all available relevant data for Wamberal Beach to understand short and long term change to the site. This included:

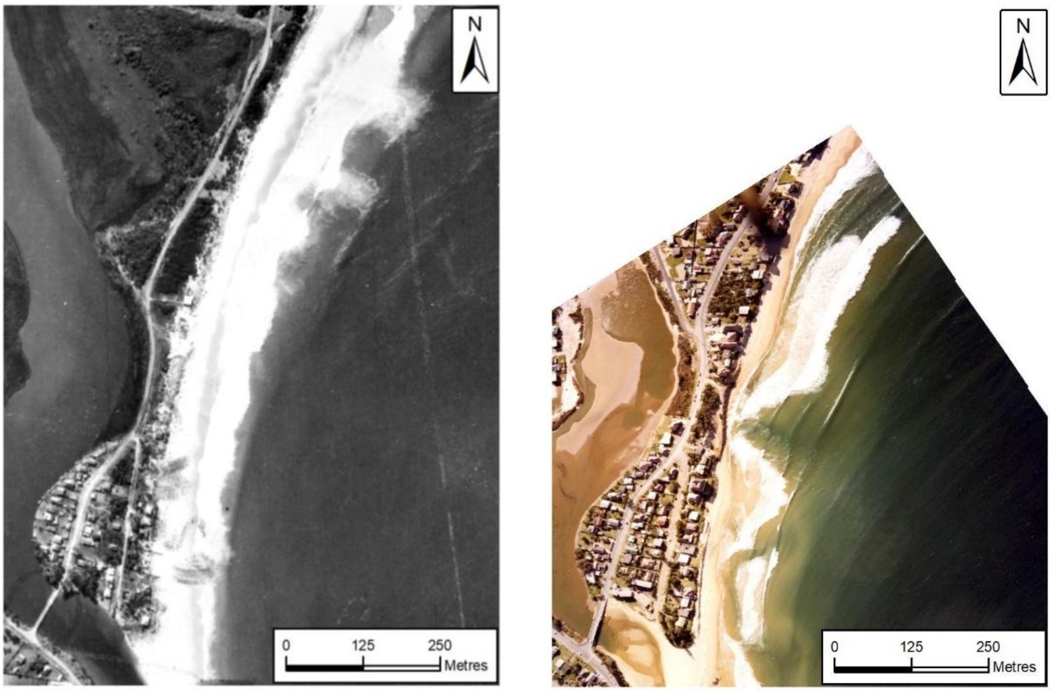
- Historical aerial imagery
- Satellite imagery
- More recent Nearmap images
- High resolution elevation surveys undertaken by the University of New South Wales (UNSW) since 2015 using:
    - Drone photogrammetry
    - Quadbike with differential real-time kinematic global positioning system (RTK-GPS)
    - Aircraft based Light Detection and Ranging (LiDAR).
- Short term camera based shoreline monitoring established by WRL in 2020

The compiled datasets used in this study are summarised in Table 2.1, with examples of images shown in Figure 2.1.

Table 2.1: Sources of data

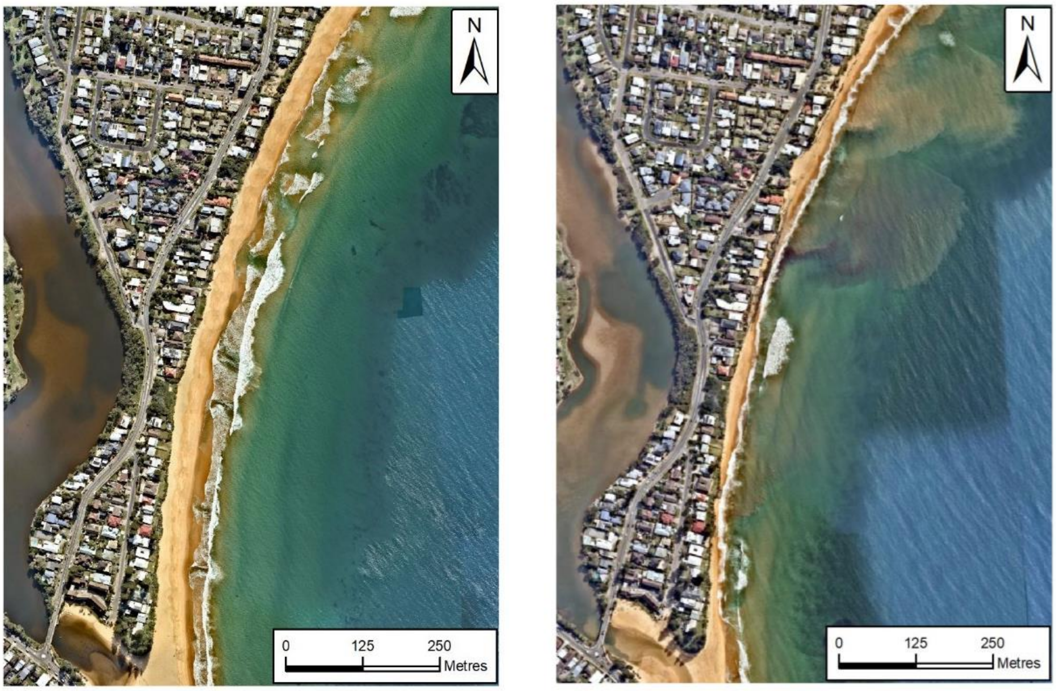
Data type	Source	Date Period	Number of datasets
Images/ shorelines	Historical aerial images	1941-present	30
	Satellite shorelines	1987- present	633
	Nearmap shorelines	2010-present	28
	WRL Camera monitoring	2020-present	One image every 15 minutes
Elevation data	OEH photogrammetry	1941-2008	15
	WRL Quadbike survey	2011-2014 (monthly)	37
	UNSW Aviation LiDAR	2015-Present	25
	OEH Bathy-topo LIDAR	2018	1
	Drone survey	Post 2016 storm Post 2020 July storm	1 4
	DPIE Jetski survey	Post 2020 July storm	1

Historical images were digitised from the NSW Department of Planning, Industry and Environment (DPIE, formerly OEH) photogrammetry archive and supplemented with additional imagery from the NSW Spatial Services image archive. These images were georeferenced using a number of control points of recognisable features such as street intersections or building footprints that were extracted from a reference Nearmap image.



25 November 1941 (OEH archive)

7 July 1978 (OEH archive)



1 July 2020 (Nearmap)

31 August 2020 (Nearmap)

Figure 2.1: Examples of aerial images from the compiled catalogue

3 Historical beach width analysis

An analysis of historical beach width at Wamberal Beach was performed by tracking the horizontal movement of the mean high water springs (MHWS) shoreline which is located at an elevation of +0.7 m AHD. The use of the MHWS shoreline has been adopted in this study as it is well established as a robust indicator for tracking shoreline variability (Harley et al, 2010).

Slightly different methods were used to extract the shoreline from each data source, which are each associated with varying levels of accuracy as summarised in Figure 3.1. The preferred method was to directly extract the +0.7 m AHD contour from measured elevation data. This was not possible for shorelines extracted from Nearmap or satellite images (which are two-dimensional images rather than three dimensional surveys) which required corrections for the tide and wave conditions. Once calculated, the position of the +0.7 m AHD shoreline from all sources was extracted at shore-normal transects corresponding with the photogrammetry database to provide a timeseries of beach width between 1941 to present day.

OEH photogrammetry Accuracy: +/- 5 m	• Direct extraction of +0.7 m AHD contour from elevation data
Drone/LiDAR/Quadbike Accuracy: +/- 0.1 m	• Direct extraction of +0.7 m AHD contour from elevation data
Nearmaps Accuracy: +/- 2 m	• Shoreline corrected for measured tide level at Sydney using average beach slope
Satelite Accuracy: +/- 7 m	• Shoreline corrected for measured tide level at Sydney using average beach slope
WRL Camera monitoring Accuracy +/-3 m	• Shoreline corrected for measured tide level at Sydney using average beach slope

Figure 3.1: Comparison of shoreline analysis techniques

3.1 Photogrammetry derived shorelines

The horizontal position of the +0.7 m AHD contour was extracted from the NSW DPIE Photogrammetry dataset using the “Beach Contour Timeseries” tool on the NSW Beach Profile Database website (http://www.nswbpd.wrl.unsw.edu.au). This tool uses linear interpolation between measured photogrammetry data points to calculate the position of a given elevation at each profile. This information was extracted at each transect before being used to reconstruct a +0.7 m AHD shoreline along the beach.

3.2 Drone/LiDAR/Quadbike shorelines

The +0.7 m AHD contour was extracted from a total of 60 surveys conducted by UNSW since 2011. This included monthly surveys conducted between 2011-2014 using quadbike mounted RTK-GPS for a PhD project (Bracs et al., 2016) and drone photogrammetry surveys following large storm events in more recent years (2016 and 2020). Also included in the analysis were 25 manned aircraft LiDAR surveys conducted by UNSW Aviation since 2015 which were quality controlled for accuracy through comparison with a number of control points measured using RTKGPS.

3.3 Tidal corrections of shorelines

Tidal corrections were applied to adjust the horizontal position of Nearmap and satellite derived shorelines to the +0.7 m AHD contour by using ocean water levels measured at Sydney (HMAS Penguin), the timestamp of each image and an average intertidal beach slope. Analysis was completed of the 80 year OEH photogrammetry dataset to calculate a typical intertidal beach slope to be used for tidal corrections (Figure 3.2). This led to the adoption of a beach slope of 1V:11H (0.09) for tidal corrections at the site. The average horizontal tidal adjustment was generally between 5 m to 15 m depending on the measured tide level of each image.

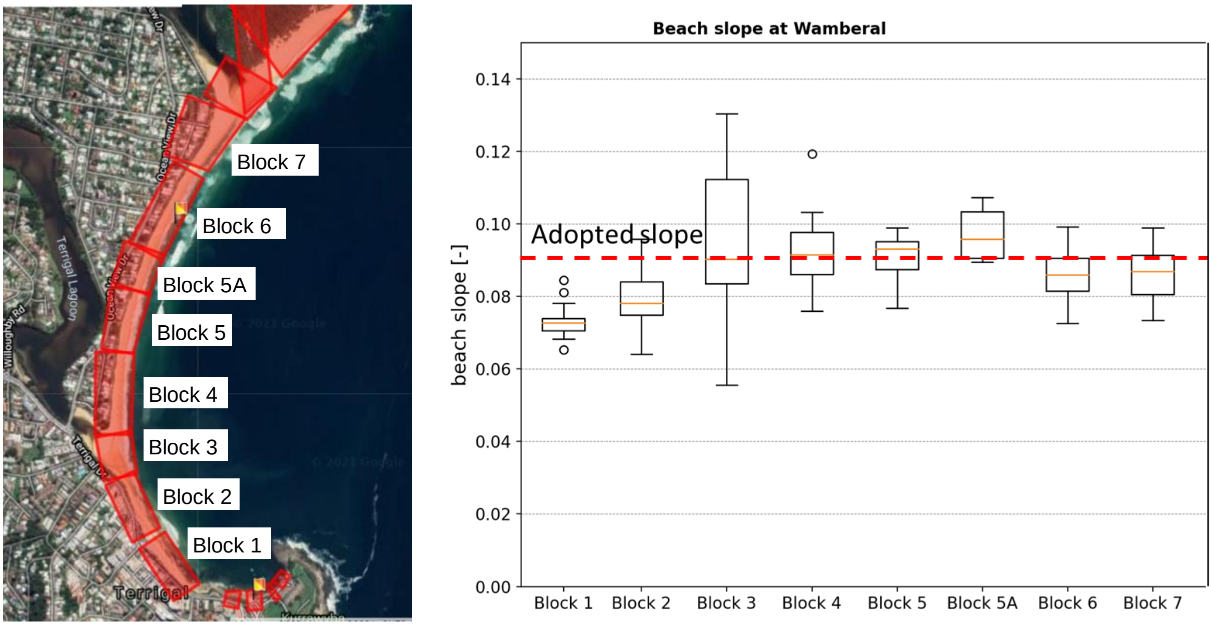


Figure 3.2: Intertidal beach slope from photogrammetry data for tidal corrections

3.4 Nearmap shorelines

Nearmap is a global database that provides very high resolution geo-rectified aerial imagery with a typical resolution of 10 cm per pixel. Capture of imagery at Wamberal Beach commenced in 2010 and while the interval between capture is variable, there is typically an image every few months. Shorelines digitised from Nearmap images were defined as the position of the groundwater seepage as it has a clear visual contrast and is less susceptible to variations in the instantaneous water level from effects such as wave run up (Horn, 2002). The timestamp of each image was then used to tidal correct shorelines to the +0.7 m AHD contour using the method described in Section 3.3.

3.5 Satellite derived shorelines

Shoreline variability at Wamberal Beach was also assessed using the Coastsat technique developed by Vos et al (2019) that extracts the shoreline positions from satellite imagery dating back to 1985. The method uses three main steps in the process including image classification, sub-pixel shoreline detection and tidal correction. Image classification utilised spectral information captured in each image of the visible spectrum (RGB), near-infra red (NIR) and shortwave infrared band (SWIR) to classify each image into four classes of sand, water, swash zone or other. Once an instantaneous shoreline was detected, its horizontal position is tidally corrected to the +0.7 m AHD contour using the method described in Section 3.3.

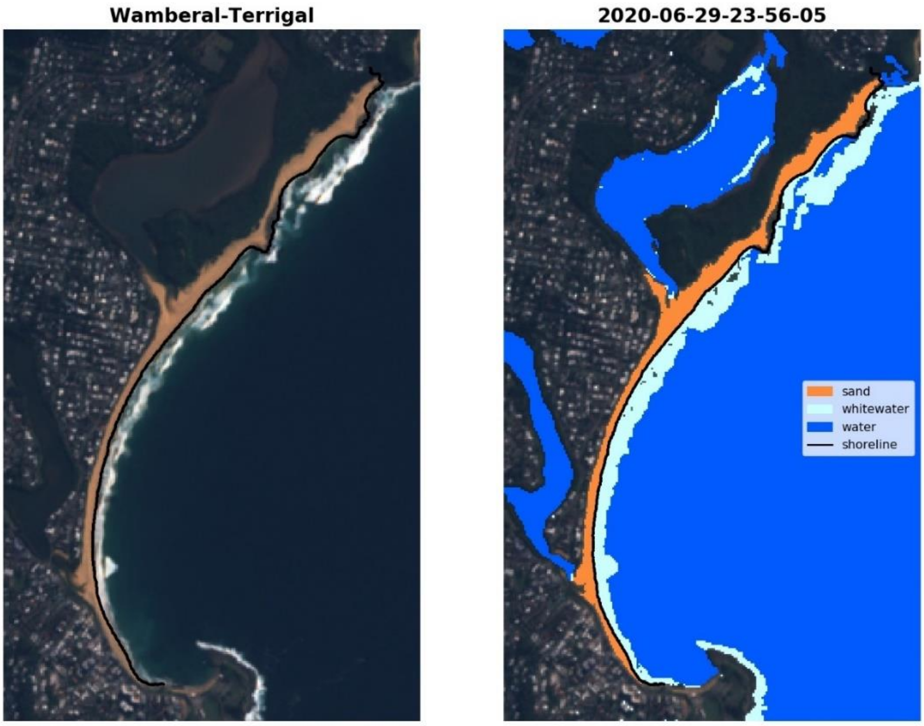


Figure 3.3: Example of satellite derived shoreline detection at the site on a Sentinel 2 image

3.6 Monitoring camera

Camera based monitoring systems were established by WRL in early 2020 to monitor beach width change at Wamberal. These systems are still operational and were installed above Terrigal Lagoon facing north in April 2019 and onto the Wamberal Beach lifeguard tower looking south in July 2020 immediately after the storm event (Figure 3.4). These customised systems transmit images every 15 minutes during daylight hours and are used to monitor shoreline change using a custom-built coastal imaging software package using the methodology described in Harley et al. (2019). The impact of the July 2020 storm on beach width is shown in Figure 3.5, while recovery of the beach following the storm is shown in Figure 3.6 and Figure 3.7

Camera 1: Wamberal SLSC looking south

Camera 2: Terrigal Lagoon looking north

Figure 3.4: Monitoring cameras installed at Wamberal SLSC and Terrigal Lagoon in 2020

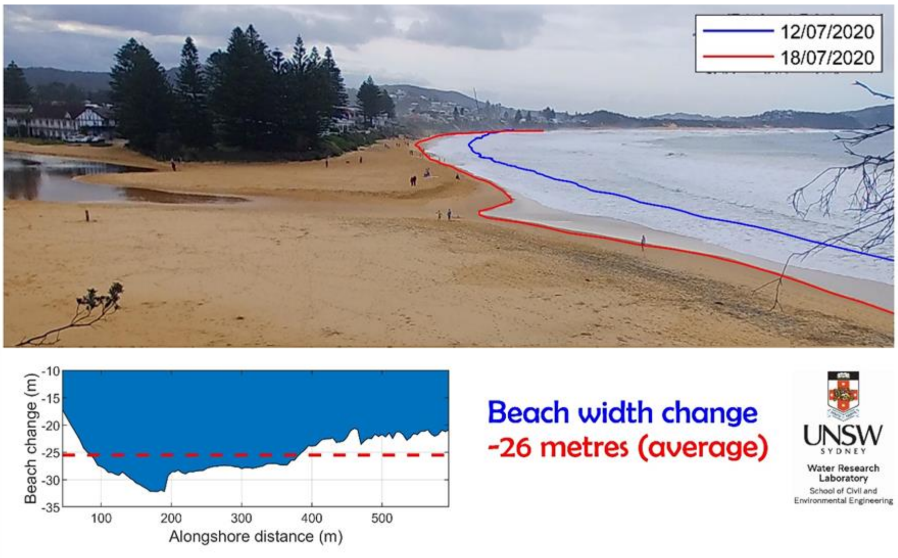


Figure 3.5: Shoreline change at Wamberal in response to the July 2020 storm event

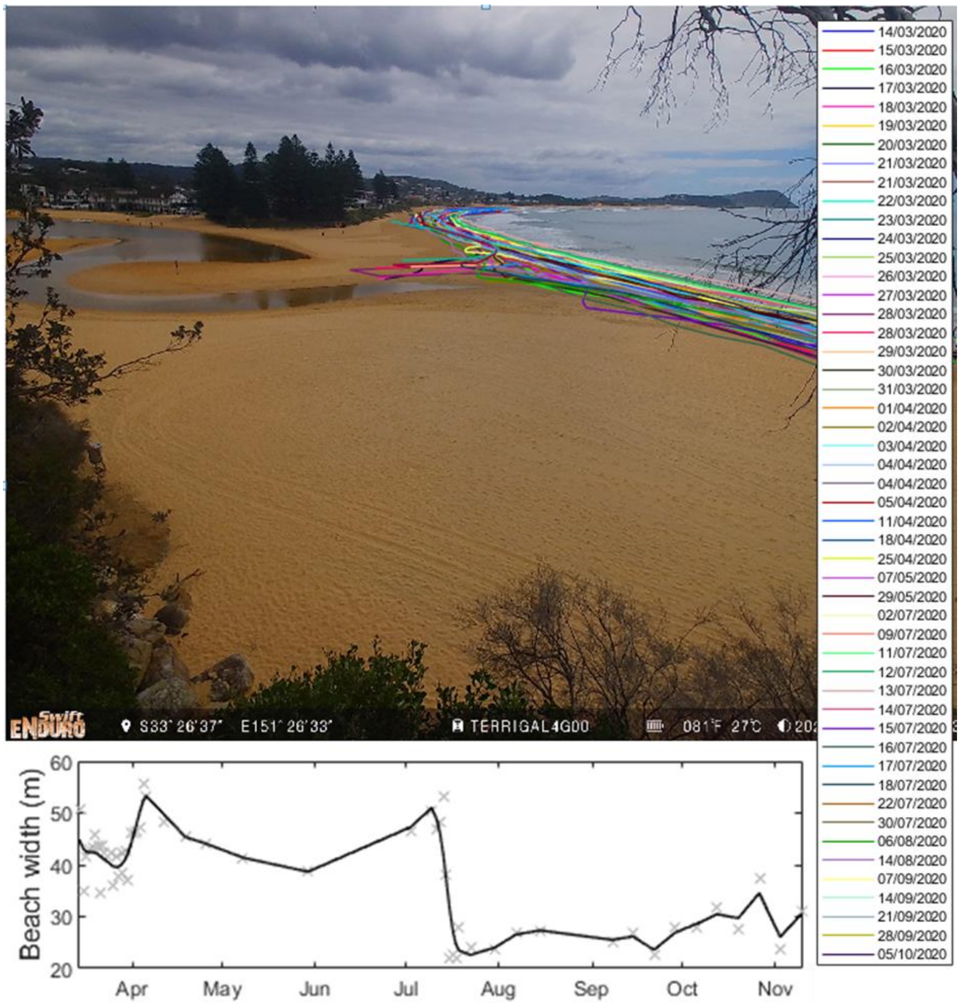
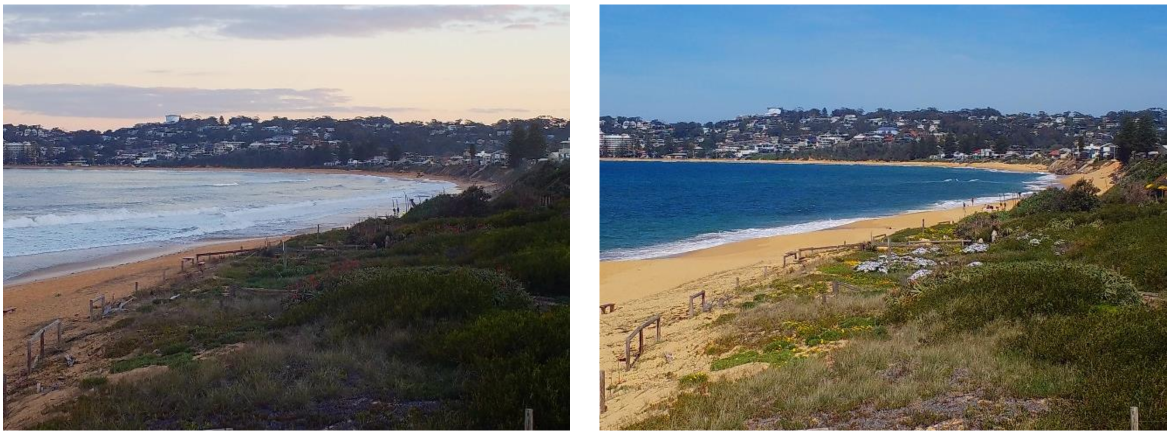
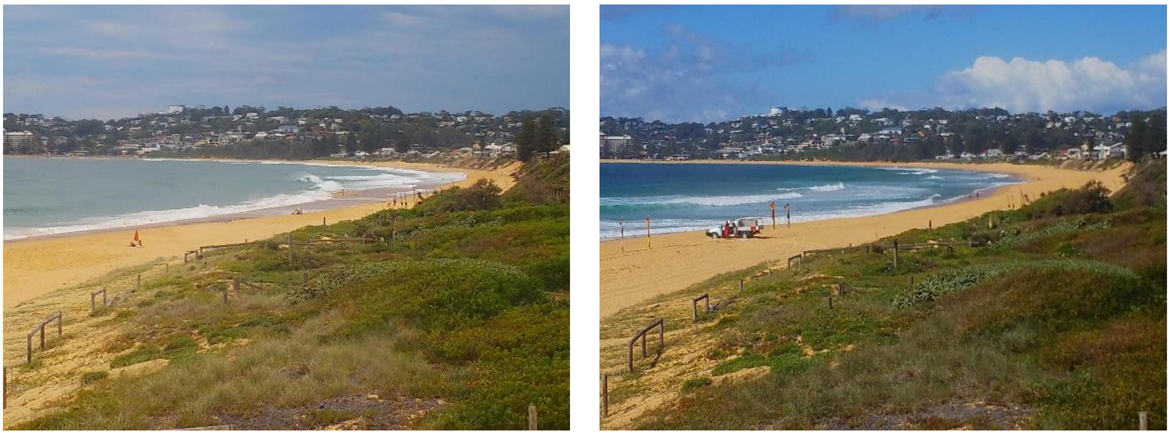


Figure 3.6: Beach width change throughout 2020 from Terrigal monitoring camera



Post Storm- July 2020 **2 months post storm- Sept 2020**



6 months post storm- Dec 2020 **8 months post storm- Mar 2021**

Images taken at approximately mid to high tide.

