Wamberal Terminal Coastal Protection Assessment

DRAFT FINAL Stage 4 – Sand Nourishment Investigation

June 2021

Prepared for:

Central Coast Council

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Report Classification

☒	Public	Report existence and contents publicly available.
☐	Release by consent only	Report existence and contents available only with consent of publisher
☐	Private	Report existence and content are strictly confidential.

Foreword

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*. 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
3. Seawall concept design options
4. **Sand nourishment investigation (this report)**
5. Provision of coastal monitoring (online webpage)
6. Cost benefit analysis and distributional analysis of options

This report provides the outcomes of Stage 4 of the Wamberal Terminal Coastal Protection Assessment, namely the undertaking a sand nourishment investigation for Wamberal Beach. The report includes an outline of sand nourishment requirements for Wamberal Beach and investigation of potential sand sources including indicative unit cost estimates.

This report is issued as Draft Final and will be finalised following public consultation along with a summary report that integrates key findings of all stages of the Wamberal Terminal Coastal Protection Assessment.

The report 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), development of seawall concept design options (Stage 3), *sand nourishment investigation (Stage 4 current report)*, 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). A summary report, integrating findings of all stages of the Wamberal Terminal Coastal Protection Assessment will be provided upon the finalising of all the aforementioned assessment reports.

This report provides the outcomes of Stage 4 of the Wamberal Terminal Coastal Protection Assessment, namely the investigation of sand nourishment options to be undertaken in association with terminal protection design at Wamberal Beach (CZMP, 2017). Sand nourishment has been investigated for the primary purpose of maintaining public beach amenity for the Wamberal/Terrigal embayment over the life of the terminal protection structure, considering underlying long-term recession rates, sea level rise and seawall encroachment. The report includes an outline of sand nourishment requirements for Wamberal Beach and investigation of potential sand sources including indicative unit cost estimates.

Sand nourishment as structural protection for un-piled beachfront structures has not been considered in the sand nourishment investigation given the adoption of terminal protection outlined in the certified Gosford Beaches CZMP (2017). This has previously been reported primarily due to the lack of readily available sand sources (potential sources subject to future legislative and planning viability) required for large-scale nourishment to sufficiently mitigate the prevailing storm erosion hazard without terminal protection. Large-scale nourishment also poses a number of complexities including implications on flooding and lagoon entrance management, broader embayment-wide environmental impacts on existing nearshore environments, seabed habitats and reefs, as well as ongoing commitments to maintaining a sufficient storm erosion buffer.

The design objectives of sand nourishment in this study are to:

A. Assess the merits of sand nourishment requirements to mitigate the impacts on public beach width amenity for each of the proposed seawall concept designs options detailed in *Stage 3 Seawall Concept Design Options (in draft).*

B. Maintain an acceptable level of public beach width amenity over the 50-year life of the seawall concept design planning period accounting for underlying recession trends and sea level rise.

Optional upfront nourishment objective (dependent on sand availability):

C. Optional upfront nourishment to restore any sand losses over recent decades in the Wamberal Beach embayment associated with historical recession.

It is important to note that it is unrealistic to expect a nourishment program to maintain a consistent beach width given the dynamic nature of high-energy sandy beaches such as Wamberal Beach. Nourished beaches will continue to naturally fluctuate and evolve due to temporal changes in wave conditions, storm erosion and accretion cycles, beach rotation and other coastal drivers. Beach nourishment seeks to address longer-term deficiencies in public beach amenity over periods of years to decades.

Establishment of a beach monitoring program is considered fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works. This would benefit from the provision of subaqueous and subaerial beach surveying on a regular basis and before/after major events similar to that undertaken on the Gold Coast and at Narrabeen-Collaroy Beach (Strauss et al., 2017; Turner et al., 2016).

To enhance sand nourishment longevity, nourishment should ideally be undertaken for the 2.7 km Terrigal-Wamberal embayment between the rock shelf at the southern end of Terrigal Beach near Ash St to the rock shelf approximately 500 m north of Wamberal Lagoon (excluding Terrigal Haven and Spoon Bay). This however is subject to sand availability at the time of the nourishment campaign. Smaller sand nourishment targeting the 1.4 km region fronting the seawall (between Terrigal and Wamberal Lagoon Entrances) is still considered beneficial to enhancing beach amenity, albeit with higher potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration for larger volumes. Sand volume requirements have been provided for both these regions. Design parameters for nourishment are provided including long-term recession rates, sea level rise, cross-shore and alongshore spatial considerations, placement considerations, native sand characteristics and borrow sand compatibility criteria.

Required nourishment volumes to meet each of the design objectives are provided in Table E.1 including design beach width increases after nearshore spreading and estimated impacts on beach amenity (based on Stage 2 results). Excavation sand won during seawall construction should be used to contribute toward nourishment requirements and has also been estimated in the report.

To address objective A, sand volume requirements were calculated to mitigate or offset the impacts of seawall encroachment on the present-day dry beach width available for public use. Seawall concept options from the *Stage 3 Seawall Concept Design Options (in draft)* were assessed. Sand volume requirements to meet objective A are provided in Table E.1 and are considered an upfront nourishment requirement to be undertaken with seawall construction.

Significantly larger volumes of sand for objective A are required to mitigate rock revetment Seawall Options 1 and 2, with higher encroachment impacts on the available dry beach width (Table E.1). Such volumes are subject to future viability of larger sand nourishment sources being available at the time of construction. This scale of nourishment would require careful design placement considerations to avoid significant increases in beach width fronting the lagoons which would likely pose additional complexities to lagoon entrance management.

Table E.1: Summary of design nourishment volumes

Design Objective	Nourishment Volume	Total volume required [a]		Design beach width increase after nearshore spreading (m)	Estimated average beach width conditions fronting seawall (based on Stage 2 results) & impact on dry beach user area			
					Without Nourishment		With Nourishment	
		$m^3 \times 10^3$	Average m^3 / m		% of time less than 5 m	Impact on existing dry beach user area	% of time less than 5 m	Impact on existing dry beach user area
					Existing beach estimated to spend on average ~3% of time less than a 5 m width (from Stage 2 results)			
A (Offset)	A) Offsetting seawall encroachment volume							
	Seawall Option 1: Basalt Rock Revetment	491 (252)	179 (181)	+12 m	10 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 2: Sandstone Rock Revetment	528 (270)	193 (195)	+13 m	13 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 3: Vertical Seawall	0 (0)	0 (0)	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 4: Vertical Seawall with Rock Toe	0 (0)	0 (0)	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 5: Tiered Seawall with Promenade	20 (10) [d]	7 (7) [d]	<1 m [d]	3 %	Maintained beach width + added promenade amenity	3 %	Maintained beach width + added promenade amenity
	TIMING: Upfront							
B (Maintain)	B) Design recession maintenance volume *TIMING: Optional upfront* *Required ongoing approx. every 10 years* [b]	141 (78)	51 (55)	+ 6 m	Diminishing beach width over design life (foreshore access maintained via promenade for Seawall Option 5)		Maintained beach width over design life (with added promenade amenity for Seawall Option 5)	
Optional C (Restore)	C) Optional historical recession restoration volume [c] *TIMING: Optional Upfront*	274 (181)	100 (135)	+ 1 to 10 m	3%	As per existing beach	~1%	Restored for past ~30 years of historical recession at start of project.

[a] Volumes not in brackets are for 2.7 km Terrigal-Wamberal embayment nourishment region.
Volumes in brackets are for 1.4 km section between lagoon entrances fronting seawall (subject to increased potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration for larger volumes).
All volumes include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD) and apply an overfill factor of 1.0.
Nourishment volumes are for provision of beach amenity only and do not include storm demand.
Nourishment volumes will vary depending on the sediment composition of source material and do not consider excavation sand won during seawall construction.
[b] Increased risk of more frequent maintenance nourishment for rock revetment structures (Seawall Options 1 and 2) every 5-10 years due to high beach encroachment. Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.
[c] To be refined during detailed design with pre-nourishment design reference profile survey.
[d] Stage 2 results indicate Seawall Option 5 has minimal impact on available beach width relative to existing conditions. Minor volumes presented for this option in this report offset what is a relatively negligible degree of maximum encroachment of 0.5 m and will be covered by excavated sand won during seawall construction.

Without nourishment for objective A, the rock revetment structures would lead to more frequent narrow beach conditions reducing access along the beach approximately four times more often than present day beach conditions, approximately five times more often than for the tiered vertical seawall with promenade (Seawall Option 5) and approximately twenty times more often than for vertical seawall options (Seawall Options 3 and 4) (based on Stage 2 report findings).

In comparison, vertical structures with a smaller footprint and alignment at the rear of the rock revetment options provide minimal encroachment on available beach width. Set back further than the existing ad-hoc rock protection (to be removed during seawall construction), vertical Seawall Options 3 and 4 are expected to enhance beach amenity by providing additional beach width availability relative to the present day beach (refer to Stage 2 report) and require no additional volume to offset encroachment impacts for objective A (Table E.1).

The tiered vertical seawall option with promenade (Seawall Option 5) is expected to have a similar level of beach width amenity as present-day conditions (refer to Stage 2 report). Nourishment requirements for objective A for Seawall Option 5 in Table E.1 are minor and offset what is a relatively negligible degree of maximum encroachment of 0.5 m for this option. This volume is expected to be covered by excavated sand won during seawall construction. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade (including safe foreshore access following storms when the beach is narrow and otherwise hazardous to traverse).

To address objective B, a design recession maintenance nourishment volume was calculated to account for both long-term recession of -0.2 m/year (Worley Parsons, 2014) and sea level rise recession of -0.39 m over the next 50 years (central value RCP 8.5 2070 projection). A total design recession maintenance volume (B) to be applied nominally every 10 years is provided in Table E.1. This volume provides approximately 6 m of added beach width (after nearshore spreading) every 10 years to offset design recession. Sensitivity to upper and lower bound estimates of sea level rise resulted in -22%/+13% variations to calculated design recession volumes representing the expected range of variability in future maintenance nourishment campaigns. Without nourishment volume A, there is likely to be increased risk of more frequent maintenance nourishment (volume B) for Seawall Options 1 and 2 every 5-10 years, due to the high encroachment of the rock revetment structures into the active beach.

An optional nourishment (objective C) has been investigated to restore sand losses over recent decades due to historical recession at Wamberal Beach. This was calculated by adopting a design restoration profile for Wamberal Beach that provides a maximum level of beach width amenity within the natural envelope of beach profile variability in the last 20 years. The amount of nourishment volume required to achieve the design restoration profile was calculated based on a reference profile prior to the July 2020 storm event. A preliminary sand volume for objective C is provided in Table E.1. Key areas requiring restoration nourishment identified include the south end of the embayment at Terrigal Beach (Sections 1 and 2) and in the mid-section of the beach between "The Ruins" (25A/B Ocean View Dr) and Lumeah Ave (Sections 5 to 9). Where the beach has been recently depleted between Wamberal and Terrigal Lagoon (Sections 5 to 9), this option will provide on average an additional 10 m (after nearshore spreading) of beach width relative to 2020 pre-storm conditions. This option provides a total sand volume to the Terrigal-Wamberal embayment equivalent to approximately three decades of historical recession for Wamberal Beach (as quantified by Worley Parsons, 2014).

A summary of nourishment feasibility for seawall options is provided in Table E.2. Larger volumes are subject to future viability of larger sand nourishment sources being available at the time of the nourishment campaign, as well as potential added complexities around lagoon entrance management depending on design placement. Given the feasibility of sand nourishment requirements, present day beach width amenity is likely to be maintained for Seawall Options 3 to 5, and reduced amenity would be expected for Seawall Options 1 and 2. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade. Seawall Options 3-5 require minimal upfront nourishment to maintain the existing beach user area (utilising excavated sand won during seawall construction for Option 5).

A range of potential sand sources for nourishment were investigated and assessed including local and regional quarry sources, sand transfer from sediment sinks within the Terrigal-Wamberal compartment (including sand transfer from lagoon entrances and foredunes), regional port and estuary entrance sources, offshore inner shelf sources and Sydney tunnel project spoils. Preliminary assessment of potential sand sources has taken into consideration:

- Sediment composition and compatibility for nourishment at Wamberal Beach
- Resource availability
- Potential constraints including legislation, licensing, environmental and social implications
- Indicative unit cost estimates ($/m^3) for extraction, delivery and placement at Wamberal Beach

A summary of recommended sand sources for nourishment of Wamberal Beach is provided in Table E.3. Overall, there are a number of feasible sources of sand to nourish Wamberal Beach, however, few of these (all subject to future viability and availability at the time of works) offer sufficient capacity to cater for upfront nourishment requirements in excess of around 50,000 m^3. This is insufficient for upfront nourishment requirements for Seawall Options 1 and 2. Minimal upfront nourishment requirements for Seawall Options 3 to 5 are considered advantageous in this regard, being less dependent on the availability of larger sand sources at the time of construction.