Figure 3.7: Beach width recovery throughout 2020 from Wamberal SLSC monitoring camera.

3.7 Accuracy of satellite derived shorelines

The ability to accurately track shoreline variability at Wamberal Beach was tested against a set of shorelines mapped from verified techniques including DPIE photogrammetry, quadbike mounted RTK-GPS, drone photogrammetry and manned aircraft LiDAR. A ten (10) day moving average window comparing 50 satellite derived shorelines to ground truth data produced a root mean square error (RMSE) of 7 m with a slight tendency for the method to underpredict the width of the beach (Figure 3.8 and Figure 3.9). This accuracy is comparable to a horizontal RMSE of 10 m obtained from application of the technique to the Narrabeen-Collaroy monitoring dataset (Vos et al, 2019). While the resolution of satellite imagery has improved substantially over time, with a pixel footprint reducing from 30 m to 10 m, analysis by Vos et al (2019.) indicates that the accuracy of satellite derived shorelines do not appear to vary much between satellite missions (Figure 3.9).

This demonstrates the robustness of the sub pixel shoreline mapping technique when applied to the lower resolution images and suggests that the dominant source of error is introduced by inaccuracies in the tidal correction process due to wave run up or assumed beach slope. It also demonstrates reliability in the shorelines derived from the earlier lower resolution Landsat missions.

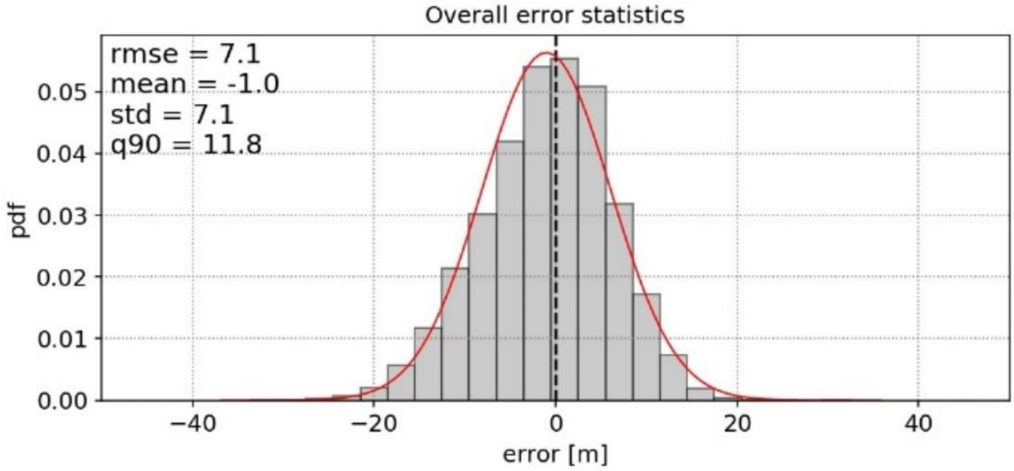


Figure 3.8 Accuracy of satellite derived shorelines compared to ground truth measurements

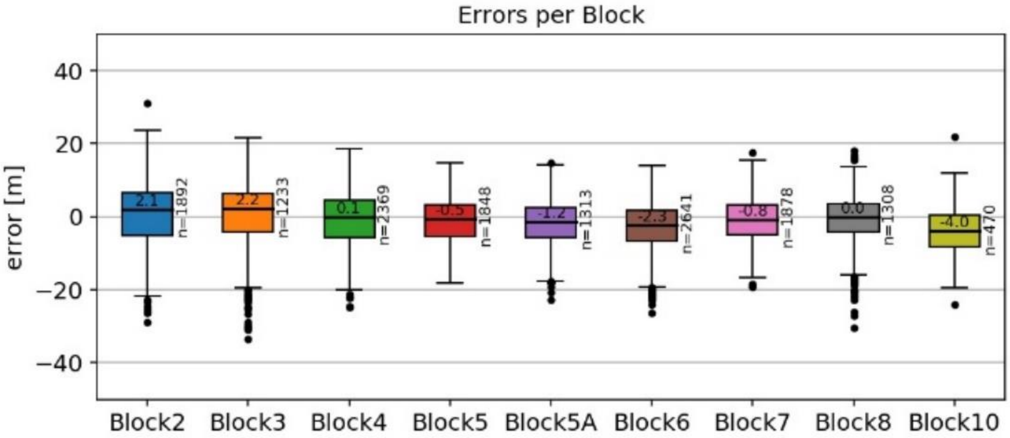


Figure 3.9: Alongshore variation in calculated error of satellite derived shoreline positions

3.8 Beach width change results

The analysis of long term beach change over the past 80 years at Wamberal Beach is shown in Figure 3.10 to Figure 3.13. Beach width here is defined as the horizontal distance from the +0.7 m AHD contour to the July 2020 dune toe (or toe of existing rock protection).

A number of relevant observations can be drawn from the long-term beach width analysis including:

- There is close agreement in beach width data extracted from each of the data sources demonstrating confidence in the variety of methods used in this study;
- The envelope of natural beach width fluctuation (difference between widest and narrowest beach state) is approximately 80 m;
- The data indicates that in the early 1990s Wamberal Beach was the widest (approx. 50-80 m) it has been in the 80 years of data for the site;
- The narrowest beach widths occurred in the late 1970s and in 2020 (sections of beach reaching less than 10 m width and resulting in damage to beachfront houses);
- Satellite derived data indicates that since the 1990s, the beach has undergone a long-term recession, though this is less evident from the longer term (though more temporally sporadic) photogrammetry data.

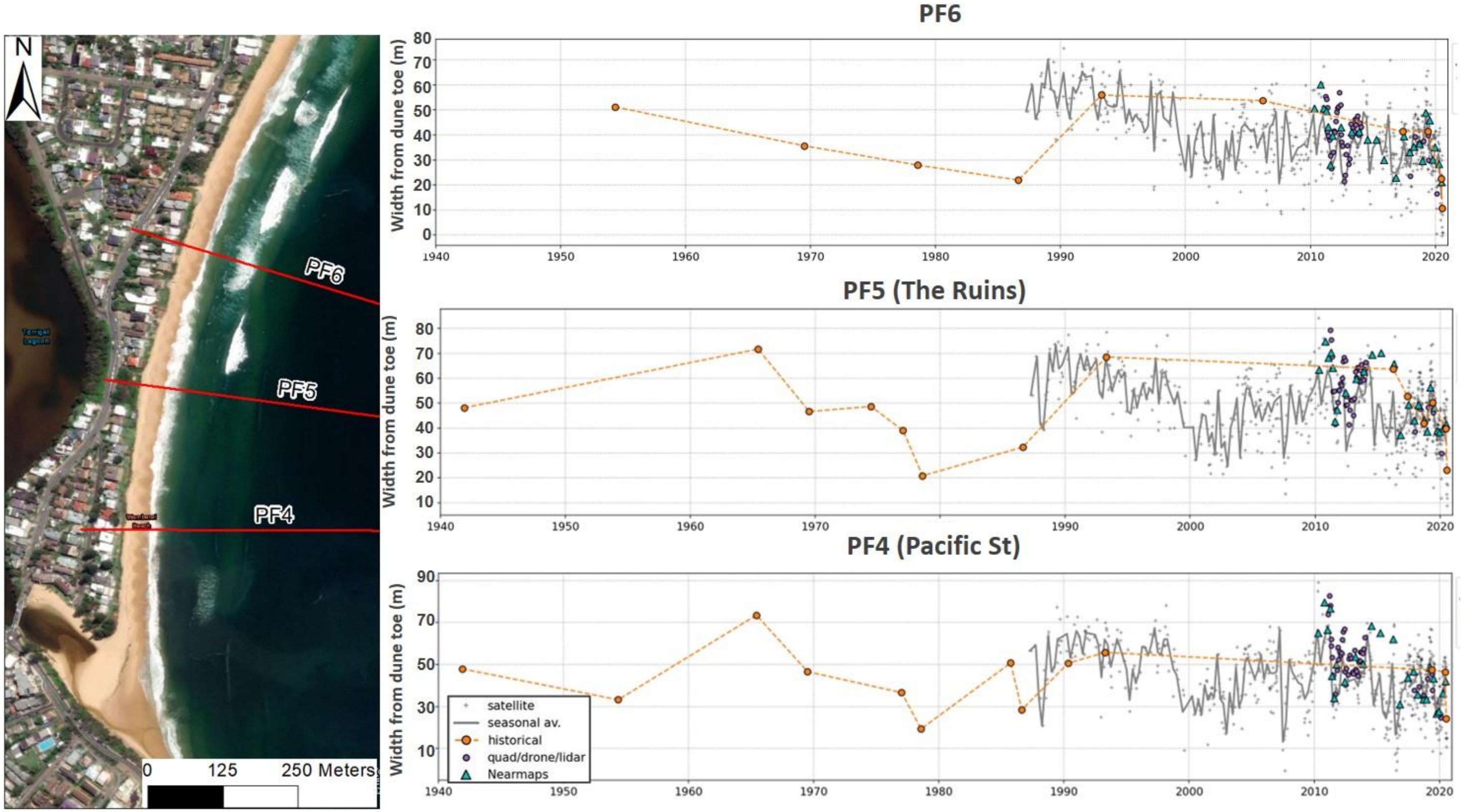


Figure 3.10: 80 years of beach width at Wamberal, 1941 to present day

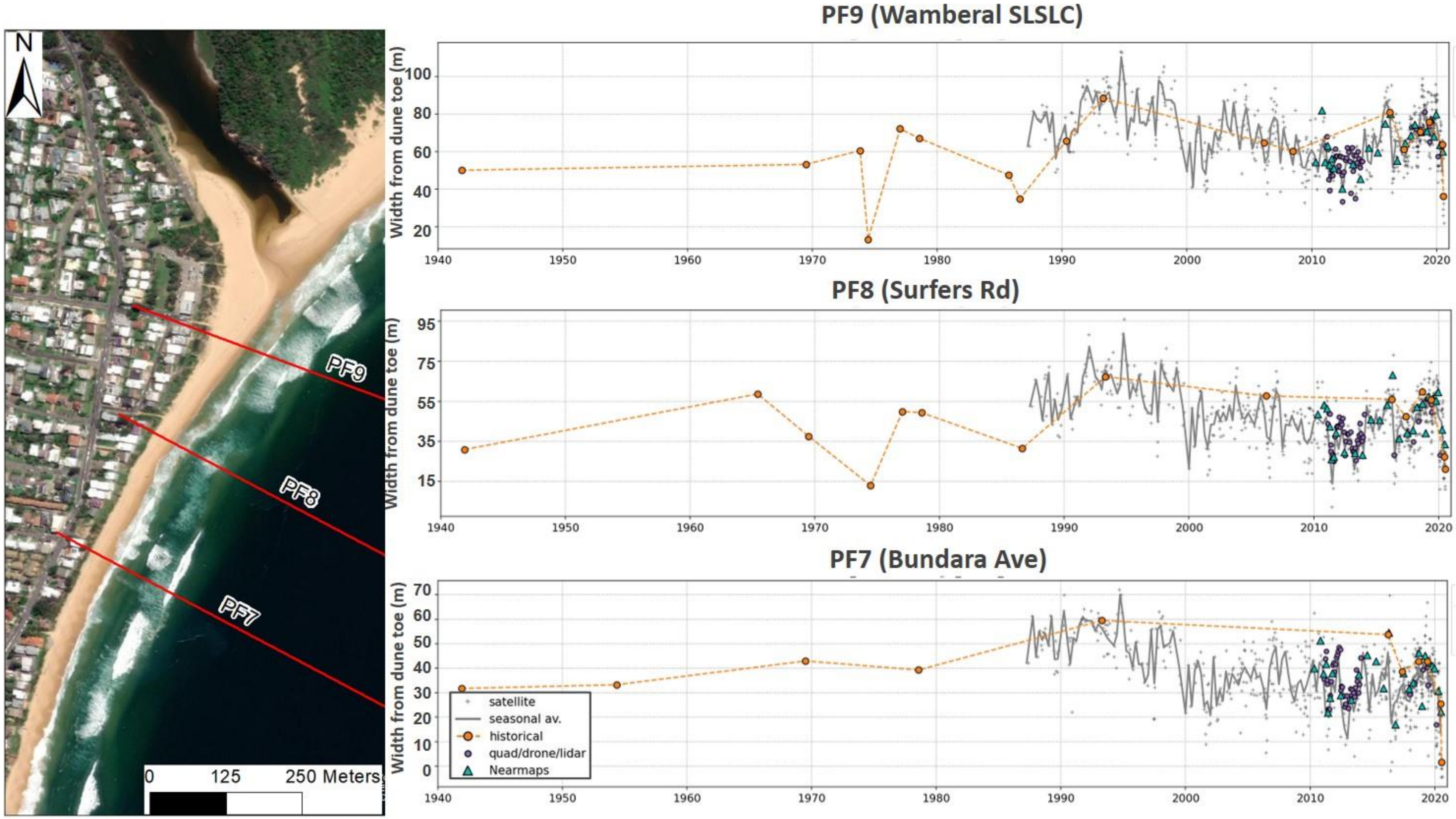


Figure 3.11: 80 years of beach width at Wamberal, 1941 to present day (cont)

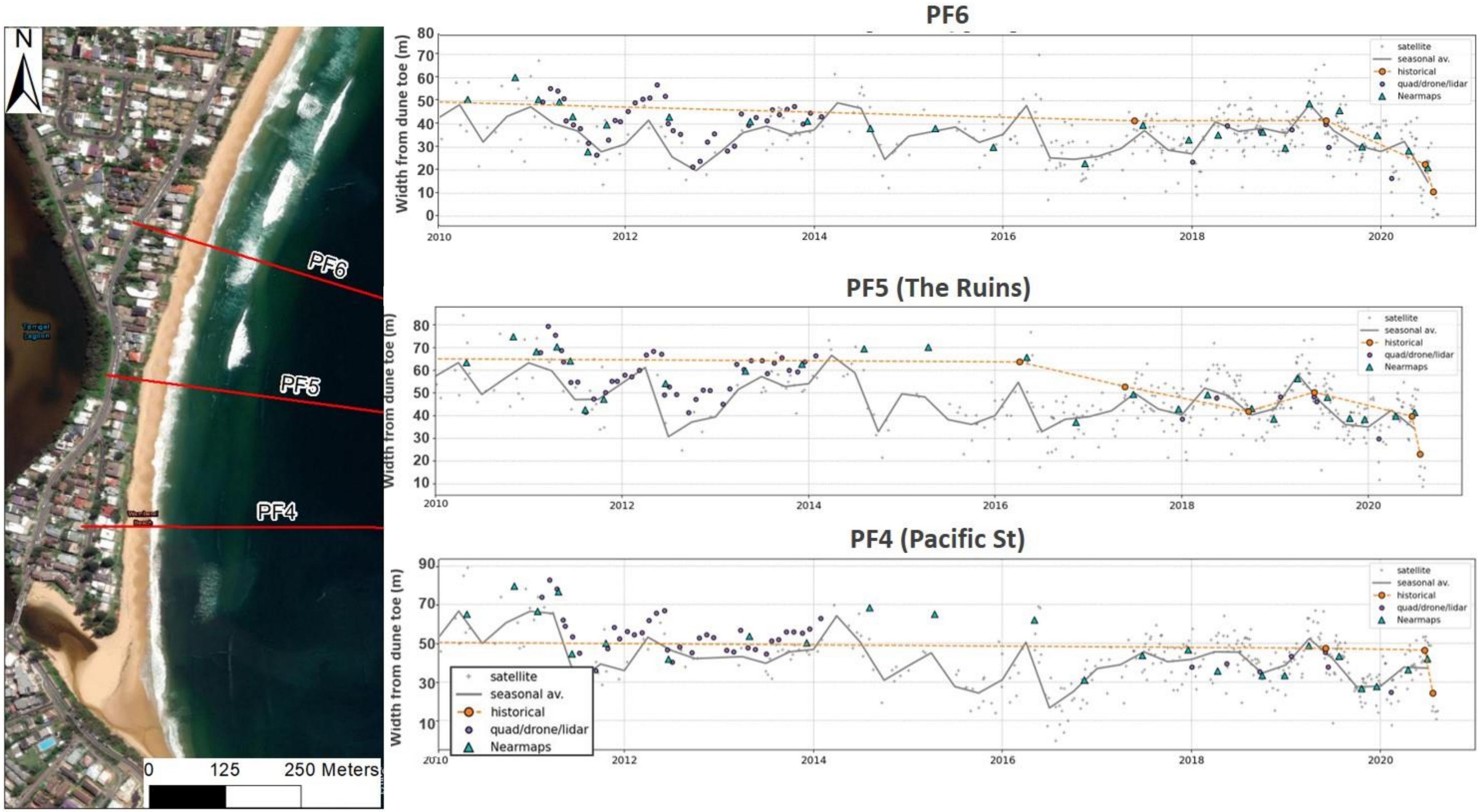


Figure 3.12: Past decade of beach width at Wamberal, 2010 to 2020

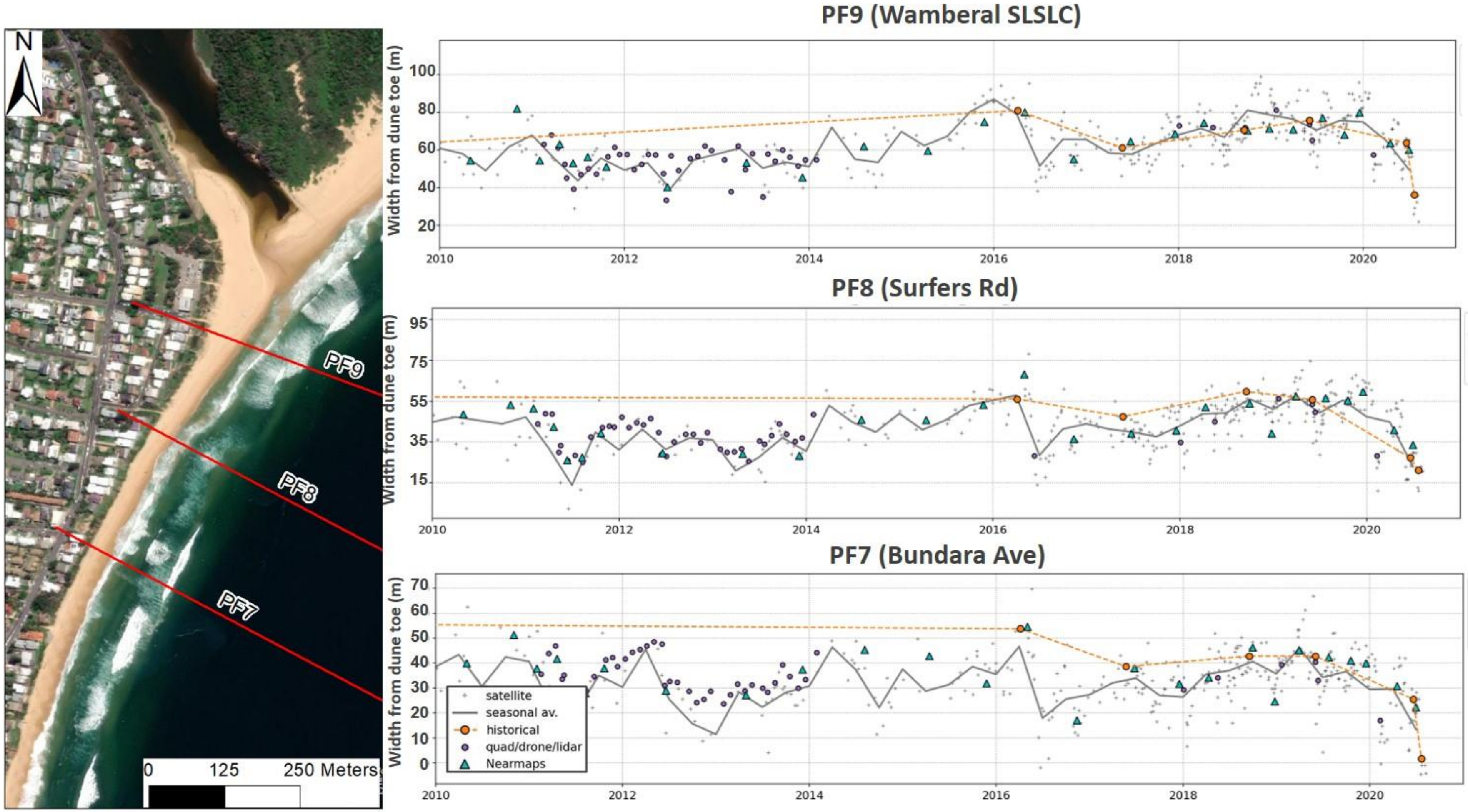


Figure 3.13: Past decade of beach width at Wamberal, 2010 to 2020 (cont.)

4 Beach width impact assessment

4.1 Beach width amenity literature review

Overwhelming feedback obtained during community consultation (November 2020 and August 2021), highlighted the importance of natural amenity that Wamberal Beach provides to its users and the broader community. Beach width is an important criterion for communities' enjoyment of a beach, and up to a limit, people prefer wider beaches (King, 2006). Anning (2012), investigated the economic value of selected Sydney beaches, and highlighted that while beach width has been used extensively in valuation literature as a proxy for beach quality, determining what is acceptable to a community for recreational use is complex. Anning noted that the majority of beach width studies have been based on housing market impacts, rather than recreational use.

Parsons et al. (2013) and Gopalakrishnan et al. (2016) both completed literature reviews on the economic value of beach width. Their studies included valuations of beach width in terms of recreational use, impact of erosion and housing market impacts. Both these studies found that there are economic losses due to beaches being too wide and too narrow.

The definition of acceptable beach width varies greatly depending on usage patterns, precedent and personal preference. Parsons et al. (2000) considered beaches in the mid-Atlantic region of the USA (primarily Delaware and New Jersey), and suggested that beaches can be too narrow and too wide. It was proposed that the ideal beach width was between 75 and 200 ft (23 – 61 m) between the dune toe and the berm. Morgan (1999) investigated acceptable beach width in Wales, finding the optimal beach width to fall between 50 and 200 yards (46 – 183 m) at low tide and 20 to 50 yards (18 – 46 m) at high tide, similar values to those of Parsons et al. (2000). King (2006) suggested that the ideal beach width is approximately 100 – 250 ft (30 – 76 m), without reference to the tidal stage of the beach. King (2006) also highlighted that it is possible that a beach could be so wide that access to the water is too onerous (for example this was experienced in some regions on the Gold Coast)

Todd and Bowra (2016) found recent studies conducted on a number of Gold Coast beaches suggested the optimum beach width for amenity was between 38 and 70 m. They specifically highlighted one case study comparing a large beach width at Coolangatta Beach (85 m) to a smaller beach width at Palm Beach (35 m) indicating that the smaller beach width was more valuable for beach amenity.

The US Army Corps of Engineers, responsible for many beach nourishment programs in the USA, often follow a policy that 100 ft^2 (9 m^2) of beach area is desirable per person (King, 2006), which means that estimates of beach user numbers are also needed to establish estimates of beach width/area required for beach amenity.

Harley et al. (2016) conducted a study to assess the effectiveness of the Emilia-Romagna early warning system during a storm event in northern Italy. As part of this study the safe corridor width (SCW) was defined. This is the distance between the dune foot and a model-derived position of the water line. Harley et al. (2016) set three risk categories for the SCW; a SCW greater than 10 m was defined as low-hazard, a SCW between 5 m and 10 m was defined as medium hazard, and a SCW less than 5 m was defined as high-hazard conditions. This study only looked at storm conditions and the hazard ratings were based upon the ability of people being able to escape hazardous conditions when in the beach corridor.

Large scale nourishment of the southern Gold Coast beaches is ongoing as part of the Tweed Sand Bypassing Project (TSBP). A number of dredging campaigns of the Tweed River entrance have taken place and a permanent sand bypass system was introduced in 2001. This has resulted in significant changes in the Coolangatta Bay morphology. In 2006, the southern Gold Coast beaches were estimated to be the only Gold Coast beaches with sufficient width to be able to withstand a sequence of storm wave erosion events without exposing the underlying ("A-line") boulder wall (Castelle et al., 2006). By 2006, a seaward accretion of the shoreline by more than 200 m occurred at Kirra Beach, compared to the shoreline prior to the TRESBP commencement in 2001. In 2006 some local stakeholders and tourists considered that the beaches were too wide, especially at Kirra Beach, and that surfing, swimming, fishing, diving and beach use amenity was compromised as a result of over widening (Castelle et al., 2006). This highlights the importance of not making a beach too wide.

Carley et al. (2003) and Short and Trembanis (2004) each analysed one of Sydney's northern beaches, Manly Ocean Beach and Collaroy-Narrabeen Beach, respectively. Carley et al. (2003) assessed the average mid-tide beach width of Manly Ocean Beach, seaward of the seawall to 0 m Australian Height Datum (AHD) between 1930 and 2001. The average mid tide width of the entire beach over this period was 48 m, ranging between 32 m at the southern end, to 75 m at the northern end. Their qualitative observations are that the northern end is almost always acceptably wide for the community, but the southern end is too narrow at times (high tides and large waves). Along Collaroy-Narrabeen Beach between 1976 and 2001, Short and Trembanis (2004) observed an overall mean width of 78 m, considering five (5) different profiles spaced along the beach. The mean of the maximum widths observed was 119 m and the mean of the minimum widths was 46 m.

Todd et al. (2015) presented a Beach Volume Index (BVI) for quantifying beach width on the Gold Coast. Calculation of the index has evolved since its initial development in the 1970s, noting that the seawall ("A-line") used to define the BVI provides structural property protection. BVI is an indicator of the beach amenity which would be available (seaward of the seawall) following major storm erosion. The current BVI number comprises components of sand volume seaward of the seawall above 0 m AHD and between 0 m and -14 m AHD. This is somewhat specific to the Gold Coast, but various BVI scores are associated with descriptors of excellent, good, adequate, poor and critical. Low BVI scores are a trigger for more targeted management intervention on that section of coast. The earlier 1970s work of the Queensland Beach Protection Authority cited in Todd et al. (2015) developed a design beach profile for the Gold Coast which had a beach width of 120 m between the crest of the seawall and mean sea level.

Todd et al. (2015) highlighted that the visible beach width does not necessarily relate to the total volume on a beach. The implications of this means that beach amenity, in terms of its ability to resist erosion events, is better correlated to beach volume rather than beach width. As outlined by Todd and Bowra (2016), it was due to the empirical nature of the BVI that it was used to determine beach health. Furthermore, the BVI is now being used on the Gold Coast to determine the amount of sand that should be placed on beaches during nourishment projects (Colleter, 2017). This is aligned with local strategies on the Gold Coast which now require annual reporting on beach amenity in terms of volume specifically in relation to storm demand (CoGC, 2013).

4.2 Beach width for Wamberal

Beach width at Wamberal Beach provides a highly valued space for community recreational use, as identified in community consultation (November 2020 and August 2021). An absence of dry beach width and the presence of ad hoc coastal structures (and the fact that no promenade exists) limits the ability of people to walk along the foreshore at times. At Wamberal, available dry beach width is particularly popular for sunbathing and recreational use at Wamberal Surf Life Saving Club (SLSC) and in the vicinity of Terrigal Lagoon, with the broader Terrigal-Wamberal sandy beach also highly popular amongst beach walkers.

Key considerations for desirable beach width at Wamberal Beach in terms of recreation include:

- Ability to walk along the beach safely without getting wet or coming in contact with the wave runup of the shoreline.
- Ability to sit or lie on the beach without getting wet or feel at risk from ad-hoc structures.
- Ability for sporting or other recreational activities to be completed on the beach such as exercise programs, football, surf life saving activities, or setting up surfing or kite surfing equipment.

It should be noted that in some circumstances, the value of beach width can be seasonal. During winter months there is generally a lower utilisation of the beach compared with summer. Additionally, while one section of the beach might be narrow, a wider, adjacent section might serve the purpose needed for amenity, provided there is some means for alongshore access.

Other considerations for beach amenity include safety, particularly when Wamberal Beach is an eroded state with existing ad-hoc seawalls exposed in the mid-section of the beach. Historically the beach has been closed to the public in such circumstances. Note that Carley and Cox (2017) point out that (even on a natural beach) “it is unrealistic to expect an acceptable beach width to be present during or following an extreme storm event.” Therefore, as with areas exposed to natural weather processes, it cannot be expected that a beach width suitable for recreational use is available 100% of the time.

At Belongil Beach in northern NSW, a beach width of 20 m at +2 m AHD was recommended as an acceptable width for beach amenity (Carley et al., 2016). This was based on a storm demand of ~40 m3/m above 0 m AHD for a 1 in 1 year annual recurrence interval (ARI) storm, as defined by Gordon (1987). Following a similar methodology to Carley et al. (2016), a minimum acceptable dry beach width of 5 m (distance from the dune toe or existing ad-hoc rock protection to the wave runup limit) has been adopted for the purpose of this report to assess impacts on beach width amenity. While the volume of sand eroded during a storm event is not needed to protect the backshore assets (this protection will be achieved via provision of an engineered seawall structure) it can be used to determine how much sand is needed for an acceptable dry beach width to be present after a storm event.

A minimum dry beach width of 5 m (between the seawall and the wave runup limit) allows for some storm erosion and would mean that the beach falls into the medium hazard category as defined by Harley et al. (2016). In addition to this, the distance to the water is not too onerous on beach users. This value can be compared to beach width model results to assess the impacts on beach amenity of existing and proposed options for seawalls.

4.3 Beach width model

The width of dry beach available for use by the community is one way of quantifying the amenity of a beach. In order to assess the relative impact of each of the seawall designs on beach width amenity, WRL has developed a beach width model as described in Tucker et al (2019). This model incorporates empirical data including tide, wave, wave runup and shoreline profile datasets. This has been used as an input to a runup model, which was selected after a thorough assessment of alternate runup models and implementation techniques. This runup model estimates wave runup and dry beach width at hourly time steps using predominantly measured data as input. The beach width model estimated the range of beach widths at Wamberal Beach over a 10 year period in its present state compared to alternative scenarios including concept design seawall geometries and alignments from the *Stage 3 Seawall Concept Design Options (MHL2780, 2021)* report.

Beach width is defined as the dry area of beach extending from the top of the wave runup to a baseline feature at the back of the beach (Figure 4.1). The baseline is typically considered to be either a fixed object that bounds the beach such as a seawall, fence or cliff, or is a pre-defined stable position on a beach profile such as vegetation line or erosion scarp. The limiting feature at Wamberal Beach is either existing ad-hoc rock protection, a seawall (to be constructed) or a dune scarp generally associated with the most eroded state of the beach. Wave runup reaching the baseline feature defines the case with zero beach width. i.e. when the seawall, scarp or other feature is directly exposed to wave runup. A beach width model has been developed for Wamberal in this study to create hourly dry beach width for a period of 10 years. The beach width model incorporates measured offshore wave height, modelled nearshore wave height, measured tide, measured and modelled wave runup, and measured beach profile measurements (see Section 3), to create a continuous beach width timeseries. The beach width model was applied at six profiles located between Terrigal and Wamberal Lagoon entrances as shown in Figure 4.3.

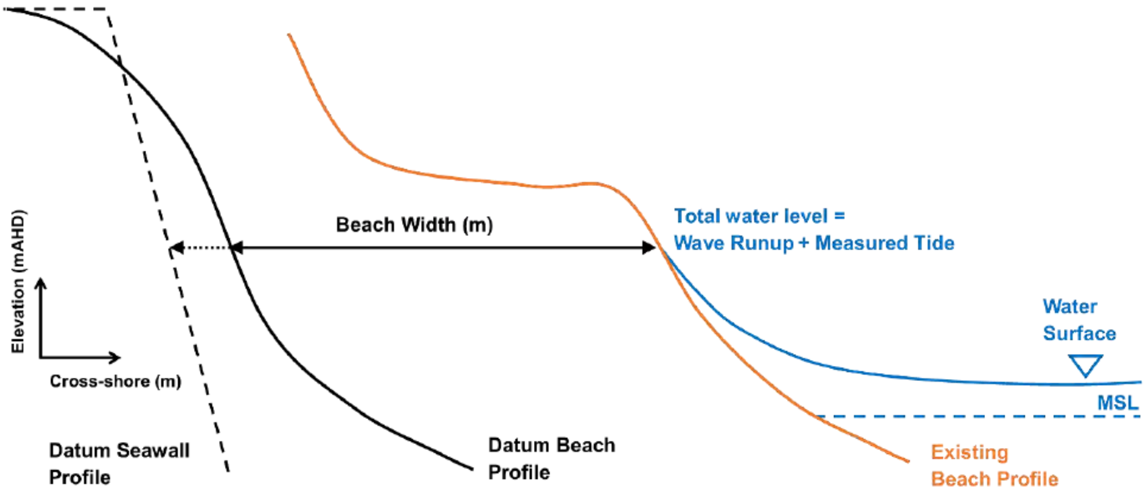


Figure 4.1: Definition of beach width

Since wave runup is continuously changing with waves and tides, and the beach profile is also continually evolving, the dry beach width varies with time. This means that during some periods there may be limited beach width during large waves and high tides when the beach is narrow, while there may still be useable beach at low tide. During other periods, a substantial beach width will be present for extended periods.

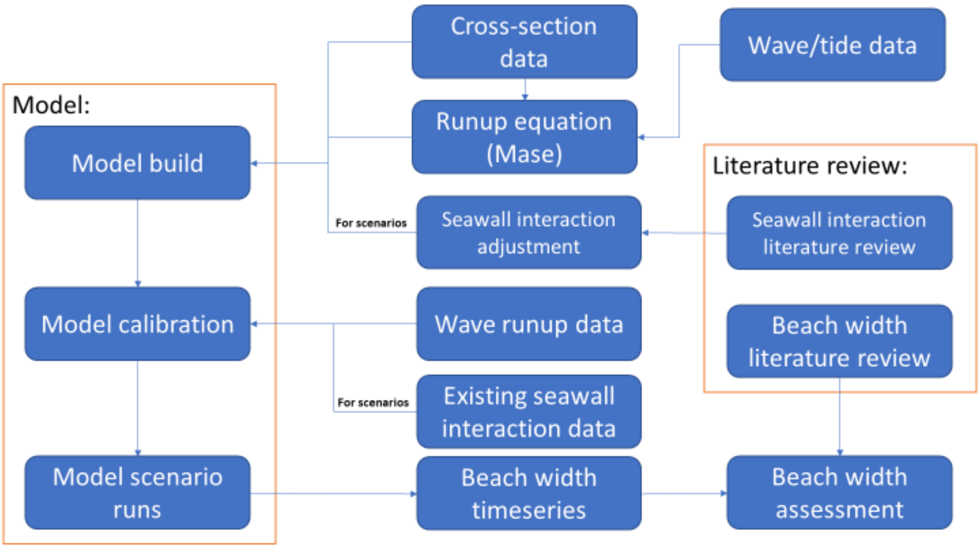


Figure 4.2: Beach Width amenity model development

Figure 4.3: Profiles used in beach width model

4.3.1 Wave runup

On any sandy beach that is influenced by waves, the shoreline is in a constant state of transition. As waves interact with a sandy beach, depending upon the wave energy, water will run up the sloped beach face to a certain level. The height of this 'runup' varies and will determine the dry beach width at any given time. Generally, larger waves lead to an increase in runup and result in a narrower beach width while smaller waves result in a wider beach width. A number of empirical models have been developed to calculate wave runup level which are generally based on the following dominant parameters (Power et al., 2018):

- Beach slope;
- Wave height; and
- Wave period.

Using these parameters, models can estimate wave runup statistics such as the maximum wave runup height (R_{max}) and the wave runup height that is exceeded by 2% of waves for a given period of time ($R_{2\%}$). The accuracy of these models vary from beach to beach and can be limited by a lack of underwater profile data. Furthermore, the tide elevation at the time when runup occurs affects the overall runup height.

The Mase (1989) model was selected in this study to empirically simulate runup for Wamberal Beach based on the extensive runup validation study presented in Tucker et al (2019) for Collaroy-Narrabeen Beach in Sydney. This study compared the performance of the Mase (1989) and Stockdon et al. (2006) runup model compared to runup field measurements collected using a LiDAR system. Tucker et al (2019) determined that there was marginal difference between the two runup models, however, the Mase equation performed slightly better than the Stockdon equation while providing the additional benefit of determining the R_{max} statistic. A regression plot validating the performance of the Mase equation relative to measured runup data at Collaroy-Narrabeen Beach is shown in Appendix A. The Mase (1989) runup model is presented in Equation 1 with details of each input parameters provided in the following sections.

$$\boldsymbol{R_p = H_0 a_p I^{b_p}} \tag{1}$$

$where:$

$R_p = Runup\ for\ the\ p\ quantile\ or\ statistic\ value\ desired$

$H_0 = deepwater\ significant\ wave\ height$

$\theta = angle\ of\ the\ beach\ slope$

$a_p, b_p = constants\ based\ on\ statistic\ or\ quantile\ value\ of\ desired\ runup$

$I = Iribarren\ number = \frac{tan\ \theta}{\left(\frac{H_0}{L_0}\right)^{\frac{1}{2}}}$

$L_0 = deepwater\ wavelength$

4.3.1.1 Wave runup validation with fixed LiDAR data

As part of the project a LiDAR instrument was installed in early 2021 to measure wave runup on Wamberal Beach for an anticipated duration of 12 months. Wave runup and beach profile data collected from the Lidar instrument were used to validate model results and provide coastal monitoring benefits. The maximum runup height for each hour (R_{max}) and the runup height that was exceeded by 2% of waves for each hour ($R_{2\%}$) was extracted from the Lidar profile timeseries. Calculation of these two (2) statistics for each hour was implemented using a MATLAB script with the following methodology:

1. Extract bed elevation: The Lidar sensor collects free surface measurements of the beach profile without any distinction between the water surface and the bed elevation. Using the variance threshold method, described by Turner et al. (2008) and adopted for use in Lidar measurements by Almeida et al. (2015), the stationary bed elevation was separated from the non-stationary water surface.
2. Calculate water depth: The depth of water at each location along the beach profile was calculated by subtracting the extracted bed elevation from the free surface measurements.
3. Track swash zone edge: The landward edge of the swash zone represents the intersection between the water surface and the bed profile. A water depth threshold of 80 mm was used to estimate the change in the position of the landward edge of the swash zone with time.
4. Extract wave runup statistics: The tidal signal was removed from the time-series of the swash edge using measured data from the Fort Denison tide gauge. A peak detection algorithm was used on the time-series to extract the highest elevation of individual runup events. $R_{2\%}$ for each hour was calculated by determining the elevation exceeded by 2% of individual runup events. R_{max} for each hour was calculated as the highest elevation obtained by an individual runup event during each hour.

Further details regarding use of fixed LiDAR for beach data collection is provided in Phillips (2018).

Measured wave runup data collected from February to November 2021 from the Wamberal LiDAR was compared to the modelled wave runup results based on Mase (1989) estimates. Results are compared for R_{max} and $R_{2\%}$ in Figure 4.4.. The model was found to predict the measured wave runup level with a root-mean-square error (RMSE) of approximately 0.5 m, corresponding to an average beach width accuracy of approximately 5 m (assuming 1:10 beachface slope). On average the model results slightly overpredicted the measured wave runup (and underpredicted beach width). Overall the model results show a suitable degree accuracy in predicting wave runup levels for the purpose of the present beach width amenity assessment

In assessing model performance, the accuracy limitations of the measured wave runup data and swash edge tracking calculations should be noted. The accuracy of the LiDAR instrument is limited to tracking a swash edge of at least 30mm water depth. A lower grazing angle of the lidar beam can further reduce swash tracking performance. Measured wave runup levels were determined using an automated swash edge tracking algorithm that identifies water depth changes greater than 80 mm, a value found suitable for real-time data processing requirements. In reality the swash edge will have a shallower depth with a thinner water lens extending higher up the beachface. More detailed data processing and quality assurance of the measured wave runup data could be done to improve the accuracy of the swash tracking signal however is consider beyond the scope of the present study.