Table E.2: Summary of nourishment feasibility for seawall options

Seawall option	Nourishment volume A) offsetting seawall encroachment	Nourishment volume B) design recession maintenance [a]	Optional nourishment volume C)	Relative impact on existing dry beach user area
Seawall Option 1: Basalt Rock Revetment	Subject to future viability of larger sand sources available at time of construction Potential lagoon entrance management complexities depending on design placement	✓ (Optional upfront & required ongoing every 5-10 years[b])	Subject to future viability of larger sand sources available at time of construction (Optional upfront)	Moderate to high adverse impact without Nourishment A
Seawall Option 2: Sandstone Rock Revetment	Subject to future viability of larger sand sources available at time of construction Potential lagoon entrance management complexities depending on design placement	✓ (Optional upfront & required ongoing every 5-10 years[b])		Moderate to high adverse impact without Nourishment A
Seawall Option 3: Vertical Seawall	Not Required	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact
Seawall Option 4: Vertical Seawall with Rock Toe	Not Required	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact
Seawall Option 5: Tiered Vertical Seawall with Promenade	✓ (Upfront – covered by excavated sand won during construction)	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact + added promenade amenity

[a] Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.
[b] Increased risk of more frequent maintenance nourishment due to high beach encroachment.

Table E.3: Summary of preliminary sand source assessment

Location	Total Resource Available	Estimated Overfill Factor [a]	Indicative unit cost ($/m^3)	Constraints / Comments	Recommendation
Local Quarries - Grants Rd Sand	~50,000 m^3/y	1.3	50	• Supply limited due to high regional construction industry demand and limited resource availability • Volume requires supplementing from other sources	Further investigation recommended.
Regional Quarries - Stockton	~200,000 m^3/y	2 - 3	>100	• High cost due to haulage • Supply limited due to high regional construction industry demand and limited resource availability	Not recommended. (high cost)
Wamberal and Terrigal Lagoon Entrance	43,000 m^3 (20,000 at Terrigal and 23,000 at Wamberal)	1	20 - 40	• Requires repeat entrance clearance program to maintain. • Volume requires supplementing from other sources • Maintains transfer of sand within Terrigal-Wamberal sediment compartment (i.e. beach replenishment) • Variable volumes and sediment quality dependent on dredge campaign. • Impacts on recreational area and amenity at entrances	Further investigation recommended.
Active foredune management	25,000 m^3	1.5 - 3	15 - 30	• Requires repeat foredune maintenance program • Disturbances to foredune ecology in Wamberal Lagoon Nature Reserve • Volume requires supplementing from other sources • Maintains transfer of sand within Terrigal-Wamberal sediment compartment (i.e. beach replenishment)	Subject to detailed EIA in consultation with NPWS.
Hunter River (South and North Arm)	Several million m^3	Unknown. Fine to medium grained sand	60 - 120	• High cost due to haulage • Potentially cheaper if undertaken as part of broader regional nourishment program	Subject to future viability. (potential high cost due to haulage)
Brooklyn, Hawkesbury River	100,000 m^3	Unknown. Fine to medium grained sand	23 - 43	• Potentially cheaper if undertaken as part of broader regional nourishment program	Not recommended. (sand required in source compartment)
Swansea Channel	10,000 - 50,000 m^3 every 1-5 years with infrequent major dredging	2	45 – 80	• Likely exhausted by local sand requirements closer to the source	Not recommended. (sand required in source compartment)
Tuggerah Entrance	30,000 -80,000 m^3/y every 1-2 years	Unknown. Fine to medium grained sand	40 - 60	• Likely exhausted by local sand requirements closer to the source	Not recommended. (sand required in source compartment)
Offshore dredging	Order of 10 million m^3	1 – 1.5	10 - 30	• Environmental concerns of Government and community • Potentially cheaper costs (<$10/m3) if undertaken as part of a broader regional nourishment campaign	Subject to future viability. Further investigation recommended.
Sydney tunnel spoils	Several million m^3	Unknown	<10	• Low cost option • Sand compatibility of spoils for nourishment purposes requires further investigation	Subject to future viability. Further investigation recommended.

[a] Factor applied to design volume to account for additional nourishment due to finer borrow sand grain size composition than that of native beach.

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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 (in draft). 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".*

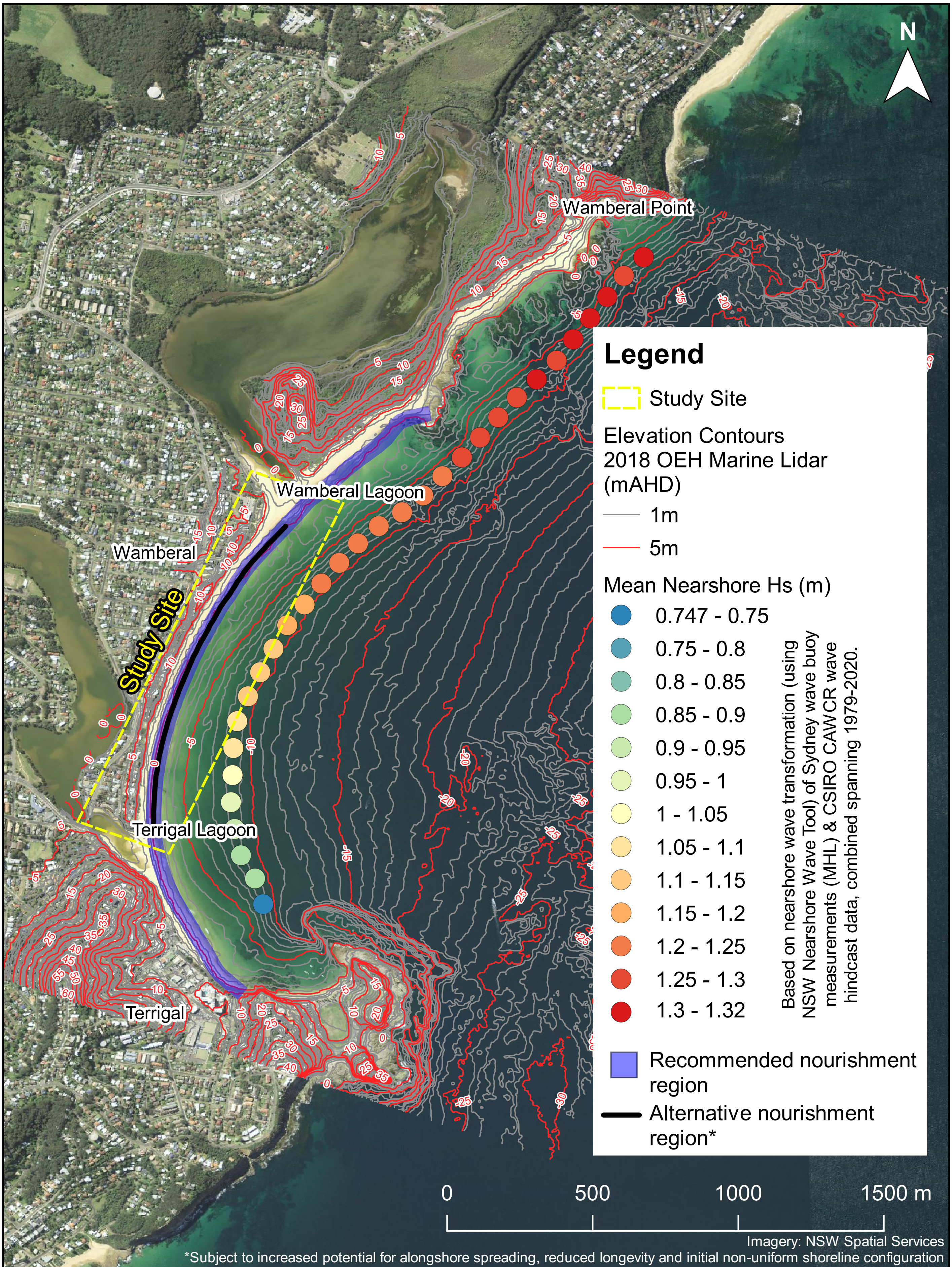
Major actions recommended for Wamberal Beach from the CZMP (2017) were the following:

- *"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
3. Seawall concept design options
4. **Sand nourishment investigation (current report)**
5. Provision of coastal monitoring
6. Cost benefit analysis and distributional analysis of options

This report provides the outcomes of Stage 4 of the Wamberal Terminal Coastal Protection Assessment, namely the undertaking of a sand nourishment investigation for Wamberal Beach following recommended actions items TW14 and TW15 of the CZMP (2017).



NSW GOVERNMENT

LOCATION OF STUDY SITE SHOWING ELEVATION CONTOURS (2018 OEH MARINE LIDAR) AND AVERAGE NEARSHORE WAVE CLIMATE (-10M CONTOUR)

Manly Hydraulics Laboratory

Report MHL2795

Figure

1.1

Figure1.1.pdf

1.2 Stage 4 study aim

The primary aim of Stage 4 of the Wamberal Coastal Protection Assessment is to investigate sand nourishment options for Wamberal Beach with a primary purpose to provide an acceptable level of public beach amenity for the Wamberal/Terrigal embayment over the life of a terminal protection structure. Nourishment requirements for the five different seawall concept design scenarios detailed in the Stage 3 report are assessed. The Stage 4 study documents nourishment sand requirements, sources and indicative unit cost estimates for Wamberal Beach.

1.3 Stage 4 overview

The Stage 4 report includes the following:

- Analysis of sand nourishment requirements for Wamberal Beach including nourishment design objectives, beach width for public amenity, nourishment design parameters and sand volume requirements for each design objective (Section 2).
- Investigation of potential sand sources and associated indicative unit cost estimates for nourishment of Wamberal beach (Section 3).
- Recommendations regarding sand nourishment requirements and sources for Wamberal Beach considering different seawall concept design configurations (Section 4).

2 Sand nourishment requirements

2.1 Sand nourishment design objectives

Beach nourishment coupled with the provision of a terminal protection structure was recommended as the preferred management action for Wamberal Beach under the certified Gosford Beaches Coastal Zone Management Plan (CZMP, 2017). When coupled with the provision of a terminal protection structure, beach nourishment serves the primary objective of maintaining an acceptable level of public beach amenity over the design life of the structure.

Sand nourishment in this study aims to provide an acceptable level of public beach amenity for the Wamberal/Terrigal embayment over the life of the terminal protection structure, considering underlying long-term recession rates, sea level rise and seawall encroachment.

It is important to note that it is unrealistic to expect a nourishment program to maintain a consistent level of acceptable beach width given the dynamic nature of high-energy sandy beaches such as Wamberal, that will continue to naturally fluctuate and evolve with temporal changes in wave conditions, storm erosion and accretion cycles, and beach rotation cycles even with a nourishment program in place.

Establishment of a beach monitoring program is considered fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works. This would benefit from the provision of subaqueous and subaerial beach surveying on a regular basis and before/after major events similar to that undertaken on the Gold Coast and at Narrabeen-Collaroy Beach (Strauss et al., 2017; Turner et al., 2016).

The design objectives of sand nourishment in this study are to:

A. Assess the merits of sand nourishment requirements to mitigate the impacts on public beach width amenity for each of the proposed seawall concept designs options detailed in *Stage 3 Seawall Concept Design Options (in draft).*

B. Maintain an acceptable level of public beach width amenity over the 50-year life of the seawall concept design planning period accounting for underlying recession trends and sea level rise.

Optional upfront nourishment objective (dependent on sand availability):

C. Optional upfront nourishment to restore any sand losses over recent decades in the Wamberal Beach embayment associated with historical recession.

To undertake the design objective A, sand volumes have been assessed for each seawall option in terms of providing either:

- An equal level of beach width amenity across all options by using sand nourishment to mitigate any impacts of seawall encroachment on available dry beach width associated with each of the options.
- An unequal level of beach width amenity whereby each seawall option is associated with a different level of available dry beach width due to differing degrees of encroachment.

The latter approach has been applied in the *Stage 6 Wamberal Beach Cost-Benefit Analysis* to contrast marginal benefits and costs between each seawall option. The relative impacts on available dry beach width between each seawall option compared to the existing beach have been assessed in the *Stage 2 Coastal Protection Amenity Assessment* (in draft).

Sand nourishment as structural protection for un-piled beachfront structures has not been considered in the sand nourishment investigation given the adoption of terminal protection outlined in the certified Gosford Beaches CZMP (2017). This has previously been reported primarily due to the lack of readily available sand sources (potential sources subject to future legislative and planning viability) required for large-scale nourishment to sufficiently mitigate the prevailing storm erosion hazard without terminal protection. Large-scale nourishment also poses a number of complexities including implications on flooding and lagoon entrance management, broader embayment-wide environmental impacts on existing nearshore environments, seabed habitats and reefs, as well as ongoing commitments to maintaining a sufficient storm erosion buffer.

2.2 Beach width for amenity

Beach width is an important criterion for communities' enjoyment of a beach, and up to a limit, people prefer wider beaches (King, 2006). A detailed review of acceptable beach width amenity drawing from local and international studies abroad with recommendations for Wamberal Beach is provided in the *Stage 2 Coastal Protection Amenity Assessment (in draft).*

Beach width at Wamberal Beach provides a highly valued space for community recreational use. An absence of dry beach width, the presence of ad hoc coastal structures (and the fact that no promenade exists) limits the ability of people to walk along the foreshore.

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

- Ability to walk along the beach safely without getting wet
- Ability to sit or lie on the beach without getting wet
- 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 in an eroded state with existing seawalls exposed. Historically the beach has been temporarily 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.