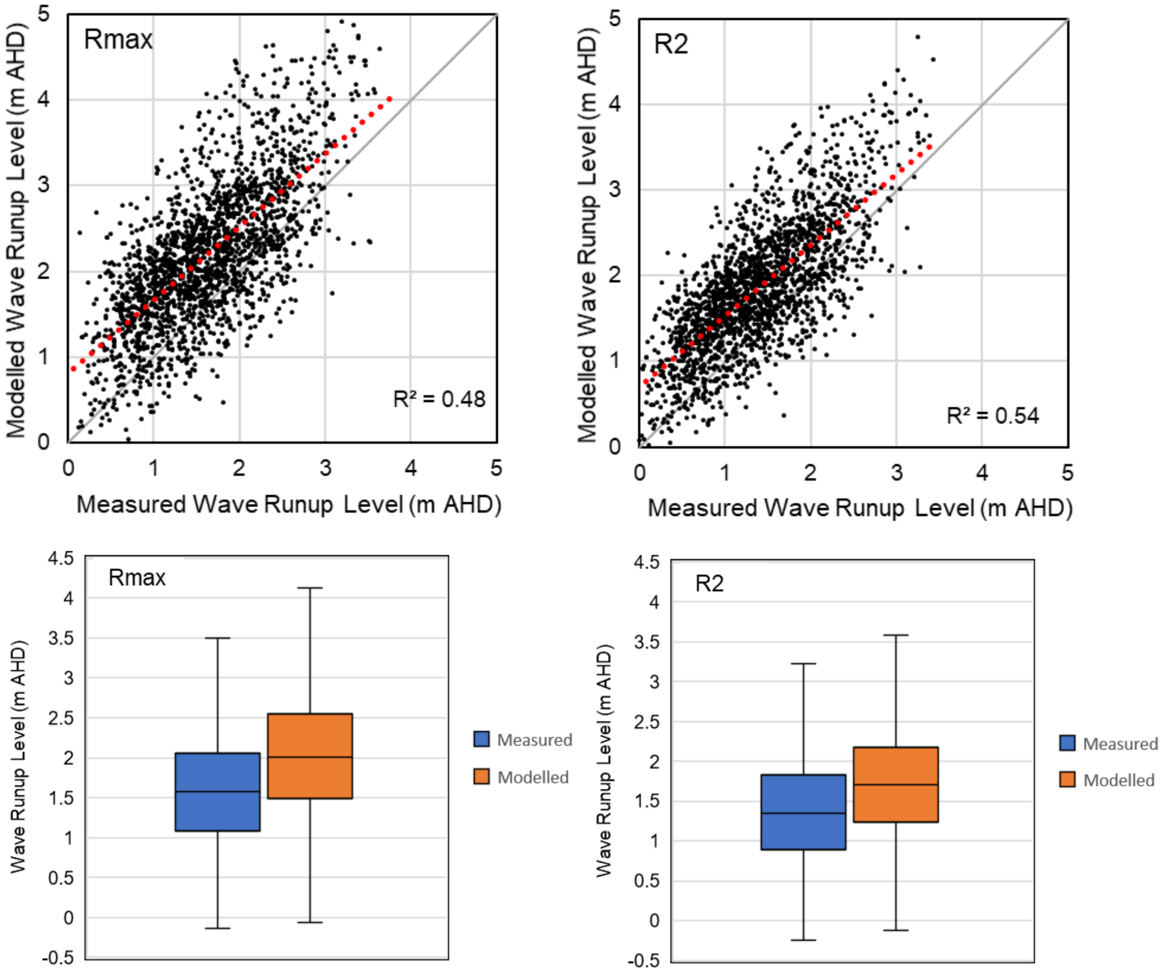


Figure 4.4: Measured and modelled wave runup levels

Limitations of the empirical wave runup technique are also noted. The Mase (1989) approach does not consider natural variations in beach slope that may impact wave runup, such as the presence of erosion scarps and berm crests in the upper swash. Nonetheless the model results show a suitable degree accuracy in predicting wave runup levels for the purpose of the present beach width amenity assessment.

4.3.2 Beach slope

The Mase equation was developed using a constant slope that stretched from the upper beach slope and continued offshore (Mase, 1989). From this analysis it can be inferred that the section of a beach slope which a wave physically interacts with should be selected as input for the Mase equation. This assumption was confirmed by Tucker et al. (2019) who used measured runup data to verify that the intertidal slope provided the most accuracy when simulating runup for Collaroy-Narrabeen Beach in Sydney. The beach slope used for runup calculations at Wamberal Beach was extracted between the seaward edge of the surf zone to the approximate high tide runup level calculated using from the NSW Marine LiDAR Topography-Bathymetry Dataset (NSW Government, 2018). Based on this analysis, a beach slope of 1V:20H was adopted for input into the Mase equation.

4.3.3 Wave data

Significant deep water wave height (H_{so}) and deep water wavelength (L_o) are used as inputs into beach width model. Offshore wave data is collected by Manly Hydraulics Laboratory at the Sydney Waverider buoy located 12 km offshore from Long Reef in Sydney in approximately 90 m water depth. Significant wave height (Hs), peak wave period (Tp) and wave direction (Dir) were extracted from the data at hourly timesteps for the 10-year study period from 2006 to 2016. Minor gaps in the timeseries were filled first using wave hindcast data for the buoy location from the Bureau of Meteorology, CSIRO, Centre for Australian Weather and Climate Research (CAWCR) WaveWatch III hindcast dataset. Remaining gaps less than 3 hours were linearly interpolated. Gaps greater than 3 hours were filled with Port Kembla direction data where available. Note that as with all measurements of natural processes, the wave data input still contains some minor gaps.

Hourly offshore wave data (Hs, Tp and Dir) was transformed to the nearshore -10 m AHD isobath at approximately 110 m alongshore intervals using nearshore lookup table coefficients generated from the NSW Nearshore Wave Tool (NSW Coastal Wave Model, 2017). This wave transformation tool was calibrated for offshore Hs up to 5 m and is used to forecast nearshore wave conditions along the NSW coast. Nearshore wave data (Hs and Tp) was interpolated along the -10 m isobath for each of the cross-sections shown in Figure 4.3 and was used as input parameters to calculate wave runup. When tide or wave data was not available (less than 1% of the time), data points for that hour were excluded from the analysis.

Deep water wavelength (L_o) was calculated from the nearshore wave period at the -10 m AHD isobath (T_{10}) using Equation 2. The nearshore (-10m AHD isobath) significant wave height can be projected offshore to a local equivalent unrefracted deep water wave height using a Padé approximation (as per Hunt, 1979) and determining the shoaling coefficient (as per USACE, 1984). Tucker et al. (2019) found that the nearshore (-10 m AHD isobath) significant wave height provided the best fit between the Mase equation and measured wave runup.

$$\boldsymbol{L_o = \frac{gT_{10}{}^2}{2\pi}} \qquad \textbf{(2)}$$

$where:$

$L_o = The\ deepwater\ wavelength$

$T_{10} = The\ nearshore\ wave\ period\ at\ the - 10\ m\ AHD\ isobath$

$\mathrm{g} = Acceleration\ of\ gravity$

4.3.4 Tide data

Tidal water levels were measured every 15 minutes at the Patonga tide gauge located approximately 15 km south west of the study site. Measured tide data was added to wave runup estimates to calculate beach width as shown in Figure 4.1.

4.3.5 Beach profile data

Measured elevation data of Wamberal Beach was extracted from the compiled dataset for input into the beach width model. Analysis of beach width was constrained to the 10 year period between 2010 to 2020 as this period included the most frequent and accurate beach surveys, which enhanced the accuracy of the beach width model. A total of 60 surveys were conducted by UNSW during this period using RTK-GPS mounted on a quadbike (monthly from 2011-2014), aircraft based LiDAR and drone surveys (see Section 3.2). As the model was run on an hourly timestep but measured profile datasets were collected at irregular intervals, the model used the newest available survey data for calculations until a newer profile superseded it. Beach profiles were extracted at each cross-section shown in Figure 4.3 and used to calculate beach width.

4.3.6 Seawall profile data

The model was simulated for the existing base case and four (4) scenarios as defined in Table 4.1. Profile data of the existing ad hoc rock protection (base case) was extracted from the July 2020 post storm survey when the rock was exposed and visible following erosion. The cross sectional alignments of each concept seawall design were provided by MHL at each of the transects used in the model as shown in Figure 4.5. Each seawall scenario stretches approximately 1.4 km between Terrigal and Wamberal Lagoon entrances. Detailed descriptions of the seawall options including concept design drawings and preliminary alignment are provided in *Stage 3 Seawall Concept Design Options (MHL2780, 2021)*.

Table 4.1: Model run descriptions. Seawall options from *Stage 3 Seawall Concept Design Options (MHL2780, 2021)*

Model run	Description
Base case	Beach width determined using a baseline profile defined by the eroded profile measured after the July 2020 storm, which comprises a mixture of ad-hoc rock protection and dune scarping.
Scenario 1	As per the base case except with a basalt rock revetement. (Seawall Concept Design Option 1 – Stage 3 Report)
Scenario 2	As per the base case except with a sandstone rock revetement. (Seawall Concept Design Option 2 – Stage 3 Report)
Scenario 3	As per the base case except with a vertical seawall. (Seawall Concept Design Option 3 – Stage 3 Report)
Scenario 4	As per the base case except with a vertical seawall with a rock toe. (Seawall Concept Design Option 4 – Stage 3 Report)
Scenario 5	As per the base case except with a tiered vertical seawall with a promenade. (Seawall Concept Design Option 5 – Stage 3 Report)

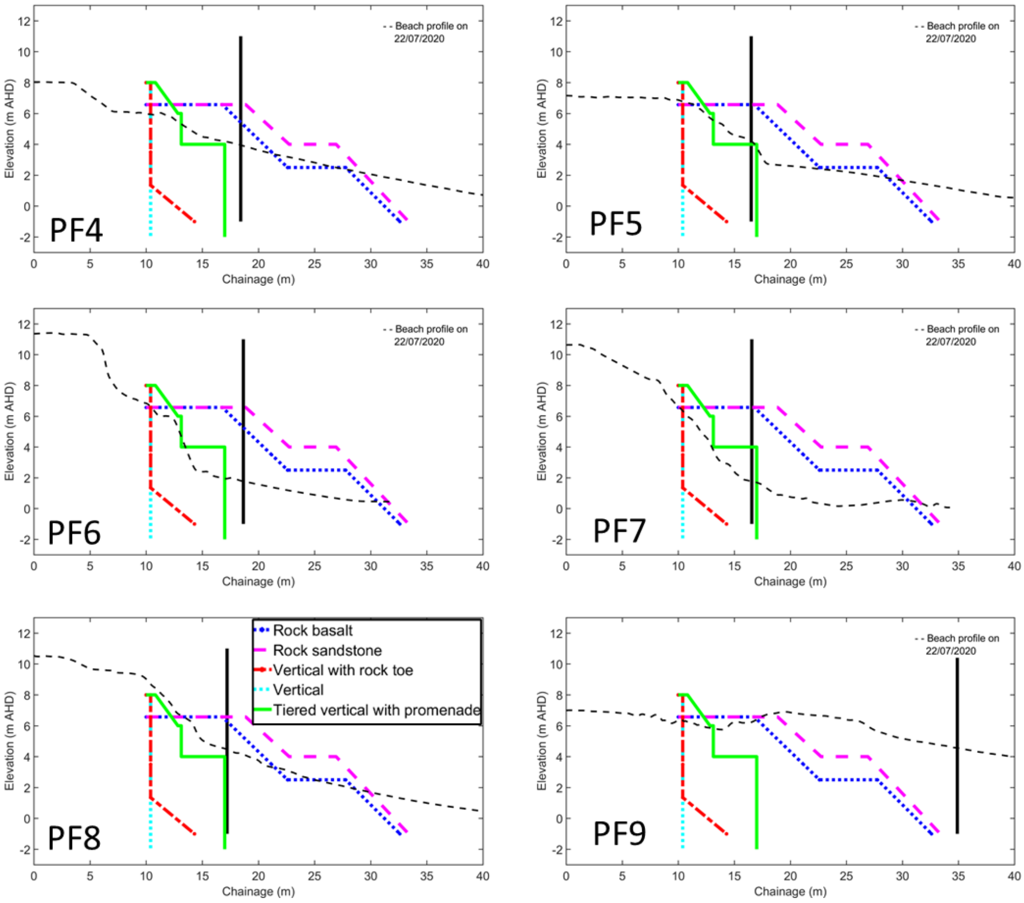


Figure 4.5: Comparison between base case (July 2020) and scenario seawall alignments

4.4 Beach width analysis results

The beach width model was run for each of the six profile locations for the 10 year period from 2010 to 2020. When tide or wave data was not available (less than 1% of the time), data points for that hour were excluded from the analysis. In depth results from the analysis are presented in Appendix A.

4.4.1 Base case: Existing beach

The model results for the base case (existing) are summarised in Figure 4.6 . As described in Section 4, a dry beach width of 5 m (above the wave runup limit) has been adopted as the minimum acceptable for amenity at Wamberal Beach. These results show the percentage of time that the existing beach was less than 5 m in width over the 10 year period for a model using the maximum wave runup height (Rmax) and the wave runup height that is exceeded by 2% of waves for a given period of time (R2%).

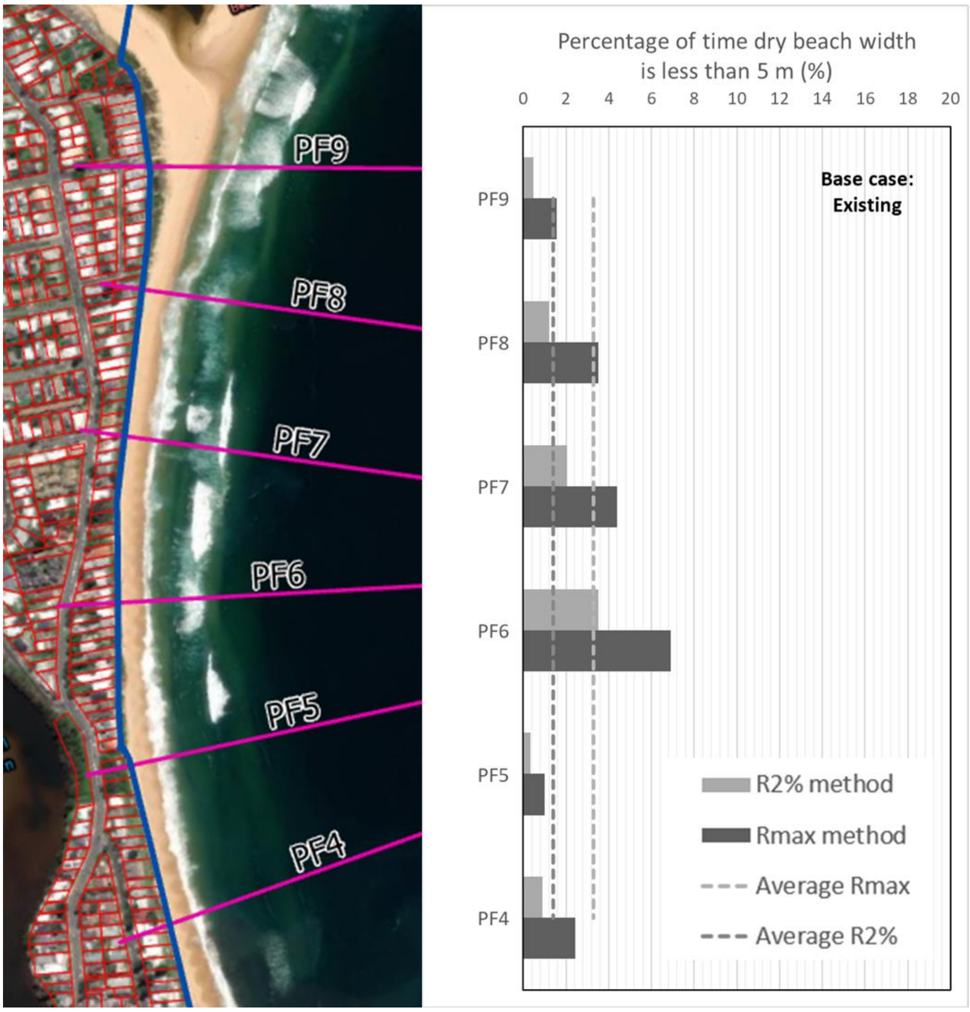


Figure 4.6: Percentage of time spent below 5 m beach width for existing scenario

The modelling identified alongshore variability in the results with a 'pinch point' in the centre of the beach (Profile 6 and 7) where the beach was less likely to maintain a 5 m dry beach width compared to locations further north and south along the beach. In this central region, the existing beach spent a higher proportion of time (approximately 3 – 7%) less than a 5 m width. At these locations, the results highlight the effect on beach width of existing rock protection encroaching further into the active beach profile. At other locations the percentage of time spent below a 5 m beach width was 2% or less. While the results varied alongshore, on average the existing beach spent approximately 3.3% of the time over the 10 year period less than 5 m in width using Rmax and 1.4% of the time when using R2%.

4.4.2 Profile by profile results

The beach width model was run for each of the four scenarios outlined in Section 4.1 incorporating concept designs for new seawalls including a basalt rock revetment, a sandstone revetment, a vertical seawall, a hybrid seawall and a tiered vertical seawall with promenade. The impact of the concept seawall designs scenarios on beach width amenity compared to the base case is shown in

Figure 4.7. If a seawall scenario model result is greater than the base case (i.e. to the right of the black line) this indicates that this scenario spends more time than the base case with a beach width less than 5 m. Conversely, if a model scenario result is less than the base case (i.e. to the left of the black line) this suggests that it spends less time than the base case with beach widths less than 5 m.

The results demonstrate that the introduction of the vertical seawall (Scenario 3 / 4) and the tiered vertical seawall with promenade (Scenario 5) had a positive impact on beach width amenity relative to the existing beach when the existing beach is fronted with an existing ad-hoc seawall. This occurs as the proposed alignment of these concept designs is generally situated landward of existing rock protection (to be removed during seawall construction) and dune scarping (i.e. further landward of the base case profile), therefore there would be less time with the beach widths less than 5 m. Conversely, the basalt (Scenario 1) and sandstone (Scenario 2) rock revetment designs were found to have a negative impact on the existing beach width amenity. The sandstone rock revetment concept design was estimated to have the most significant negative impact at profiles PF6 and PF7 where the beach was estimated to spend 13 to 19% more of the time less than 5 m in width compared to the existing case. At these locations, the existing rock protection already encroaches notably into the active beach zone (as indicated by the existing beach results in Figure 4.6) and concept rock revetment alignments encroach a further distance seaward. In contrast, at PF9 (Wamberal Beach SLSC) the crest of proposed rock revetment designs are buried within the existing foredune and the modelled impacts are substantially less.

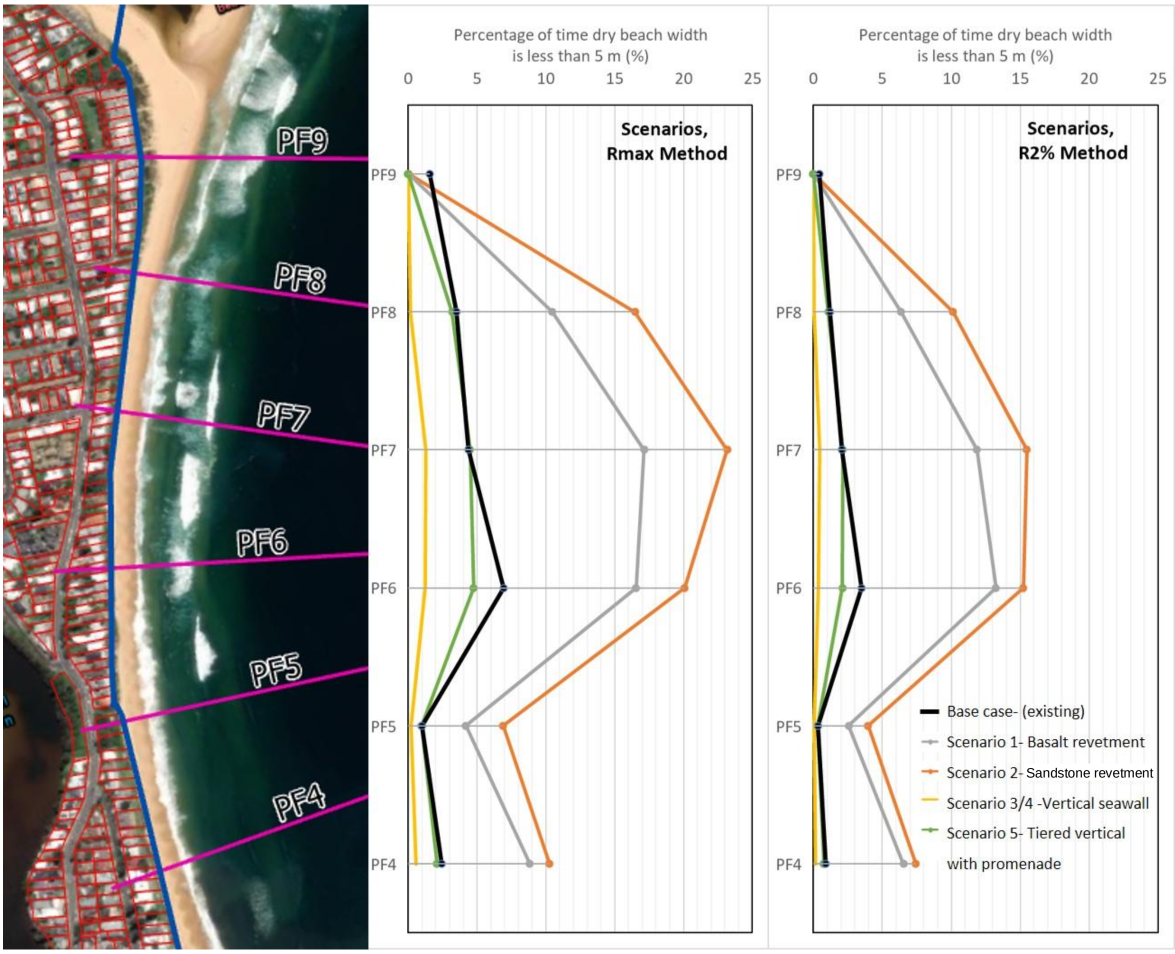


Figure 4.7: Percentage of time the dry beach width is less than 5 m

The vertical seawall (Scenario 3) and the vertical seawall with rock toe (Scenario 4) had identical model results as the design differences between these options are minimal and deep in the dune toe which do not influence beach width results. The tiered vertical seawall option (Scenario 5) was found to have a similar result to the existing case with minimal adverse impact, offering slightly more available dry beach width to alleviate the pinch point region at PF6.