The *Stage 2 Coastal Protection Amenity Assessment (in draft)* adopted a minimum acceptable beach width (distance from the dune toe or existing ad-hoc rock protection to the shoreline) of 5 m for Wamberal Beach to assess the impacts on beach width amenity of existing rock protection and proposed options for seawalls. A minimum dry beach width of 5 m is noted to allow for some storm erosion and would mean that the beach falls into the medium hazard category as defined by Harley et al. (2016). Beach widths less than 5 m are considered to become hazardous for beach walkers as well as inhibiting to sunbathing and recreational beach activities. Findings from the study indicate that the existing beach spends on average approximately 1-3% of the time less than a minimum acceptable beach width of 5 m.

It is noted that historical recession along the central regions of Wamberal Beach (WorleyParsons, 2014) combined with relatively elevated residential development and emergency rock protection has created a more frequent pinch point in beach access and reduced public amenity in this region. This region prior to the July 2020 erosion event was relatively narrow compared to adjacent sections of beach to the north and south, likely exacerbating erosion impacts in the area during the event. Similar localised trends were noted in the long-term recession analysis undertaken by WorleyParsons (2014). Nourishment objective C has considered this localised region of sand deficiency.

2.2.1 Impacts of seawalls on beach amenity

A total of five seawall concept design options were developed as part of Stage 3 of the Wamberal Coastal Protection Assessment (in draft), comprising of:

Seawall Option 1: Basalt Rock Revetment
Seawall Option 2: Sandstone Rock Revetment
Seawall Option 3: Vertical Seawall
Seawall Option 4: Vertical Seawall with Rock Toe
Seawall Option 5: Tiered Vertical Seawall with Promenade

A detailed assessment of the impacts of seawall options on beach amenity is provided in *Stage 2 Coastal Protection Amenity Assessment (in draft)* including assessment of beach width encroachment, seawall interactions with the beach profile, surfing amenity and end erosion effects. As part of the analysis, the degree of beach width encroachment of each concept design option was quantified based on a 10 year hindcast of hourly wave runup estimates at Wamberal Beach.

Findings from the study indicate that the existing beach spends on average approximately 1-3% of the time less than a minimum acceptable beach width of 5 m. Without sand nourishment, rock revetment structures (Options 1 and 2) were found to have a high level of impact on sandy beach amenity, with an increased amount of time (on average 4x higher than the current situation) below a minimum acceptable width. These options were found to reduce available dry beach width for public amenity and more frequently inhibit alongshore access for beach users. Conversely, vertical seawall options (3 to 5) without sand nourishment were found to have minimal impact on the present levels beach width amenity and coastal processes, given their relatively smaller footprints and more landward alignment at the rear crest of the revetment options.

Sand nourishment could potentially be used to mitigate the impacts of seawall encroachment on the beach profile. Nourishment volumes to mitigate impacts of seawall encroachment on the beach profile (objective A) were calculated considering the maximum degree of encroachment for each seawall option and prograding the embayment shoreline by an equivalent amount to offset this encroachment while maintaining a characteristic shoreline curvature. While these volumes are presented, this option may become unfeasible depending on the level of seawall encroachment, particularly for rock revetment options, and associated impacts with lagoon entrance management and flooding. This is discussed further in Section 2.5.4.

Suitable excavated sand won during construction of each of the seawall concept options is also estimated in Section 2.5.6. It is noted that a significant amount of ad-hoc material and rock protection exists in the beach substrate where the proposed seawalls would require excavation. All sand excavated during the construction of the proposed seawall must 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. Careful environmental and safety controls for on-ground works would be required in locations where excavation is undertaken of hazardous materials (e.g., asbestos and building waste) present in the existing beach substrate.

2.3 Beach profile data and design profile selection

The following datasets were used in design nourishment calculations:

- Subaerial beach profile data was obtained from:
  - NSW Beach Profile Database (owned by DPIE and developed/hosted by WRL UNSW) www.nswbpd.wrl.unsw.edu.au - Historical beach profile data from 1941 to present based on stereo photogrammetry of aerial images and more recently aerial Lidar and drone surveying. (Note: This dataset does not include RTK-GPS quad bike data collected between 2011-2013 at Wamberal Beach)
  - July- September 2020 MHL drone surveys of Wamberal Beach between Terrigal and Wamberal Lagoon
- 2018 and 2020 (post-storm) bathymetry data of the Wamberal-Terrigal embayment provided by DPIE.

A total of 11 representative beach profiles spaced between 200 – 300 m apart over the 2.7 km long Terrigal-Wamberal embayment shown in Figure 2.1 were used to determine nourishment volumes. These profiles correspond to profile locations from the NSW Beach Profile Database.

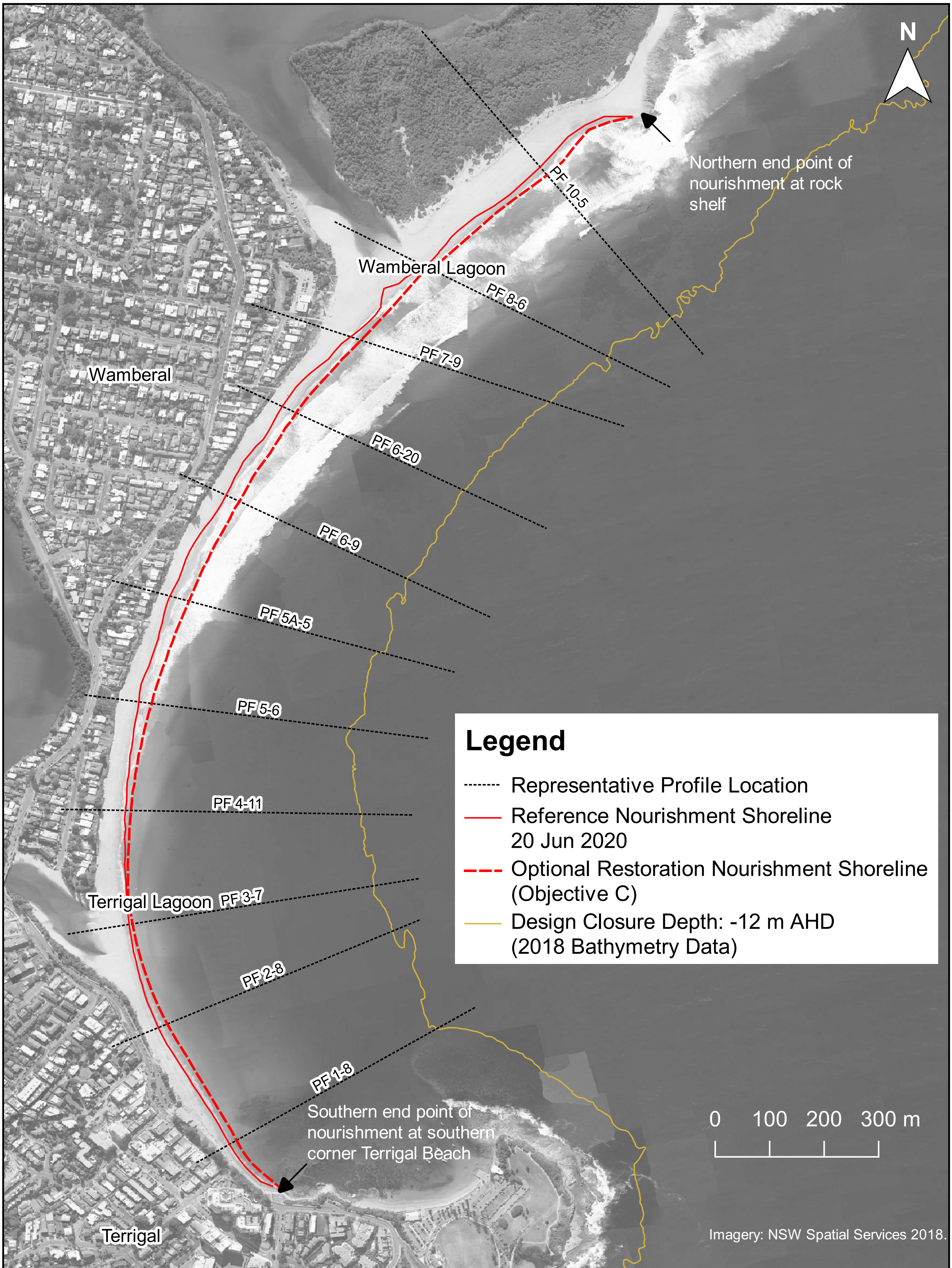
The subaerial beach profile data at each location was combined with subaqueous 2018 bathymetry, joined by applying a constant 1V:20H upper nearshore slope (approximate average nearshore slope determined from 2018 bathymetry data within the embayment) and are provided in Appendix A.

2.3.1 Preliminary reference profile

Without more recent beach profile data since the beach has recovered to an accreted state following the July 2020 storm, baseline reference beach conditions used to determine sand nourishment volumes in this report were taken to be the pre-July 2020 storm conditions. Beach profile data from 20th June 2020 was selected (Figure 2.1) and combined with 2018 bathymetry data in the subaqueous beach to represent present day conditions.

The mid-section of Wamberal Beach between Lake View Rd and Lumeah Ave was relatively depleted of sand at the time of the 2020 pre-storm survey, neighboured by wider sections of beach to the south and north. These alongshore patterns are reflected in the optional restoration nourishment requirements for objective C (see following section).

It should be noted that the reference profile will vary depending on how the beach has recovered to an accreted state since the July 2020 event as well as evolving trends in beach recession/accretion into the future. A beach survey program pre and post nourishment campaigns is to be undertaken to refine detailed design nourishment volumes and to monitor/evaluate nourishment requirements into the future.



NSW GOVERNMENT

REPRESENTATIVE PROFILE LOCATIONS, PRE JULY 2020 STORM REFERENCE SHORELINE AND DESIGN NOURISHMENT SHORELINE

Manly Hydraulics Laboratory

Report MHL2795

Figure

2.1

Figure 2.1.pdf

2.3.2 Optional restoration profile

An optional nourishment (objective C) has been investigated to restore sand losses over recent decades due to historical recession at Wamberal Beach. This was calculated by adopting a design restoration profile for Wamberal Beach that provides a maximum level of beach width amenity within the natural envelope of beach profile variability in the last 20 years. This was selected at each of the 11 representative profile locations (Figure 2.1) as the most accreted beach profile within the envelope of measured beach profile variability over the last 20 years (from the NSW Beach Profile Database). The last 20 years provides a contemporary period with higher profile data availability (and improved survey accuracy) to select a restoration profile. The shoreline for the optional restoration nourishment (objective C) is shown in Figure 2.1. For majority of locations the 5th April 2016 profile data was selected as the restoration profile in Figure 2.1. Some erosion was noted in the southern corner of Terrigal Beach in the April 2016 data. In this region data from the 3rd June 2019 was selected for the restoration profiles in the southern corner of Terrigal Beach.

2.4 Sand nourishment design parameters

2.4.1 Storm demand (not considered for structural protection)

Storm demand for Wamberal Beach was quantified by WorleyParsons (2014) in the Coastal Hazard Definition Study. The study recommended a nominal 100-year ARI design storm demand of 250 m^3/m in the subaerial beach (does not include subaqueous beach). This volume was not considered in the present analysis given the provision of a terminal protection to provide coastal protection against storm erosion under the certified Gosford Beaches Coastal Zone Management Plan (CZMP, 2017).

2.4.2 Long-term recession rates

Long-term recession rates were also quantified by WorleyParsons (2014) in the Coastal Hazard Definition Study, using photogrammetry beach profile data from 1941 to 2006. The study recommended a design recession due to sediment budget deficiency of -0.2 m/year based on the observed rate of positional change of the +5 m AHD beach contour. This value has been adopted in the present study for nourishment volume calculations for Wamberal Beach. Long-term losses in the sediment budget are reported to be associated with deposition in offshore reefs during storms and lagoon infilling at the Wamberal and Terrigal Lagoon entrances at either end of Wamberal Beach (PWD, 1994). Further discussion of lagoon infilling is provided in Section 3.2.

It should be noted that historical recession rates have varied along the broader Terrigal-Wamberal embayment (WorleyParsons, 2014). Analysis by WorleyParsons (2014) indicate slightly higher recession observations for the Terrigal region in the south, with some areas of minimal long-term recession and minor accretion observed toward the north near Wamberal Surf Club, likely due to aeolian-drive foredune growth in the area. The dune region at the north of the embayment, between Wamberal Lagoon and the rock shelf (Figure 2.1) was not presented in the WorleyParsons (2014) study. A preliminary analysis of photogrammetry data from 1941 to 2020 (from the NSW Beach Profile Database, developed by WRL UNSW on behalf of DPIE), suggest that the +5 m AHD beach contour in this region has accreted on average approximately +0.1 to +0.3 m per year, likely also due to aeolian-drive foredune growth and/or beach rotation. Potential sand losses into the dune system to the north of Wamberal Lagoon are addressed in Section 3.3.

2.4.3 Sea level rise

In 2013, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report of the state of knowledge of climate change and its environmental implications. As part of the report the IPCC developed a range of future sea level rise projections (relative to 1986-2005) associated with different greenhouse gas emission scenarios, termed representative concentration pathways (RCPs) (Church et al., 2013).