4.4.3 Alongshore averaged results

The results of the model have been averaged alongshore to simplify comparison of impact of the designs on beach width amenity compared to the base case and are presented in Table 4.2. On average, the introduction of the new seawall designs for these locations was found to reduce beach width below the 5 m target by up to 9.5% (Scenario 2) of the time compared to the existing beach condition. With the basalt rock revetment (Scenario 1), the beach was estimated to be less than a 5 m width for an average of 6.2% more time over the 10-year period compared with the existing case. The vertical seawalls (Scenario 3 and 4) were the best performing design at maintaining beach width amenity, modelled to spend 2.7% less time narrower than 5 m compared to the existing case. On average, the tiered vertical seawall (Scenario 5) performed largely the same as the base case, in some sections providing slightly more available dry beach width at the “pinch point” areas in the middle of the beach than the base case. In addition to available dry beach width, it should be noted that the tiered vertical seawall with promenade also provides an alternative means of alongshore access at the “pinch points”, so that a temporarily narrowed beach would have less impact on community amenity.

Table 4.2: Alongshore averaged scenario results

Scenario	Percentage (%) of time spent below 5 m width			
	$R_{2\%}$	Difference in time from existing	R_{max}	Difference in time from existing
Existing	1.4	-	3.3	-
1. Basalt Rock Revetment	6.8	+5.3	9.5	+6.2
2. Sandstone Rock Revetment	8.7	+7.3	12.8	+9.5
3. Vertical	0.2	-1.2	0.6	-2.7
4. Vertical hybrid	0.2	-1.2	0.6	-2.7
5. Tiered vertical	1.1	-0.3	2.6	-0.7

5 Review of seawall and beach interactions

Overwhelming feedback obtained during community consultation (November 2020 and August 2021), highlighted the importance of natural amenity that Wamberal Beach provides to its users and the broader community. The following section provides a review of seawall and beach interactions including seawall end effects, frontal seawall erosion, sea level rise effects, impacts on surfing and beach amenity and other potential amenity implications of the proposed seawall concept designs at Wamberal Beach.

5.1 Seawall effects

Potential physical mechanisms for beach response in the vicinity of seawalls include:

- Sand trapping by the wall;
- Groyne/headland effect of the wall;
- Wave reflection and turbulence;
- Alongshore currents;
- Rips at structure ends; and
- Oblique wave reflections leading to mach stem waves.

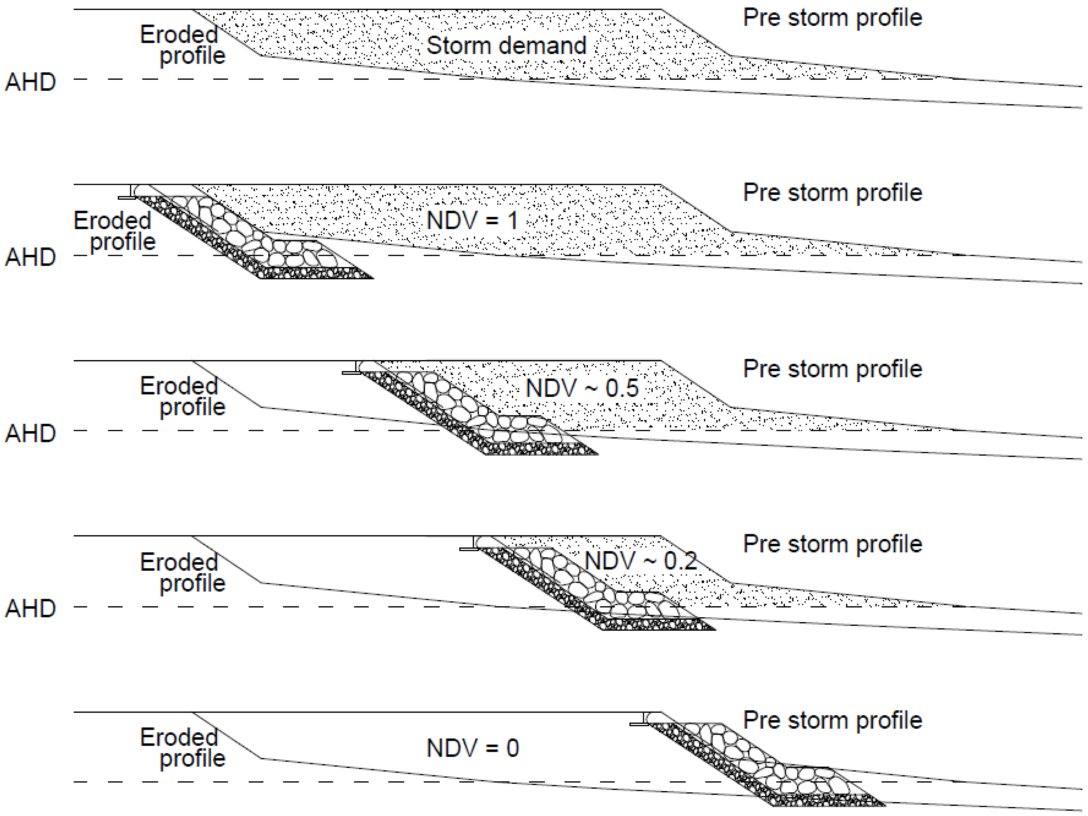
The interaction of seawalls with coastal processes is highly dependent upon their position within the active profile (Figure 5.1). When a seawall is situated more landward within the active zone of the beach profile, it impounds a smaller percentage of the beach volume and is less frequently exposed to swash and surfzone processes. On the contrary when located more seaward, a larger volume of sediment is trapped behind the wall and the structure is more frequently exposed to wave energy. Basco and Ozger (2001) discuss various applications in coastal engineering and defined the seawall trap ratio, WTR as:

$$\text{WTR} = \text{wall trap vol/active sediment vol} \quad (3)$$

Weggel (1988) presented six classifications of seawall dependent on their location within the active beach system (Figure 5.2). The intersection of the structure and beach profile may, however, change over time as beach level and position change. This is particularly relevant on long-term receding beaches where a seawall, originally built as a back-stop wall may, in time, move relatively further into the active beach zone, impound relatively more sediment and induce greater beach response. Many seawalls may encompass all six categories during their design life. (Carley et al., 2015)

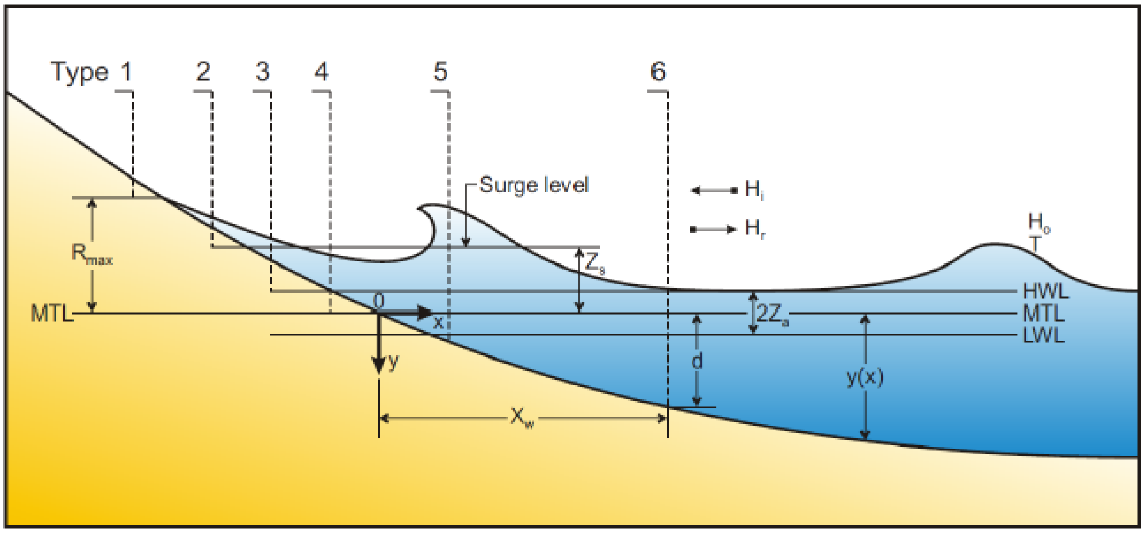
A summary of field investigations comparing beach responses at locations with and without seawalls are shown in Table 5.1. Beaches with seawalls in the active zone have been observed to erode more rapidly than natural beaches (e.g., Griggs et al.,1994), with flanking erosion effects at adjacent unprotected beaches (e.g., Griggs et al.,1997) and in some cases, higher losses in regions seaward of the structure (Basco et al.,1997; Mossa and Nakashima 1989). Methods of quantifying these effects are discussed in the following sections.

It is important to note in Table 5.1 that observations of erosion on seawalled beaches were often found to be followed by sufficient beach recovery such that the effects of seawall-beach interaction during storms were temporary and completely recovered with time (Griggs, 1990; Griggs et al., 1991; 1994; 1997; Basco et al.,1997; Mossa and Nakashima 1989). Griggs et al. (1997) observed minimal differences in beach recovery and the shape of time-averaged beach profiles on seawall and control beaches (without seawalls) over 8-years of measurements at Monterey Bay California. Similarly, Basco et al. (1997) found that seawalled beaches typically recovered in the same time as beaches without a seawall, with some differences after certain storms of differing durations and magnitudes (north-easters verses hurricanes). Longer-term recession induced by seawall interactions (active erosion) as opposed to background recession (passive erosion) remains unsubstantiated by sufficient field evidence in the literature.



From Carley et al. (2015) NDV = non-dimensional volume = 1 – WTR

Figure 5.1: Position of seawall on profile relative to design erosion



(Source: Weggel, 1988)

Figure 5.2: Weggel seawall position classification

Table 5.1: Summary of field investigations of beaches with and without seawalls

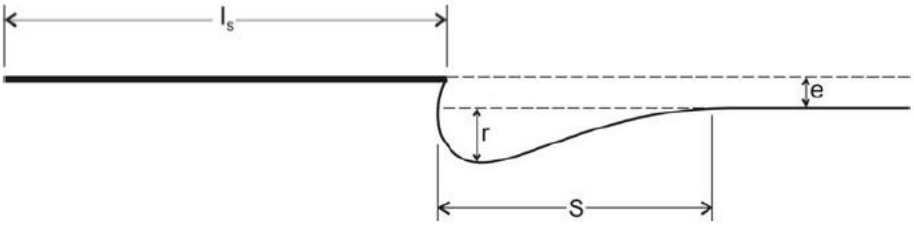
Selected Reference	Location	Observations of Seawall and Beach Interactions (Beaches with seawall compared to beaches without structures)
Griggs (1990); Griggs et al. (1991; 1994; 1997)	Monterey Bay, California	• Observations on long-term stable coast. • Faster berm cut during storms fronting seawalls located closest to shoreline. • Temporary flanking erosion at one end of seawall extending 150m downdrift (%50 of seawall length). • No evidence of disrupted beach recovery. Initial recovery sometimes more rapid fronting seawall. Uniform recovery of berm once end-effect cuts had filled in. • Minimal variation in shape of time-averaged (8-years) accreted and eroded beach profiles for seawall and control beaches. • No significant difference between beach profile changes for vertical and sloping structures of higher permeability.
Basco (1990) Basco et al. (1992; 1997; 2006)	Sandbridge Virginia	• Observations on long-term receding coast (1.1 – 2.9 m/year). • Construction of seawalls did not increase average recession rates. • Beaches recovered in similar time with some differences following storms of differing durations and magnitudes (north-easters vs hurricanes). • Volume erosion rates over ten years (negative regression slopes) were not higher in regions in front of seawalls than at beaches without seawalls.
Pilkey and Wright (1988), Hall and Pilkey (1991)	New Jersey, North Carolina and South Carolina	• Dry beach width (between high water line and seawall/dune/vegetation line) statistically narrower fronting seawall. • No details whether narrowing was induced by the seawall (active) or due to ongoing recession (passive).
Mossa and Nakashima (1989)	Fourchon, Louisiana	• Higher volume loss and higher recovery fronting seawall following Hurricane Gilbert.
Jayappa et al. (2003)	Southern Karnataka, India	• Difficult to assess interactions due to numerous additional factors including large-scale shore normal structures, high longshore sediment transport, rock outcrops and significant sand mining.
Miles et al., (2001)	Teignmouth, South Devon (UK)	Short-term field measurement campaign • Higher measured wave reflection coefficients, suspended sediment transport concentrations and longshore sediment transport rates fronting seawall.

<u>Implications for proposed seawall options at Wamberal Beach</u>

- Proposed seawall structures have been aligned as far landward as practical to minimise encroachment into the active beach profile and impacts on public beach amenity, while maintaining uniformity of alignment within the constraints of adjacent properties and setback requirements. In the north where a wider beach is present, the proposed alignment gradually transitions landward of the active beach zone to minimise encroachment.

5.2 Seawall “end effect” erosion

It is well accepted that seawalls in the active beach zone have alongshore effects, often termed the end effect. After seawall construction, sand trapped behind the wall is not available for mobilisation and transport offshore and to adjacent beaches during and after storm events (Dean, 1986). This results in excess erosional stress on unprotected adjacent beaches (CEM, 2006). Methods to predict the alongshore length of end erosion adjacent to seawalls include both linear and non-linear equations based on the alongshore length of the structure (McDougal et al. 1987 and Shand, 2010).



(Source: McDougal et al, 1987)

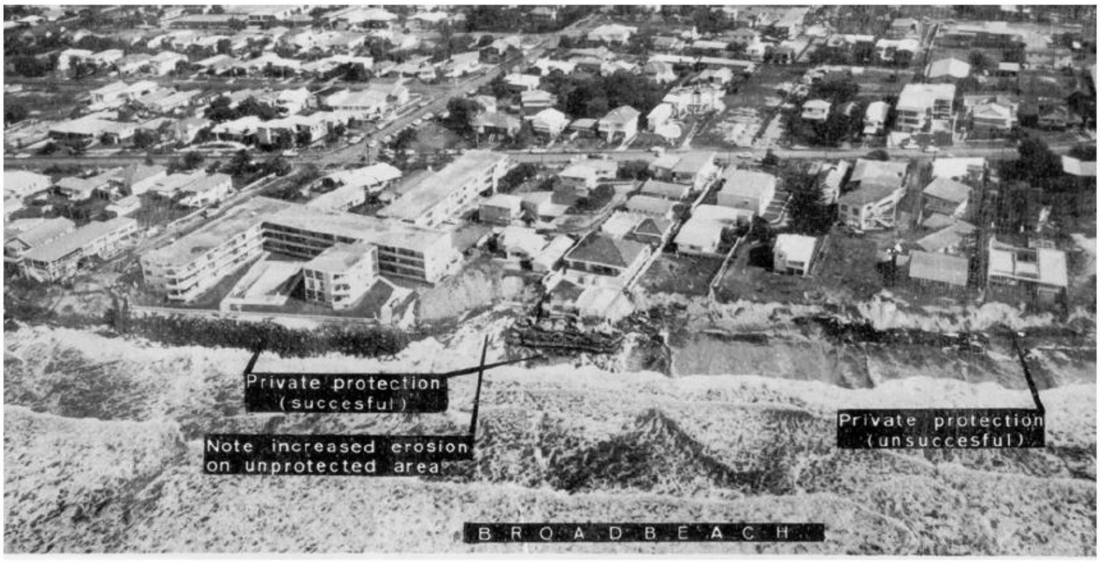


Figure 5.3: Seawall end effect (Gold Coast. 1967, Source: Delft, 1970)

A review by Carley et al. (2013) found that where a seawall does not substantially protrude into the surfzone (as a long-term groyne or artificial headland), the maximum end effect is limited to around 400 m alongshore from the structure. Carley et al. (2013) suggested that the following relationship be used:

$$S = 100 + 0.60\,Ls \text{ (maximum } S = 400\text{ m)} \quad (4)$$

$$AE = (1 - NDV) * SD \quad (5)$$

where:

S is the alongshore extent of end effect;

Ls is the length of the seawall;

NDV is the available sand volume seaward of a seawall divided by the storm demand

as shown in Figure 2.1;

AE is the expected additional erosion

SD storm demand.

End effect impacts of a seawall are reduced when situated further landward in the active beach region and may differ depending on local site characteristics such as backshore rock outcrops, headlands, lagoon entrances, rock shelfs and other factors which also control shoreline configuration within an embayment.

Implications for proposed seawall options at Wamberal Beach

- End effects are reduced for structures aligned further landward in the active beach region. Traditional end effect impacts will not apply as the proposed seawall at Wamberal Beach will be a contiguous structure extending from Terrigal Lagoon to Wamberal Lagoon. Potential end effects are unlikely to affect other developed areas along the beach. Termination of the structure at either end will transition landward of the active beach region, with minimal end erosion effects expected for vertical seawall options (Options 3 to 5). Higher encroachment of the rock revetment structures (Options 1 and 2) in the active beach at the southern end may result in slightly higher sand losses in the vicinity of Terrigal Lagoon during storm events that expose the end of the seawall to wave action. This region is also governed by dynamic lagoon entrance processes, a rocky backshore to the south and the Ocean View Dr Bridge constriction to the west such that traditional end erosion estimates are not applicable.

- Specifics of termination design at lagoon ends are subject to detailed design with further design consideration to be given to minimise impacts on coastal and lagoon entrance processes. Review of the former 1998 termination ends is provided in the *Stage 3 Seawall Concept Design Report (MHL2780, 2021).*

5.3 Seawall frontal erosion

In comparison, the cross-shore effects of seawalls in the active beach zone are less well substantiated. Dean (1986) suggested that excess erosional stress along the front of the structure produces a defined scouring of the level of bed fronting the seawall as shown in Figure 2.2. Dean (1986) proposed the “approximate principle” relating the volume of toe scour at a wall to the volume that might be potentially scoured in the absence of that wall (Figure 5.4).

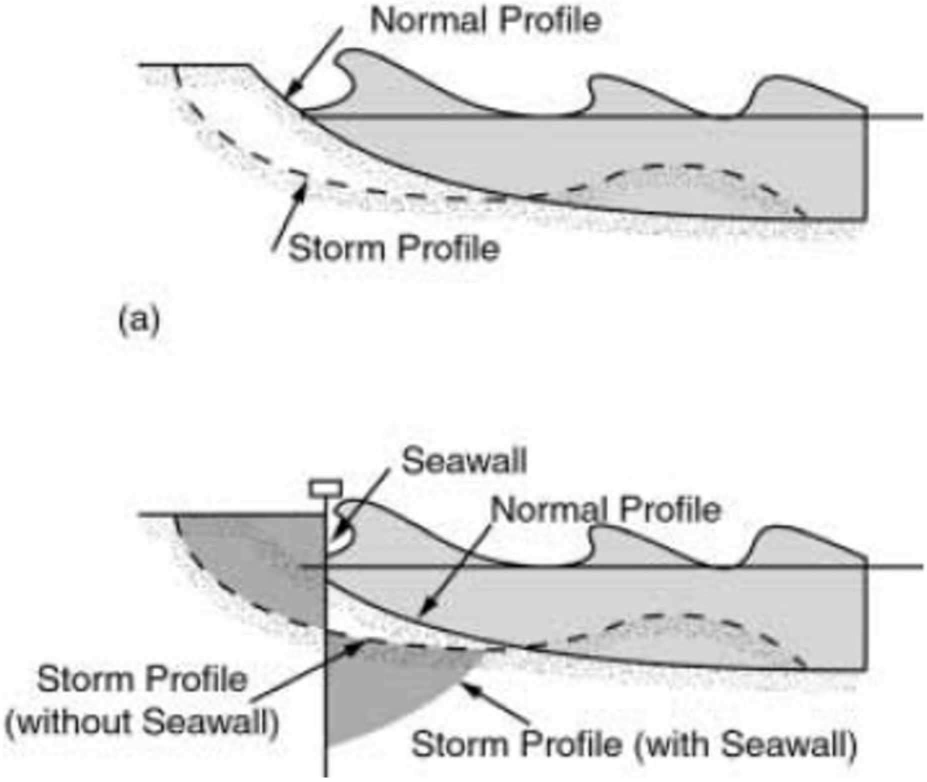


Figure 5.4: Dean approximate principle

This principle was verified in small and mid-scale physical model testing (Barnett et al. 1988; Hughes and Fowler,1990; Miselis, 1994) some of which found that the additional eroded volume was only 60% of the theoretical amount. However, field evidence of this degree of frontal scour remains unclear from studies listed in Table 5.1; probably because any such effects are quickly re-distributed along and across the beach and such three dimensionalities are not accounted for in the physical models cited. Scaling of sediment dynamics in most small to medium physical model tests is often limited and results should be primarily considered qualitative (Kraus and McDougal, 1996).

Kraus and McDougal (1996) suggested that the approximate principle will not necessarily apply in cases where the profile is in near equilibrium and no demand is made for sand to move out of the profile. Kraus (1988) suggested a general rule that limiting scour depth is a function of the deep water wave height.

More recent studies by Sutherland et al. (2007) have combined existing datasets of scour in front of vertical or sloping seawalls with new laboratory experiments to derive equations representing scour depth at the structure toe and maximum across-profile scour depth. Scour depths were found to vary as a function of relative water depth with a maximum toe scour depth on sandy beaches predicted not to exceed a function of the deep water significant wave height in agreement with Kraus (1988).

It should be noted that relationships developed by Sutherland et al. (2007) are based on values derived in small to medium scale laboratory tests following single storm events from an assumed initial profile and are likely to be subject to scale effects. These give plausible scour depths for open coast Australian situations if the local depth limited wave height is used for Hs, however, the use of deep water Hs (as suggested in Sutherland et al. 2007) gives implausibly large scour depths. Foster et.al. (1975) observed maximum scour levels along Sydney's northern beaches during major storms in 1974 to be approximately 2 m below mean sea level fronting some seawalls and that this was up to 1 m lower than other areas without seawalls, although these observations were subject to several other influencing factors. Carley et al. (2015) proposed calculation of scour based on site specific coastal processes including storm demand underlying recession and recession due to sea level rise. Design scour for seawall concept design option development at Wamberal Beach is provide in *Stage 3 Seawall Concept Design Options (MHL2780, 2021)*.

5.3.1 Vertical versus sloped seawalls

Differences in scour fronting vertical and sloping seawall designs are also noted in the literature. In the Shore Protection Manual (1984) sloping seawalls are said to experience reduced scour due to better energy dissipation. In contrast, the Coastal Engineering Manual (2006) states that scour is less dependent on wave reflection and more so on local sediment transport gradients and wave overtopping. In NSW, a scour level of -1 m AHD is commonly adopted as an engineering rule of thumb for seawalls located at the back of the active beach area, with 2 m AHD frequently adopted for vertical seawalls based on stratigraphic evidence of historical scour along the NSW coast (Nielsen et.al., 1992; Foster et.al., 1975). Despite this, no significant difference in beach profile changes between vertical and sloped seawall locations was observed in long-term field measurement studies by Griggs et al. (1991; 1994; 1997).

An important consideration in determining the impact of any type of seawall is its cross-shore alignment or positioning within the active beach region (as described in Section 5.1). For example, a vertical seawall aligned at the crest or landward of a sloped seawall will likely result in less frontal scour due to a reduced encroachment into the active beach (and vice versa with a sloped revetment aligned more landward than a vertical seawall). When a seawall is located at the landward extent of the active beach profile, any frontal scour effects are often temporary, occurring only during major storms in sections of the seawall exposed to waves. With the return of mild wave conditions, these regions gradually fill back in with natural beach recovery processes, such that for most of the time the seawall is fronted by a sandy beach. Beach recovery fronting seawalls is discussed further in Section 5.5.

Implications for proposed seawall options at Wamberal Beach

- Proposed seawall structures have been aligned as far landward as practical to minimise encroachment into the active beach profile and reduce the potential for frontal erosion. Any erosion induced by the seawall structure on the beach fronting the seawall is likely to be limited in extent and duration – occurring during instances when the beach is eroded by major storm waves and sections of the seawall are exposed to waves. This effect is mitigated by a more landward cross-shore position of a vertical seawall within the active beach profile, such that natural beach recovery processes will subsequently rebuild these regions following a storm, with minimal longer-term impact on beach morphology.

5.4 Sea level rise (SLR) effects with seawalls

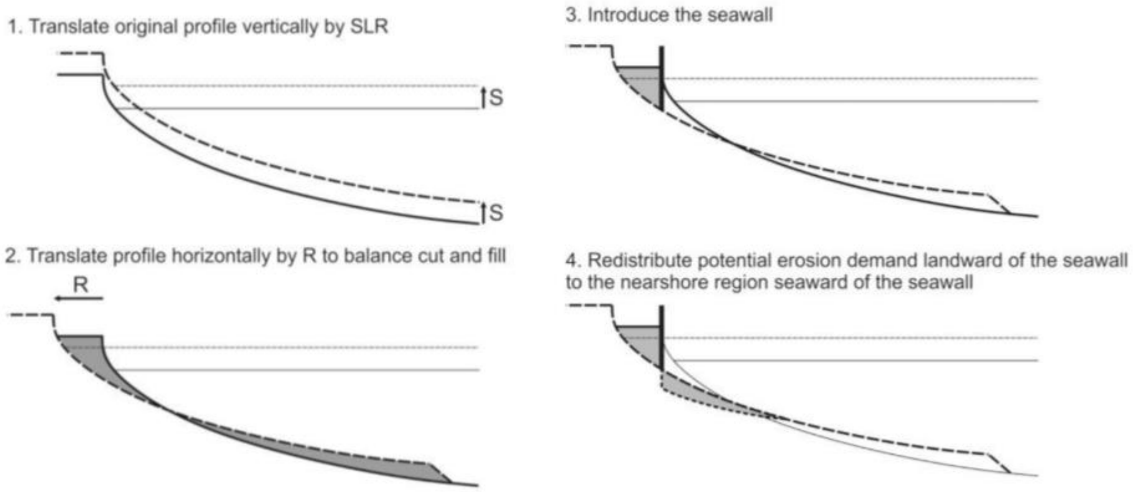
The Bruun Rule is the most widely accepted method to account for profile recession due to sea level rise (SLR) (Bruun, 1962). It assumes that an equilibrium profile is maintained during SLR and that the profile rises and shoreline recedes with increasing water levels. The following equation is now widely used for predicting shoreline recession R (m),

$$R = S\,L/(B+h) \qquad (6)$$

where S is the vertical height of SLR, L is the length of the active profile, B is the berm height and h the depth of closure.

It is noteworthy that onshore transport of inner shelf sands that is known to have occurred along the NSW coast since the last glacial period (when sea levels were much lower than present) is not accounted for in the Bruun rule.

Few studies have investigated the seawall and beach interactions due to sea level rise. A recent physical model study by Beuzen et al. (2018) investigated beach profile evolution due to sea level rise in the presence of seawalls. It was found that the erosion demand due to a rise in water level was similar for cases with and without seawall structures (including vertical and sloped rubble mound). The presence of a seawall was observed to concentrate this erosion due to water level rise in regions just offshore of the structure causing localised lowering of the profile. Little differences in profile response was observed between vertical and rubble mound seawall test cases (implying benefits of vertical walls with inherently reduced footprints and more landward proximity). The study proposed a method for estimating profile change to water level rise in the presence of seawalls based on redistribution of erosion calculated using a simple profile translation model shown in Figure 5.5.



From Beuzen et al. (2018)

Figure 5.5: Sea level rise with seawalls

Implications for proposed seawall options at Wamberal Beach

- Sea level rise has been addressed in the development and adaption of seawall concept designs (Stage 3) and investigation of beach nourishment requirements to maintain beach amenity into the future for each of the seawall options (Stage 4).
- The provision periodic beach nourishment (see Stage 4 report) is considered important in mitigating effects of sea level rise and maintaining a desired level of beach amenity into the future.

5.5 Beach recovery rates fronting seawalls

Beach recovery is the natural return of beach morphology back to pre-storm conditions following the impact of a storm. It is often described as a post-storm process of restoration, rebuilding or resilience (e.g., SPM, 1984; Morton et al., 1994; Masselink and van Heteren, 2014).

Table 5.2 shows recovery rates reported from studies (updated from Couriel et al., 2016) on beaches on the eastern Australia coastline including estimates for Wamberal Beach. Beach recovery can be measured in different ways, most typically by a rate (or duration) of return of the shoreline (beach width) or subaerial volume back to pre-storm conditions following a storm, driven by wave processes. Studies have also reported dune recovery rates driven by aeolian (wind) processes which are typically much slower, taking several years to 1-2 decades to re-establish. Following extreme erosion that occurred along the NSW coastline in May-June 1974, the recovery of subaerial volume at Bengello Moruya to a pre-storm value took several years to complete while dune re-establishment was not noted until roughly two decades after the storm (Thom and Hall, 1991; McLean and Shen, 2006).

Table 5.2: Beach recovery rates reported for Eastern Australia

Site	Average shoreline recovery rates (m/day)	Average subaerial volume recovery rates (m^3/m/day)	Average dune elevation recovery rates (m/year)	Reference
Collaroy-Narrabeen	0.1 (range 0.07 – 0.14)	0.28 (0.1 – 1 +)	0.1 – 0.2	Phillips et al. (2015; 2017; 2018)
Bilgola		0.21 (0.13 – 0.30)		Phillips (2018)
Mona Vale		0.16		Phillips (2018)
Long Reef – Dee Why		0.30 (0.14 – 1+)		Phillips (2018)
Bengello (Moruya/Broulee)		0.27 (0.12 – 0.42)	0.13	Thom and Hall (1991) McLean and Shen (2006)
Surfer Paradise, Gold Coast		0.40		Carley et al. (1998)
Gold Coast	0.04 – 0.1			Splinter et al. (2011)
Wamberal Beach	*0.1*[a]	*0.3*[a]	*0.05 – 0.15* [b]	[a] *Harley et al. (2017): Based on 6-month period following June 2016 storm for Terrigal-Wamberal embayment.* [b] *Estimated based on gradual foredune regrowth in dunes north of Wamberal Lagoon since 1974 storm erosion using NSW Beach Profile Database (Stage 4 Report)*

Recent studies by Phillips et al. (2015; 2017; 2018; in press) quantified and investigated parameters driving beach recovery at Collaroy-Narrabeen Beach. Much of this work was undertaken at sections of the beach with existing rock protection at the back of the active beach profile, that was in some cases temporarily exposed to wave action during storm activity as shown in Figures 2.4 and 2.5.

Using 10 years (2004 – 2015) of daily shoreline measurements along 400m of beach immediately north of Wetherill St, it was found that despite temporary exposure of existing rock protection to wave activity during certain storm events, the beach consistently recovered to a pre-storm width (in excess of 20 m) over the study period at net rates between 0.07 to 0.14 m/day. As such any impacts of the existing rock protection, located at the back of the active beach profile, on the width of the beach during storms were observed to be temporary and were subsequently restored by natural beach recovery processes.

An example of this is shown in Figure 5.7, depicting the erosion during a storm in June 2007 and initial 10 months of recovery following. The images show the progressive return of beach width and rebuilding of the berm that reburies the lower portion (below approximately 2 – 3 m AHD) of the existing rock protection. However, note the removal of nourished sediment by the storm in the upper profile at higher elevations that does not recover (being dependent on slower aeolian processes).

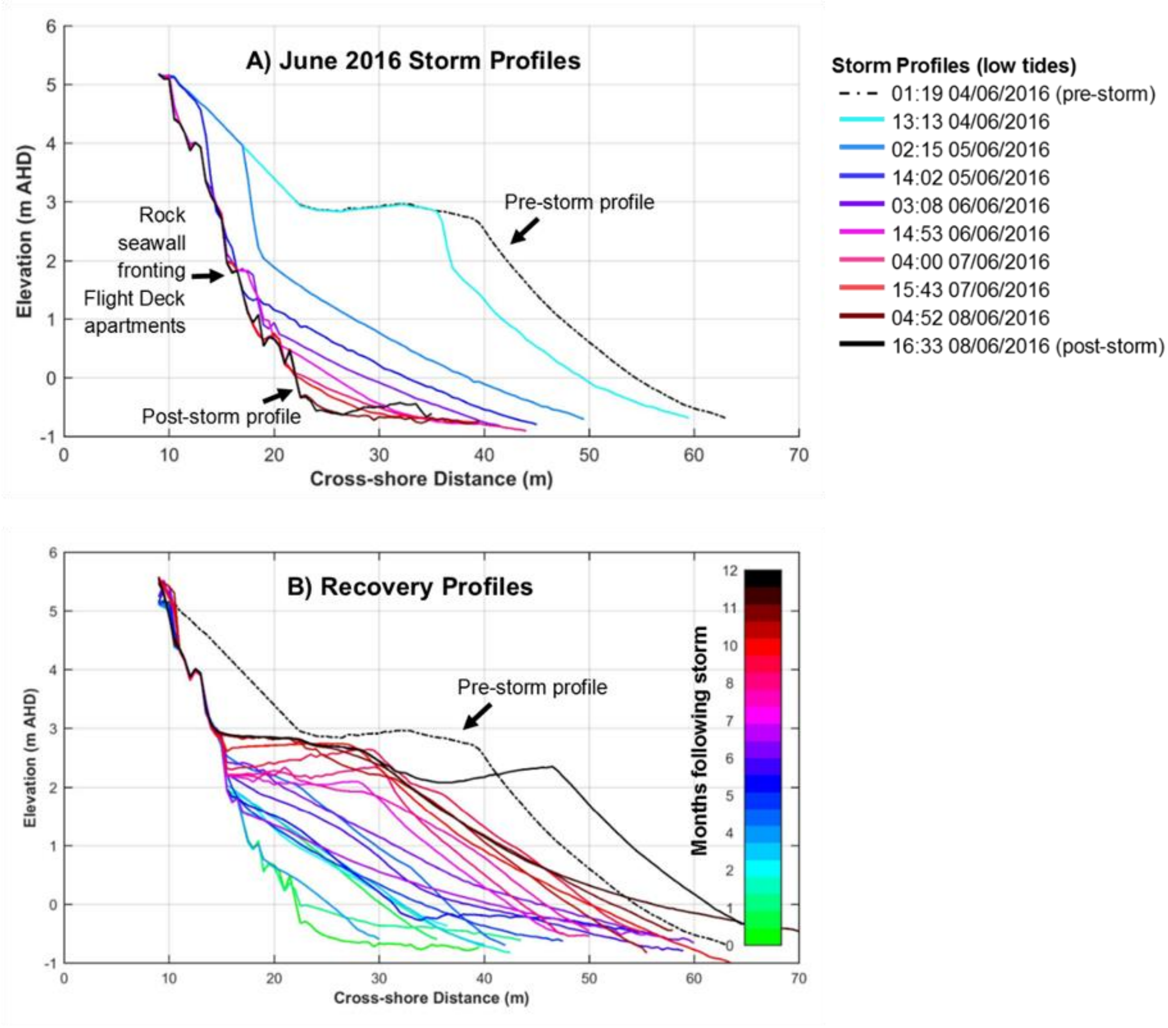
Once sediment returns to the shoreline, swash processes rework this sediment up onto the subaerial beach to rebuild the berm as shown in Figure 5.7. A high-frequency scanning LiDAR at Collaroy Beach at Fight Deck Apartment Building was used to capture this process investigating tide-by-tide recovery following a storm in April 2015 (Phillips et al. 2018; 2019). Principal modes of berm recovery were classified based on ocean water level and nearshore wave conditions as the beach built back to its pre-storm state over the months following the storm.

Observations from the LiDAR during and after the June 2016 storm when the rock seawall fronting Flight Deck apartments was exposed are shown in Figure 5.6. Significant wave reflection off the face of the seawall was observed over the course of the storm event. A scour of the beach profile at the base of the rock wall between elevations from 1 m AHD down to -0.5 m AHD is shown over the latter half of the storm, occurring at a rate of approximately 0.4 to 0.1 m^3/m/h. This scour gradually declined to minimal as the storm subsided and then filled back in with initial wave-driven beach recovery processes at rates of approximately 0.1 – 0.2 m^3/m/day in the initial 1 – 2 months following the storm. Within 12 months after the storm, the berm had recovered beyond its pre-storm width, approximately 30 m landward of the rock wall and to a height of 2 to 3 m AHD. However, the volume in the upper beach profile lost during the storm was yet to recover, dependent on slower aeolian recovery processes (also seen in Figure 5.7).

Estimated rates of beach recovery for Wamberal are provided in Table 5.2. Shoreline and volume recovery estimates were based on alongshore average observations for the Terrigal-Wamberal embayment reported by Harley et al. (2017) over a 6-month period following June 2016 storm for Terrigal-Wamberal embayment. This average includes rates of recovery fronting sections of beach with seawalls (Terrigal), lagoon entrances as well as ad-hoc rock protection and dune scarping (Wamberal). No detailed assessment of alongshore variability in beach recovery rates between these sections has been undertaken for the Terrigal-Wamberal embayment.

Implications for proposed seawall options at Wamberal Beach

- With the seawall align as far landward as possible in the backshore of the active beach profile, natural beach recovery processes following storms are expected to remain unimpacted by the presence of a seawall. With reduced encroachment compared to existing ad-hoc rock protection for the vertical seawall options (Options 3 to 5), the beach may recover more quickly to condition allowing sunbathing and alongshore access to satisfy its users.
- Any interactions of the seawall with the beach profile during storms are likely to be temporary and subsequently restored by natural (more gradual) beach recovery processes, with minimal longer-term impact on beach morphology.
- Often beach recovery processes go unnoticed in terms of public perception compared to more drastic, vivid and publicised impacts of storm erosion. However, it is these recovery processes that allow sandy beaches and seawalls to coexist when seawalls are aligned at the landward extent of the active beach region. Such is the case for a vast majority of seawalls located on the south east coast of Australia (Table 5.3).



Note: Fixed LiDAR observations of (a) storm erosion and (b) beach recovery fronting rock protection at Flight Deck apartments, Collaroy-Narrabeen Beach during the June 2016 storm

Figure 5.6: Observations of storm erosion and beach recovery fronting rock protection

Note: Beach recovery and the return of shoreline and berm morphology to pre-storm conditions following storm erosion at Collaroy-Narrabeen Beach in June 2007. Images taken at approximately mid to low tide. From Phillips (2018).

Figure 5.7: Beach recovery at Collaroy-Narrabeen Beach in June 2007

5.6 Surfing and beach amenity interactions

A list hast been developed by the authors of all known seawall structures on the open coast of south-east Queensland and NSW, together with a small number of international examples as shown in Table 5.3. This list is not exhaustive, and excludes breakwaters, training walls and groynes. Some of the structures listed are substantial whole of embayment structures, while others are subtle enhancements of the transition between natural headlands and beaches.

The following criteria were considered based on the broad awareness of the authors, without detailed literature review or interviews:

- Status as a World/National Surfing Reserve;
- Prevalence of major surfing contests (regional, state, national, international)
- Prevalence of recreational surfing
- Prevalence of surf life saving activities
- Prevalence of beach tourism
- Publicised issues, particularly regarding beach amenity or surfing impacts

Of the 91 sites considered, two to six are known to have well publicised issues, namely:

- Belongil, Byron Bay: Predominantly alongshore beach access issues when the beach is eroded, noting that underlying recession rates are approximately 0.8 m/year (Carley et al, 2017)

- Brooms Head: Narrow sandy beach width due to seaward alignment of seawall and receding beach (Carley et al, 2000)
- Stockton: Alongshore access and use of beach for surf life saving, noting seaward alignment of seawalls and underlying recession rates of approximately 1 to 2 m/year (NCC, 2020)
- Collaroy-Narrabeen: Predominantly alongshore beach access issues when the beach is eroded, noting that underlying recession rates are close to zero, and new seawalls are proposed to be more landward than existing ones
- Warilla Beach: The southern end of this beach is narrow at times, however, additional stabilisation with training walls at each end, together with a promenade on the seawall crest has reduced the severity of issues compared with 30 years ago
- Caseys Beach, Batemans Bay: Narrow sandy beach width due to seaward alignment of seawall (Coghlan et al, 2017)
- Malibu, California, USA: Predominantly alongshore beach access issues when the beach is eroded

Note that there are no widespread reports known to the authors of a deterioration in surf quality being attributable to the seawalls listed, noting that entry and exit to/from the water may be compromised for swimmers/surfers when waves are impacting the seawalls.