Sea level rise projections for the NSW coast for each of these RCP emissions scenarios are provided in Glamore et al. (2015). Considering initial design planning period from 2020 to 2070, 2070 sea level rise projections (averaged along the NSW coast) for the lowest emissions scenario with strong mitigation (RCP 2.6) range between 0.19-0.42 m (relative to the 1986-2005 mean with range equivalent to 66% confidence limits in projections). For the highest (unmitigated) emissions scenario (RCP 8.5), 2070 projections range between 0.31-0.59 m (relative to the 1986-2005 mean with range equivalent to 66% confidence limits in projections). Sea level rise of 0.45 m in 2070 was adopted for the present nourishment design, equivalent to the central value for a high-end (unmitigated) emissions scenario of RCP8.5.

The Coastal Hazard Definition Study (WorleyParsons, 2014) recommended a design recession Bruun Factor of 43, such that recession due to sea level rise is equivalent to 43 times the magnitude of sea level rise. A recession due to sea level rise of -0.39 m/year was adopted in the present study based on this Bruun Factor. A total recession (long-term underlying recession + sea level rise recession) of -0.59 m/year was adopted for decision recession volume calculations.

Sensitivity of nourishment requirements to sea level rise projections was undertaken for a lower bound value of the low-end (mitigated) emissions scenarios RCP 2.6, corresponding to a 2070 sea level rise projection of 0.19 m, and also an upper bound value of the high-end (unmitigated) emissions scenario RCP8.5, corresponding to a 2070 sea level rise projection of 0.59 m. Profile change due to sea level rise was estimated using Bruun Rule approximations which relate changes in equilibrium beach profiles to predicted sea level rise (Bruun, 1962).

2.4.4 Spatial considerations

<u>Closure Depth</u>
An important part of calculating nourishment volume requirements is determining what is known as the depth of closure, or the water depth at which beach profile changes due to wave action are small on an annual basis or over the duration of a planning horizon (Kraus et al., 1998). This determines the offshore extent as to which nourishment volumes are calculated, based on the expected spreading of nourishment material out into the surfzone and offshore by waves.

A method for calculating an inner boundary limit of intense bed activity is presented by Hallermeier (1978, 1981, 1983) and is often taken as a suitable closure depth in sand nourishment and engineering design (Carley and Cox, 2017). Using the inner Hallermeier approach, a closure depth of approximately -11 m AHD was calculated for Wamberal Beach. Nielsen (1994) recommended a similar value of -12 m AHD (±4 m) for the offshore limit of significant wave breaking and beach fluctuations for south-east Australia. For the purpose of this study, a design closure depth of -12 m AHD was adopted to determine nourishment requirements for Wamberal Beach as shown in Figure 2.1. This was found to be in good agreement with maximum depths of storm deposition during the July 2020 event observed to be approximately -10 m AHD (based on comparisons post-storm 2020 and 2018 bathymetry data).

<u>Subaerial nourishment extent</u>

For the purpose of maintaining public beach amenity in the form of a dry beach above tides and wave runup, the present study considers nourishment volume for the beach profile extending from the depth of closure (-12 m AHD) to the approximate dune toe elevation contour (+4 m AHD) or point of intersection with each of the seawall concept designs as shown in Appendix A. Nourishment of elevations above +4 m AHD elevations was not considered, with the primary purpose of nourishment being to maintain a dry beach fronting the seawall structure for public amenity.

<u>Alongshore nourishment extent</u>

To enhance sand nourishment longevity, nourishment is ideally to be undertaken for the 2.7 km Terrigal-Wamberal embayment between the rock shelf at the southern end of Terrigal Beach near Ash St to the rock shelf approximately 500 m north of Wamberal Lagoon as shown in Figure 1.1 (excluding Terrigal Haven and Spoon Bay). Hereafter in this report this region is referred to as the Terrigal-Wamberal embayment.

Providing nourishment for this broader region is expected to minimise alongshore spreading effects, by utilising the natural barriers of the surrounding embayment rock shelfs. Based on techniques in the Coastal Engineering Manual (CEM, 2002-2011), this is estimated to have a longevity at least four times longer than if nourishing only the approx. 1.4 km section fronting the proposed seawall options between Terrigal and Wamberal Lagoon.

Nourishing over the broader embayment also aims to enhance broader public beach width amenity to the more frequented southern end of the embayment at Terrigal Beach, which attracts approximately five times the annual visitors of Wamberal Beach each year, and is also characterised by historical long-term recession (WorleyParsons, 2014, 2015).

The alongshore extent of the nourishment region is however subject to sand availability at the time of the nourishment campaign. Smaller sand nourishment targeting the 1.4 km region fronting the seawall (between Terrigal and Wamberal Lagoon Entrances, Figure 1.1) is still considered beneficial to enhancing beach amenity, albeit with higher potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration.

Unless otherwise stated sand volumes in this report are in reference to the broader 2.7 km Terrigal-Wamberal embayment nourishment region (Figure 2.1). Sand volume are also presented for the 1.4 km beach region fronting the proposed seawall between lagoon entrances.

Implications of nourishment for lagoon entrance management at Terrigal and Wamberal Lagoon are described in Section 2.5.4.

2.4.5 Placement considerations

Depending on the desired outcomes of nourishment regimes, sand can be placed in alternative configurations as shown in Figure 2.2, including placement in the dune zone, visible beach, swash and wave zone, full nearshore profile, offshore berm bar or subaqueous beach (Carley and Cox, 2017). These placements form the initial configuration of a nourished beach prior to waves redistributing nourished material over the full profile from the berm in the subaerial beach to the depth of closure in deeper waters offshore as shown in Figure 2.2.

To enhance available dry beach width amenity for Wamberal Beach, placement in the swash and wave zone is recommended to have the largest upfront and visible positive impact on available beach width (Carley and Cox, 2017). Nourishment should be placed in a manner consistent with characteristics of the natural beach berm at Wamberal. As such, placement of material should extend seaward from the existing shoreline or seaward face of the seawall, with a maximum elevation of approximately +2 to +4 m AHD and with a beachface slope of approximately 1V:10H at its seaward edge (Hanslow et al., 2000).

Depending on the preferred seawall option, additional sand may be placed against the seawall to partially bury its seaward face in exposed regions. It should be noted that storm events are likely to remove this sand in sections of the seawall exposed to waves, which may require beach scraping to accelerate the recovery of sand above a natural berm level (approximately 2.5-3.5 m AHD). This is not expected to be required for sections of a promenade seawall with a promenade level above natural berm height.

Offshore bar placement aims to position beach fill in 6 to 10 m water depth to mimic the formation of an offshore storm bar that naturally forms during erosion events (Carley and Cox, 2017). This encourages wave breaking during storms and redistributes the sand onshore during milder wave conditions to gradually build up the beach berm. Drawbacks of this placement is that it has a low initial visible impact on the dry beach width amenity with small or almost imperceptible change perceived by the community, as it may occur over several months. However, offshore placement can generally be undertaken with less equipment and for lower cost than other forms of placement, particularly when offshore dredging is undertaken to source sand (see Section 3.5). Offshore placement near lagoon entrances may help to lower immediate impacts on lagoon entrance berms of nourishment regimes and temporarily enhance surfing amenity in these regions in the months following placement (depending on the desired placement depth & configuration). Further consideration of nourishment implications for lagoon entrance management at Terrigal and Wamberal Lagoon are described in Section 2.5.4.