The following factors contribute to the low surfing impacts of most of these seawall structures:

- Most structures are set back and are only impacted by waves during eroded beach conditions, large waves and high tides
- Except during small swells and high tides, surfing takes place well offshore from the shoreline and any structures at the back of the beach
- Boulder structures have similar wave reflection characteristics to sandy beaches, noting that reflected waves may not necessarily be detrimental to surfing

Table 5.3: Examples of renowned surf breaks or beaches coexisting with seawalls

	Location	Notes	World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	Queensland							
1	Noosa	Renowned point break Buried rock rubble covered with sand most of the time through nourishment program	✓	✓	✓	✓	✓	
2	Coolum	Near vertical seawall		✓	✓	✓	✓	
3	Alexandra Headland	Near vertical seawall		✓	✓	✓	✓	
4	Maroochydore	Geobag seawall and groynes			✓	✓	✓	
5	Mooloolaba	Near vertical seawall, geobags			✓	✓	✓	
6	Moffat Head Caloundra	Rock boulders		✓	✓	✓	✓	
7	Kings Beach Caloundra	Near vertical seawall, ocean pool			✓	✓	✓	
8	Almost all Gold Coast beaches, with iconic sites below	~30 km of A-line boulder wall Predominantly buried with sand nourishment	✓	✓	✓	✓	✓	
9	Burleigh	A-line boulder wall	✓	✓	✓	✓	✓	
10	Currumbin	A-line boulder wall	✓	✓	✓	✓	✓	
11	Kirra	A-line boulder wall	✓	✓	✓	✓	✓	
12	Greenmount	A-line boulder wall	✓	✓	✓	✓	✓	
13	Snapper Rocks-Rainbow Bay	A-line boulder wall	✓	✓	✓	✓	✓	

	Location	Notes						
			World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
14	Kingscliff	Vertical concrete, boulder wall, stepped concrete			✓	✓	✓	
15	Byron Bay, Belongil	Boulder wall, geobags			✓	✓	✓	✓
16	Byron Bay, Jonson St	Boulder wall, Mini Kirra surf break next to groyne and seawall			✓	✓	✓	
17	Byron Bay, Wategos Beach	Boulder wall			✓	✓	✓	
18	Lennox Head	Boulder wall away from main surf break, buried wall at Lake Ainsworth	✓	✓	✓	✓	✓	
19	Yamba Main Beach	Boulder wall, grouted rocks, ocean pool			✓	✓	✓	
20	Brooms Head	Boulder wall					✓	✓
21	Arrawarra	Indigenous fish traps, boulder wall			✓		✓	
22	Nambucca Heads	Boulder wall			✓	✓	✓	
23	Scotts Head	Boulders			✓	✓	✓	
24	South West Rocks	Stepped sandstone			✓	✓	✓	
25	Crescent Head	Boulders	✓	✓	✓	✓	✓	
26	Point Plomer	Indigenous fish traps			✓		✓	
27	Port Macquarie, Town Beach	Boulders, vertical concrete		✓	✓	✓	✓	
28	Flynns Beach	Vertical concrete, boulder wall			✓	✓	✓	
29	Shelly Beach	Boulders			✓		✓	
30	Rainbow Beach, Bonny Hills	Geobags		✓	✓	✓	✓	
31	Black Head Hallidays Point	Boulders, ocean pool		✓	✓	✓	✓	
32	Forster	Vertical concrete, ocean pool		✓	✓	✓	✓	
33	Seal Rocks	Boulder wall		✓	✓		✓	
34	Anna Bay	Boulder wall		✓	✓	✓	✓	
35	Stockton	Boulder wall, geobags		✓	✓	✓	✓	✓

	Location	Notes	World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	Newcastle Beaches							
36	Nobbys Beach	Vertical concrete			✓	✓	✓	
37	Newcastle Beach	Vertical concrete, ocean pool		✓	✓	✓	✓	
38	Merewether	Vertical concrete, ocean pool	✓	✓	✓	✓	✓	
39	Redhead	Boulders		✓	✓	✓	✓	
	Central Coast							
40	Norah Head – Cabbage Tree Bay	Boulder wall					✓	
41	The Entrance	Boulder wall, ocean pool			✓	✓	✓	
42	Wamberal	Existing boulder walls, concrete walls			✓	✓	✓	
43	Terrigal	Vertical concrete			✓	✓	✓	
44	Avoca	Boulders, stepped sandstone		✓	✓	✓	✓	
45	MacMasters	Boulders, ocean pool			✓	✓	✓	
46	Killcare	Boulders			✓	✓	✓	
47	Ocean Beach-Umina	Boulders, geobags, stepped sandstone			✓	✓	✓	

	Location	Notes	World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	Sydney Northern Beaches							
48	Palm Beach	Vertical sandstone, boulders, ocean pool			✓	✓	✓	
49	Avalon	Boulders, ocean pool			✓	✓	✓	
50	Bilgola	Vertical sandstone, boulders, ocean pool			✓	✓	✓	
51	Bungan	Boulders			✓	✓	✓	
52	Mona Vale, Basin Beach	Vertical sandstone, boulders, ocean pool			✓	✓	✓	
53	Warriewood	Boulders			✓	✓	✓	
54	Collaroy-Narrabeen	Various on southern 1.2 km of beach, ocean pools	✓	✓	✓	✓	✓	✓
55	Dee Why	Stepped and vertical concrete, ocean pool		✓	✓	✓	✓	
56	Curl Curl	Vertical concrete, boulders, ocean pool		✓	✓	✓	✓	
57	Freshwater Beach	Buried vertical sandstone, ocean pool	✓	✓	✓	✓	✓	
58	Manly	Vertical sandstone, vertical concrete, sloping concrete, ocean pools	✓	✓	✓	✓	✓	

	Location	Notes						
			World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	Eastern & Southern Sydney Beaches							
59	Bondi	Vertical concrete, ocean pools		✓	✓	✓	✓	
60	Tamarama	Vertical concrete			✓	✓	✓	
61	Bronte	Vertical concrete, ocean pool			✓	✓	✓	
62	Clovelly	Vertical concrete, ocean pool					✓	
63	Coogee	Vertical concrete, stepped concrete, ocean pools			✓	✓	✓	
64	Maroubra	Vertical concrete		✓	✓	✓	✓	
65	Cronulla	Vertical concrete, sloping concrete, ocean pools	✓	✓	✓	✓	✓	

	Location	Notes	World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	Illawarra							
66	Coalcliff	Geobags, ocean pools			✓	✓	✓	
67	Scarborough	Boulders			✓	✓	✓	
68	Wombarra	Vertical concrete, ocean pool			✓	✓	✓	
69	Coledale	Vertical concrete			✓	✓	✓	
70	Austinmer	Vertical concrete, ocean pool			✓	✓	✓	
71	Thirroul	Vertical concrete, ocean pool			✓	✓	✓	
72	Sandon Point Beach	Boulders			✓	✓	✓	
73	Woonona	Ocean pool			✓	✓	✓	
74	Belambi	Boulders, ocean pool			✓	✓	✓	
75	Towradgi	Stepped concrete, ocean pool			✓	✓	✓	
76	North Wollongong	Stepped concrete			✓	✓	✓	
77	Oilies Port Kembla	Hanbar concrete armour			✓			
78	Fishermans Beach Hill 60 Port Kembla	Boulders with concrete wave return, mostly fishing					✓	
79	Port Kembla Beach	Vertical concrete, ocean pool			✓	✓	✓	
80	Warilla Beach	Boulder wall			✓	✓	✓	✓

	Location	Notes	World/National Surfing Reserve	Major surfing contests	Recreational surfing	Surf life saving activities	Beach tourism	Publicised issues
	South Coast							
81	Kiama Surf Beach	Vertical concrete			✓	✓	✓	
82	Boat Harbour Gerringong	Boulder wall					✓	
83	Boat Harbour Beach, Bendalong	Boulder wall			✓		✓	
84	Mollymook Beach	Vertical concrete, gabions			✓	✓	✓	
85	Mollymook Golf Course Surf Break	Boulder wall			✓		✓	
86	Caseys Beach, Batemans Bay	Boulder wall					✓	✓
	International							
87	Oahu Hawaii, Most south shore beaches	Vertical concrete, boulders			✓	✓	✓	
88	Malibu	Boulder wall	✓		✓		✓	✓
89	Rincon	Boulder wall			✓		✓	
90	Ocean Beach San Francisco	Stepped, vertical concrete			✓		✓	
91	Thurso Scotland	Vertical concrete		✓	✓		✓	

Implications for proposed seawall options at Wamberal Beach

- Seawall structures located at the landward extent of the active beach region are unlikely to have significant adverse impacts on surfing and beach amenity. Such is the case for a vast majority of seawalls located on the south-east coast of Australia that coexist with sandy beaches without significant adverse impacts on surfing and sandy beach amenity (Table 5.3). Many of these seawalls (particularly those with promenades) have enhanced the usability and amenity of the foreshore region landward of the sandy beach.
- Seawall options for Wamberal Beach which are situated at the landward extent of the active beach are unlikely to have adverse impacts on surfing and beach amenity.

5.7 Amenity impacts of ad-hoc protection debris

Since the 1970’s, various ad-hoc material and emergency protection works has been placed in the beach and foredune substrate at Wamberal Beach to protect against erosion. These materials are documented in Appendix B of the *Stage 3 Seawall Concept Design Options (MHL2780, 2021)* report and included various rock protection (rock armour and rock bags), rock rubble/fill/ballast, brickwork, concrete slabs and capping pieces, terracotta fragments, wire, corrugated iron, rubber tyres, old septic tanks filled with sand/gravel and relics of old timber retaining walls and staircases. Some of this material is seen in Figure 5.8, taken after the July 2020 storm prior to further emergency rock works being placed.

These materials are exposed and mobilised with storm erosion events, causing public safety concerns and inhibiting alongshore beach access such that sections of the beach have required to be closed to the public for periods of time after storms. Often these materials are left strewn on the beach by waves creating hazards for beach users as shown in Figure 5.8.

Figure 5.8: Wamberal Beach after storm erosion on 20th July 2020. MHL drone survey.

During construction, it is strongly recommended that any existing ad-hoc material and emergency rock toe protection works seaward of the proposed new seawall be removed to enhance beach amenity, or where suitable used as fill where required landward of the seawall. Any existing rock protection removed with construction should be replaced by sand nourishment wherever possible to extend the level of the natural beach berm or foredune seaward of the seawall. All sand excavated during the construction of the proposed seawall should be screened (to remove any oversized materials) and placed seaward of the works with any necessary fill landward of the seawall comprised of the separated materials (if suitable) and/or suitable clean fill that would be imported to the site. This will maximise the amount of sand added to the beach area as a result of the works and largely improve existing beach amenity.

5.8 Visual amenity impacts of seawalls

The natural visual amenity of the embayed sandy foreshore of Wamberal Beach is highly valued by beach users, beachfront homeowners, and the broader community (community consultation, Nov 2020). Following storms, the visual amenity of the existing beach is temporarily degraded by erosion events which remove sections of the sandy beach, expose ad-hoc materials and emergency rock protection works and worsen large unstable foredune scarps that threaten residential dwellings in the backshore (Figure 5.8). With time the sandy beach recovers after the storm and visual amenity of the sandy foreshore is restored although with partially buried ad-hoc emergency works and dune scarps remaining in the backshore.

The visual impacts of a seawall on a sandy foreshore will vary depending on the adopted design and configuration. For most of the time the lower portion of the seawall below a natural berm level of approximately +3 m AHD would be buried by sand fronting the seawall, with a larger proportion (down to approximately 0 m AHD) of the seawall exposed during storms in eroded sections of the beach. Where the beach widens in the north near Wamberal SLSC and the alignment transitions landward of the active beach region, the seawall is likely to be completely buried for majority of the time.

The presence of a large rock revetment (Options 1 and 2) or vertical seawall with a visually imposing vertical drop (Options 3 and 4) is likely to deter visual amenity in the backshore. The tiered vertical seawall option with reduced vertical relief, mid-level promenade and opportunities for landscape design is likely to enhance the visual amenity of the backshore. Design crest (and promenade if adopted) levels are to be refined in detailed design considering the alongshore natural variability of berm and dune levels along the structure to reduce adverse visual amenity impacts.

Visual amenity will benefit from removing any existing ad-hoc material in the beach during seawall construction as recommended. The proposed contiguous alignment extending between lagoon entrances would likely create a more uniform appearance to the backshore region of the beach compared to the various ad-hoc protection works and dune scarps present in the existing beach.

5.9 Foreshore access and safety concerns

A number of foreshore access issues and safety concerns of ad-hoc protection works at Wamberal Beach were raised following the recent July 2020 storm erosion event. Storm events result in narrow sections of beach backed by unstable ad-hoc protection and/or large dune scarps that create hazards for beach users and beachfront residents. Beach access points often require to be closed due following storms due to hazardous erosion scarps and private staircase access points for residents are left damaged and not functional.

Seawall options which encroach further into the active beach (Options 1 and 2) are likely to worsen constrictions in alongshore access after storms and associated hazards. The more landward alignment of the vertical seawall options (Options 3 and 4) (with removal of ad-hoc protection works) will benefit alongshore access by providing a wider beach and reduced encroachment. Conversely, the substantial vertical relief of these structures when exposed to waves will result in adverse public safety risks. From a safety point of view the tiered option is considered most beneficial, with a reduced vertical relief and maintaining a safe means of foreshore access after a storm when the beach is in an eroded state. The foreshore promenade would require to be closed during large storm events with wave overtopping hazards and subsequently reopened once waves subside. Structurally integrated beach access points will be developed during detailed seawall design stages to provide improved and safer beach access including after storm events.

5.10 Summary of beach amenity impacts of proposed seawalls at Wamberal Beach

Findings of the beach amenity assessment for each of the seawall concept options are summarised in Table 5.4. Overall vertical wall options (Options 3 to 5) are expected to have relatively low to beneficial impacts on present levels of amenity at Wamberal Beach. Rock revetment options (Options 1 and 2) will likely have a moderate to high adverse impact on beach amenity. The tiered vertical seawall option (Option 5) is expected to provide added foreshore amenity value via inclusion of a public promenade. Beach nourishment requirements to restore and maintain beach amenity into the future for each seawall concept option are investigated in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021).*

The degree of interaction of a seawall with beach processes and sandy beach amenity is highly dependent upon its position within the active beach profile. The seawall alignment has been addressed in *Stage 3 Seawall Concept Design Report (MHL2780, 2021)*. As per Section 4 of the present report, an average dry beach width of less than 5 m is estimated to occur for between 0.2% and 9% of the time depending on the seawall design adopted. It is anticipated that the impact on beach amenity will be a key criterion in selecting the chosen option.

The best performing options for sandy beach amenity (Vertical or Tiered vertical) will only be impacted by waves on an infrequent basis, so will not have frequent cross shore impacts on the beach. These impacts will be akin to iconic beaches such as Manly and Bondi, where whole of embayment seawalls coexist with sandy beaches. Future ongoing recession and recession due to sea level rise will be managed through beach nourishment as addressed in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021)*.

Options with low interaction with cross shore processes will also have low end effects. However, for the present project, the works are proposed to extend from Terrigal Lagoon to Wamberal Lagoon. At the southern end, the works will transition into the lagoon breakout area, which in turn is controlled by the bridge abutments, and lagoon breakout processes – both natural and mechanical. At the northern end where a larger sand buffer is present, the seawall alignment is proposed to gradually become more landward, such that the seawall will gradually transition out of the active zone as it reaches its northern limit. Subject to detailed design, the northern extent of the seawall is likely to abut the normal natural and mechanical breakout zone of Wamberal Lagoon, in a similar manner to Manly Beach.

Wamberal Beach is characterised by minimal net littoral drift, a modest underlying recession rate, a large sand buffer north of Wamberal Lagoon, and rock and reef outcrops in the north controlling the beach planform. Therefore, for a seawall having low interaction with cross shore processes, there is no mechanism for the seawall to cause erosion/recession north of Wamberal Lagoon.

Design specifications to further improve foreshore amenity are to be considered in detailed design and may include (depending on the adopted option) refined crest/promenade levels, landscape design, viewing platforms, designated beach access points, lighting, shower facilities and vertical seawall finishes/artworks.

Table 5.4: Summary of beach amenity impacts of proposed seawall options for Wamberal Beach

Seawall Concept Option	Percentage of time with less than 5 m available dry beach width (%) [a]	Encroachment into active beach and cross-shore impact	Available dry beach width impact	End erosion impact	Surf amenity impact	Post-storm ad-hoc protection debris on beach	Visual amenity impacts	Foreshore access impacts	Safety Impacts	Overall beach amenity impact assessment
Existing beach (including present ad-hoc rock protection)	*1.4% to 3.3%*	*Average of ~5 to 12 days per year when beach is less than 5 m.* *Higher encroachment of ad-hoc protection in central region of beach.*	*Infrequent disruptions following major storms with narrow beach conditions*	*Potential end effects at gaps in ad-hoc protection.*	*No adverse impacts identified.*	*Emergency works 1974 to present, rock rubble fill, brickwork, concrete, rubber tyres, old septic tanks, failed timber structures, etc. Exposed and dislodged with storms.*	*Poor after storms when existing ad-hoc material exposed. Large unstable dune scarp.*	*Alongshore access inhibited after storms with large unstable dune scarp at access points.*	*Dangerous narrow beach conditions and access points after storms. Risks trying to traverse ad-hoc protection encroaching into shoreline. Large unstable dune scarp.*	*As present – undesirable conditions particularly after storms*
Impacts relative to existing beach amenity										
Option 1: Basalt Rock Revetment	6.8% to 9.5%	Adverse - Average of 24 to 34 days per year when beach is less than 5 m. Higher encroachment	Adverse – More frequent conditions with narrow beach	Potential for minor added erosion when end of seawall is exposed to waves [b]	No adverse impact expected	Beneficial – Existing ad-hoc material removed during seawall construction	Moderate - Presence of large rock structure where not buried [d]	Adverse – Alongshore access inhibited more frequently	Moderate – safety risks at narrow beach sections	Moderate to high adverse impact
Option 2: Sandstone Rock Revetment	8.7% to 12.8%	Adverse - Average of 32 to 47 days per year when beach is less than 5 m Higher encroachment.								Moderate to high adverse impact
Option 3: Vertical Seawall	0.2% to 0.6%	Beneficial - Average of 1 to 2 days per year when beach is less than 5 m. Reduced encroachment	Beneficial – Reduction in conditions with narrow beach	Minimal end effects expected due to landward alignment [b]			Moderate - Large vertical relief visually imposing where not buried [d]	Beneficial – Wider beach to improve alongshore access	Moderate - safety risks associated with vertical relief [d]	Low to beneficial impact
Option 4: Vertical Seawall with Rock Toe:	0.2% to 0.6%	Beneficial - Average of 1 to 2 days per year when beach is less than 5 m Reduced encroachment								Low to beneficial impact
Option 5: Tiered Vertical Seawall with Promenade	1.1% to 2.6%	Slightly Beneficial - Average of 4 to 9 days per year when beach is less than 5 m Reduced encroachment	Beneficial – Slight reduction in conditions with narrow beach + provision of promenade access				Beneficial – Reduced vertical relief + opportunities for enhanced foreshore landscaping [d, e]	Beneficial – Slightly wider beach to improve alongshore access + provision of promenade access	Beneficial – safer alongshore access after storms + reduced vertical relief. [d]	Low to beneficial impact [f]

[a] Values defined by R2% (the wave runup exceeded by 2% of waves) and Rmax (the maximum estimated wave runup) and averaged along the length of the beach between lagoon entrances.

[b] Region of potential end effects are also influenced by lagoon entrance processes, bridge abutments and rocky foreshores. Potential end effects are unlikely to affect other developed areas along the beach. Specifications of termination design at lagoon ends are subject to detailed design.

[c] Does not consider other sources of debris from eroded vegetated dunes and lagoon entrances.

[d] Concept design crest levels to be refined during detailed design. Visual and safety amenity will benefit from removal of ad-hoc protection and unstable dune scarps.

[e] Design considerations to mitigate privacy impacts on beachfront residents are addressed in the *Stage 3 Seawall Concept Design Options (MHL2780, 2021).*

[f] Also provides broader public amenity value of foreshore promenade.

6 Conclusions

Overwhelming feedback obtained during community consultation (November 2020 and August 2021), highlighted the importance of the natural amenity that Wamberal Beach provides to its users and the broader community. This report provides the outcomes of Stage 2 of the Wamberal Terminal Coastal Protection Assessment, namely an amenity impact assessment of seawall concept design options for Wamberal Beach. The report includes quantifying impacts on available dry beach width for beach users as well as evaluating interactions with natural beach processes, cross-shore encroachment impacts and other potential amenity implications. The report has adopted both quantitative and qualitative approaches to assessing impacts to beach amenity, utilising all available historical beach profile data, dry beach width estimation techniques, as well as a literature review of seawall and beach interactions along the south-east coast of Australia and abroad.

The impact of the five proposed seawall concept designs detailed in the *Stage 3 Seawall Concept Design Report (MHL2780, 2021)* on beach width amenity at Wamberal Beach was quantified and assessed. Findings of the beach amenity assessment for each of the seawall concept options are summarised in Table 5.4. In order to assess the relative impact on beach amenity of each option, the present report has not considered beach nourishment which may alleviate amenity impacts. Beach nourishment requirements to maintain beach amenity into the future for each seawall concept option are investigated in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021).*

As part of the present study, all available beach profile data for Wamberal Beach, commencing in 1941 were assembled and analysed. The data encompassed historical aerial photos, satellite shorelines, photogrammetry, WRL quadbike surveys, UNSW Aviation surveys, State Government bathymetric surveys and drone surveys. The intensity of data is sparse in early years and intense in recent decades.

The impacts of each concept design option on available dry beach width for public use were assessed by quantifying the amount of seawall encroachment on the active beach over a representative period of time. This was completed using a beach width model that derived hourly dry beach widths compiled from hourly measured data for ocean water levels and ocean waves through a wave runup model that was interfaced with the most recent 10 year period of frequently measured beach profile data (2010 to 2020 including RTK-GPS, drone and aerial Lidar surveys). Six representative beach profile locations, spread across the 1.4 km study area between the Lagoon entrances, were used to evaluate the impacts of seawall encroachment on available dry beach width for public use.

Average disruptions to available dry beach width were estimated, that is, the percentage of time (%) when the beach had less than 5 m of dry sand available for public use. Results for each of the proposed seawall concept design options are provided in Table 5.4. Values are defined based on R2% (the wave runup level exceeded by 2% of waves) and Rmax (the maximum estimated wave runup level) wave runup statistics.

Rock revetment structures (Options 1 and 2) were found to have a high level of impact on available dry beach width, with an increased amount of time (on average 4x higher than the current situation) below a 5 m width. These options were found to reduce available dry beach width for public amenity, more frequently inhibit alongshore access for beach users and have a relatively higher encroachment on beach processes (Table 5.4). Conversely, vertical seawall designs (Options 3 to 5) were found to have a positive impact on the present levels of beach width amenity (resulting in a wider beach), given their relatively smaller footprints and more landward alignment at the rear crest of the revetment options and lower encroachment into the active beach (Table 5.4). The tiered vertical option would result in minor improvement to the beach width and offers additional preservation and enhancement of alongshore access through the incorporation of a promenade.

The report also undertook a literature review of other aspects of beach amenity and the cross shore and longshore impacts on beach processes of the proposed concept seawall designs for Wamberal Beach. Approximately 91 seawall structures on sandy beaches were catalogued, predominantly in south-east Queensland and NSW. Of these 91 seawall structures, up to 7 have known adverse publicity regarding their impacts on beach amenity. The common feature of these seawalls is an alignment more seaward than that proposed for Wamberal, sometimes on a beach that is receding at a rate more than five times the rate of Wamberal (for example Stockton Beach). Exposed seawalls can cause entry and exit to/from the water to be more hazardous for surfers and swimmers, but (unlike some large breakwaters) direct attribution of any reduction in surf quality to these seawalls is rare. This is likely because most surfing is undertaken in deeper water away from the seawall.

The degree of interaction of a seawall with beach processes and sandy beach amenity is highly dependent upon its position within the active beach profile. The proposed vertical seawall designs (Options 3 to 5), with a low degree of encroachment into the active beach will for most of the time be fronted by sand and have minimal impact on coastal processes (Table 5.4). A higher degree of impact on coastal processes is expected for the revetment options concept designs (Options 1 and 2) which encroach further seaward into the active beach and would be more frequently exposed to waves (Table 5.4). The best performing options for sandy beach amenity (Options 3 to 5) will only be impacted by waves on an infrequent basis, so will not have frequent cross shore impacts on the beach. These impacts will be akin to iconic beaches such as Manly and Bondi, where whole of embayment seawalls coexist with sandy beaches.

For the vertical seawall designs (Options 3 to 5) any impacts are expected to be limited in extent and duration and are unlikely to affect other developed areas along the beach nor cause longer-term changes to present-day beach and lagoon entrance processes (Table 5.4). During major storms there may be slightly higher, albeit temporary, sand volume losses in isolated regions where the seawall is exposed to waves. However, given the proposed alignment at the landward extent of the active beach, natural beach recovery and lagoon entrance infill processes will subsequently rebuild these regions following a storm, with minimal longer-term impact on beach and lagoon entrance morphology. The provision of beach sand nourishment to maintain beach amenity in front of the seawall will further limit this effect (*Stage 4 Sand Nourishment Investigation).*

End effects are reduced for structures aligned further landward in the active beach region. Traditional end effect impacts will not apply as the proposed seawall at Wamberal Beach will be a contiguous structure extending from Terrigal Lagoon to Wamberal Lagoon. Termination of the structure at either end will transition landward of the active beach region, with minimal end erosion effects expected for vertical seawall options (Options 3 to 5). Higher encroachment of the rock revetment structures (Options 1 and 2) in the active beach at the southern end may result in slightly higher sand losses during rare storm erosion events that expose the seawall end to wave action. This region is also governed by dynamic lagoon entrance processes, a rocky backshore to the south and the Ocean View Dr Bridge constriction to the west such that traditional end erosion estimates are not applicable. Specifics of termination design at lagoon ends are subject to detailed design with further design consideration to be given to minimise impacts on coastal and lagoon entrance processes. Review of the former 1998 termination ends is provided in the *Stage 3*

Seawall Concept Design Report (MHL2780, 2021).

Other aspects of beach amenity were assessed and summarised in Table 5.4 including post-storm ad-hoc protection debris on the beach, visual amenity, foreshore access and safety impacts. Overall vertical seawall options (Options 3 to 5) are expected to have relatively low to beneficial impacts on present levels of amenity at Wamberal Beach. The large vertical drop for seawall options 3 and 4, particularly after storms, would likely pose public safety risks and visual amenity issues. This is mitigated for the tiered vertical seawall with promenade option (Option 5) which is expected to also provide added public foreshore amenity. Rock revetment options (Options 1 and 2) will likely have a moderate to high adverse impact on beach amenity. Beach nourishment requirements to restore and maintain beach amenity into the future for each seawall concept option are investigated in *Stage 4 Sand Nourishment Investigation (MHL2795, 2021).*

Design specifications to further improve foreshore amenity are to be considered in detailed design and may include (depending on the adopted option) refined crest/promenade levels, landscape design (including privacy considerations), viewing platforms, designated beach access points, lighting, shower facilities and vertical seawall finishes/artworks.

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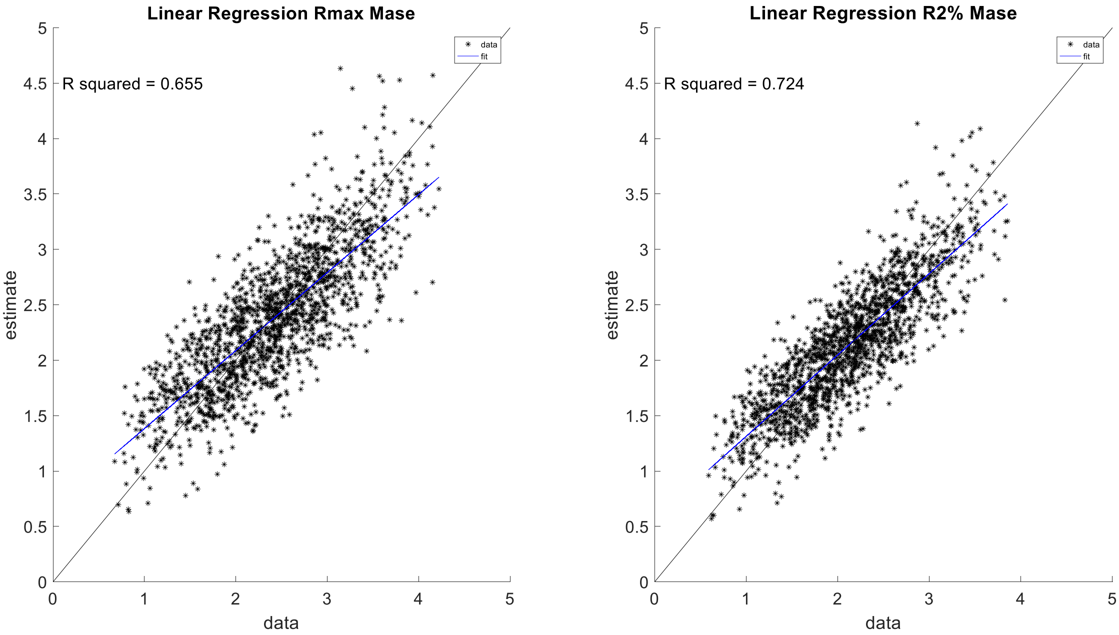
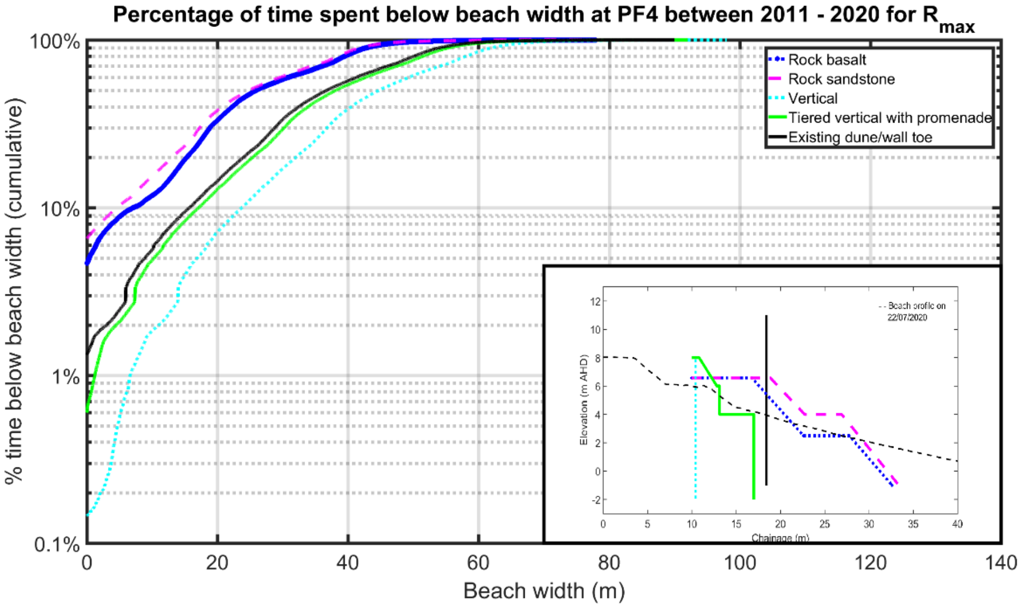
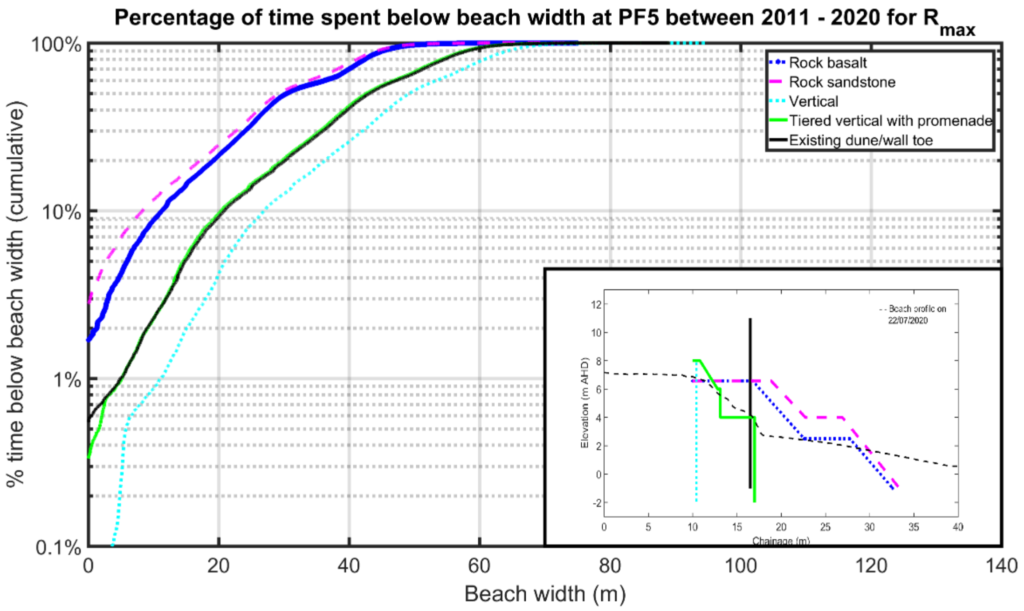
Appendix A Model comparison with measurements



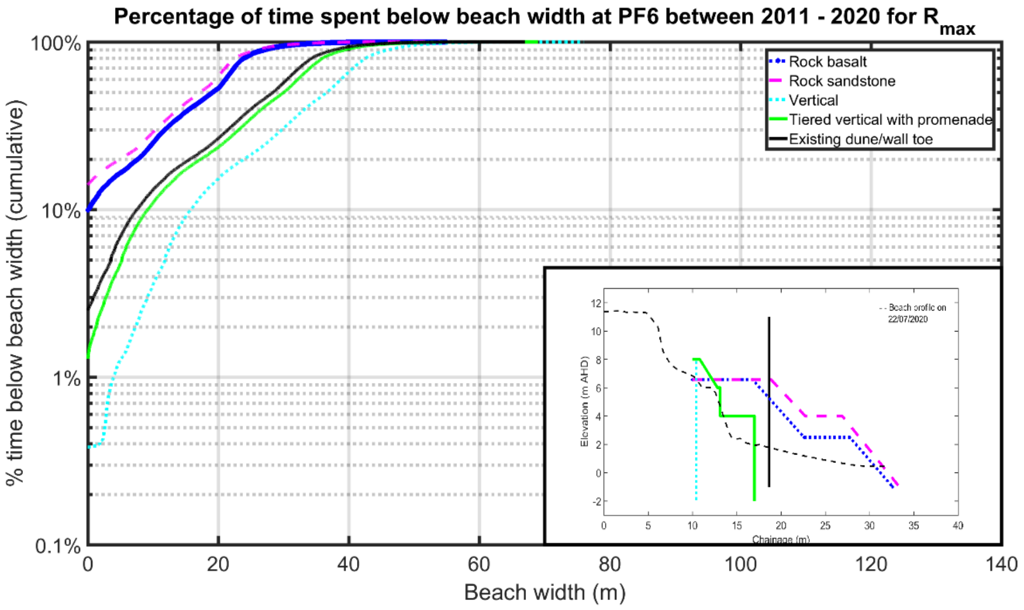
(source: Tucker et al., 2019)

Figure A.1: Performance of the Mase equation at Collaroy-Narrabeen Beach

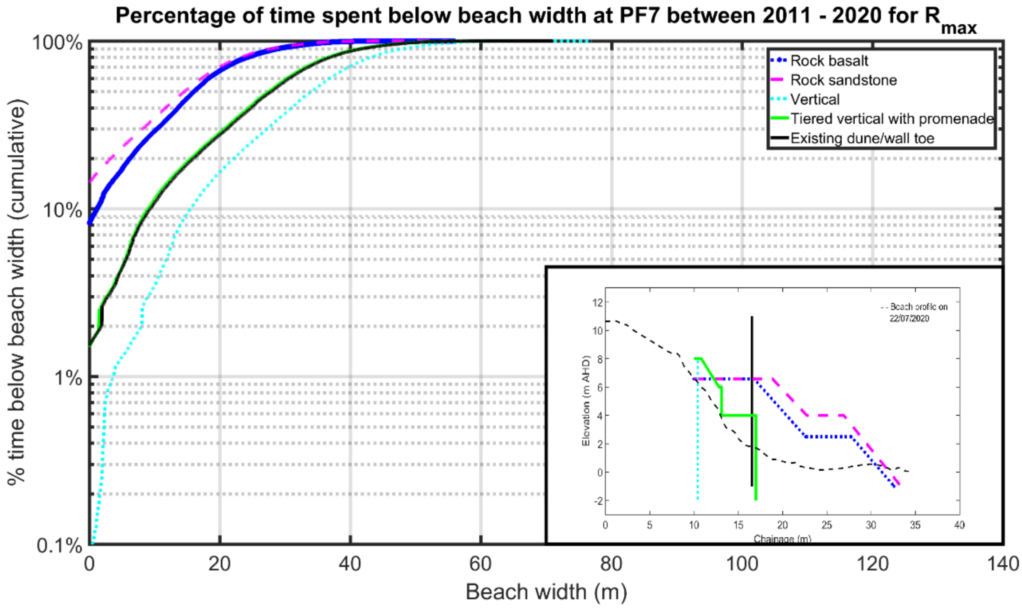


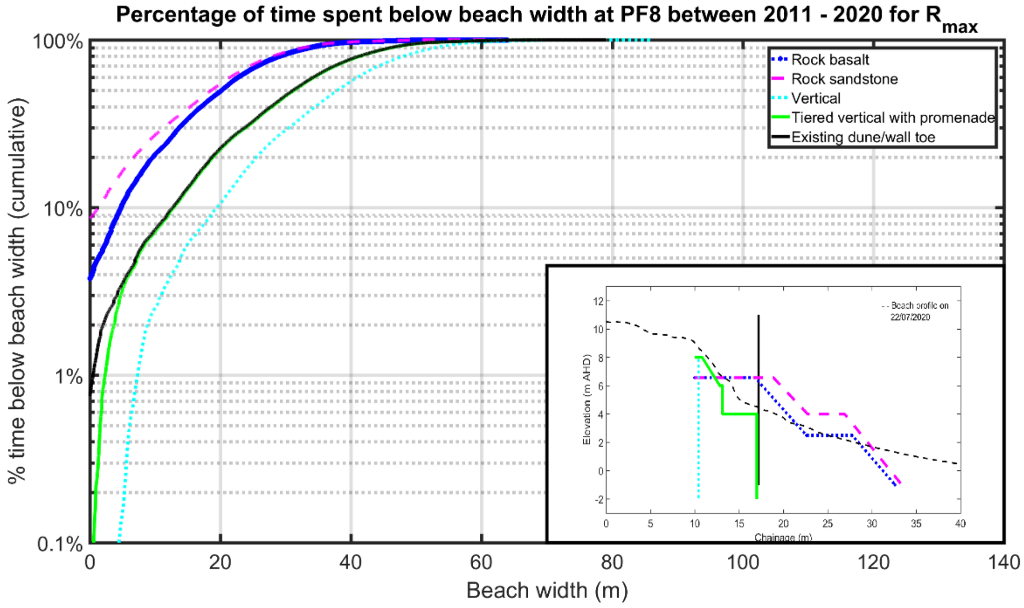


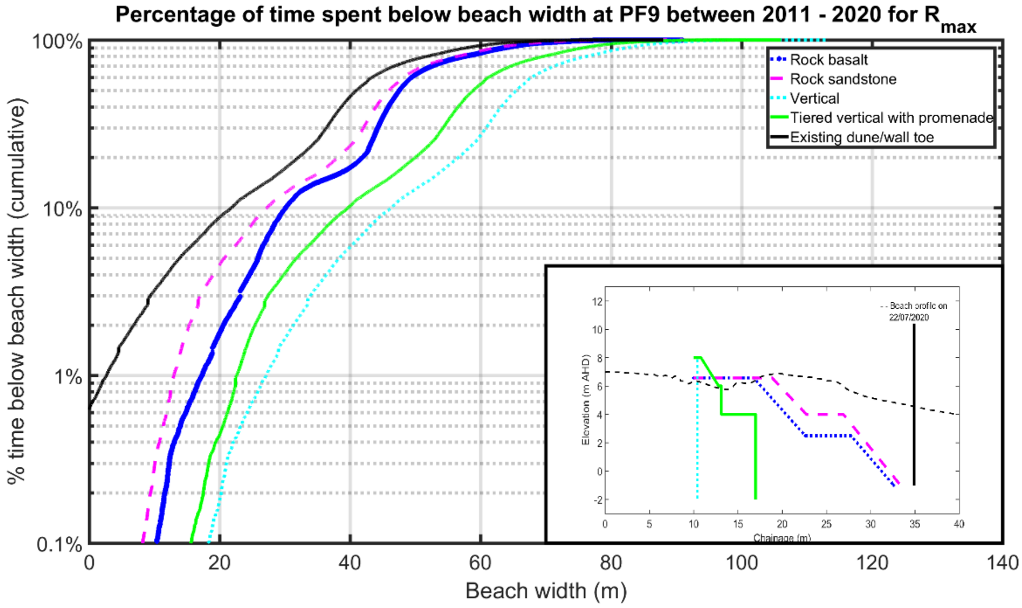
Percentage of time spent below beach width at PF5 between 2011 - 2020 for R_{max}



Percentage of time spent below beach width at PF6 between 2011 - 2020 for R_{max}


Percentage of time spent below beach width at PF7 between 2011 - 2020 for R_{max}
% time below beach width (cumulative)
100%
10%
1%
0.1%
0
20
40
60
80
100
120
140
Beach width (m)
Rock basalt
Rock sandstone
Vertical
Tiered vertical with promenade
Existing dune/wall toe
- - Beach profile on 22/07/2020
Elevation (m AHD)
Chainage (m)
12
10
8
6
4
2
0
-2
0
5
10
15
20
25
30
35
40


Percentage of time spent below beach width at PF8 between 2011 - 2020 for R_{max}
% time below beach width (cumulative)
100%
10%
1%
0.1%
0
20
40
60
80
100
120
140
Beach width (m)
Rock basalt
Rock sandstone
Vertical
Tiered vertical with promenade
Existing dune/wall toe
- - Beach profile on 22/07/2020
Elevation (m AHD)
Chainage (m)
12
10
8
6
4
2
0
-2
0
5
10
15
20
25
30
35
40


Percentage of time spent below beach width at PF9 between 2011 - 2020 for R_{max}
% time below beach width (cumulative)
100%
10%
1%
0.1%
0
20
40
60
80
100
120
140
Beach width (m)
Rock basalt
Rock sandstone
Vertical
Tiered vertical with promenade
Existing dune/wall toe
- - Beach profile on 22/07/2020
Elevation (m AHD)
12
10
8
6
4
2
0
-2
0
5
10
15
20
25
30
35
40
Chainage (m)