Relevant licenses and environmental approvals would be required to undertake the placement of nourishment on the beach profile. These would be considered in the detailed design stage of a selected nourishment campaign.

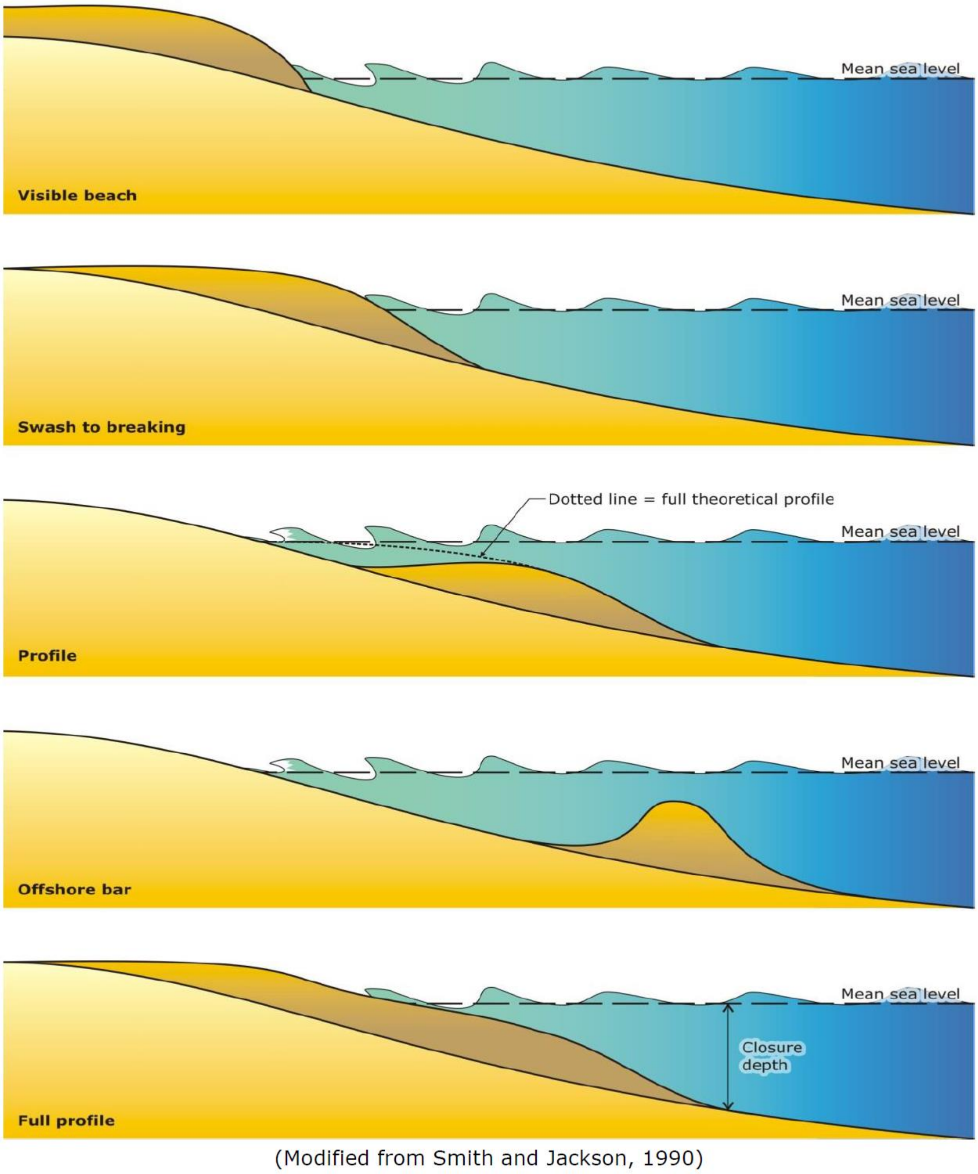


Figure 2.2: Alternative beach fill placement locations. From Carley and Cox (2017).

2.4.6 Native sand characteristics

Native sand at Wamberal beach consists of an unconsolidated sequence of well-sorted, medium grained quartz sand with common shell fragments grading to moderately well-sorted, gravelly, medium to coarse grained sand above a weathered siltstone/claystone bedrock (MHL, 1997). Transitions to gravelly sand sequences typically occur near or below 0 m AHD. Native sand properties for Wamberal Beach are summarised Table 2.1.

Typical depths to the siltstone/claystone unit have been found to vary along the study site as described in the geotechnical data review undertaken in Stage 3 (in draft). In the southern and mid sections of the study site (south of 73 Ocean View Dr), this is situated between -2 to below -10 m AHD. In the mid-north of the site, a 400 m section of elevated siltstone/claystone is situated north of 73 Ocean View Dr with shallower depths of -2 to +1 m AHD and is temporarily exposed during erosion events. The claystone bedrock returns to lower depths north of the study site. Other than existing ad-hoc and emergency protection works, the foredune is predominantly unconsolidated quartz sand from the surface to below 0 m AHD, except for a region between Bundara Ave and Renown St where elevated siltstone/claystone of up to +8 m AHD has been identified.

Table 2.1: Native sand properties at Wamberal Beach

Sand Properties	Native Sand Wamberal Beach	Source
Grain size classification	Medium-grained sand	Hudson (1997)
Colour	Dull yellow-orange (10YR 7/4) to yellow-brown (10YR 6/6) with iron staining	Hudson (1997)
Chemical/Mineral composition Carbonate Fraction	Quartz sand with common abraded shell fragments 9%	Hudson (1997) Surf Life Saving Australia Beach Database (Short, 2007)
Median grain size D_{50} (mm) (Berm and swash) Terrigal Haven Terrigal *Wamberal Beach (Terrigal to Wamberal Lagoon)*	 0.21 0.25 *0.39 (0.36 – 0.42)*	Hanslow et al. (2000) Surf Life Saving Australia Beach Database (Short, 2007)
Sorting	Well sorted (0.24)	Hudson (1997) Surf Life Saving Australia Beach Database (Short, 2007)
Skewness	0.095	Surf Life Saving Australia Beach Database (Short, 2007)
Compaction	Loose	Hudson (1997)

2.4.7 Borrow sand compatibility

Methods of assessing the compatibility of borrow sand for beach nourishment in comparison to native sand properties are outlined in the *Guidelines for Sand Nourishment - Science and Synthesis for NSW* (Carley and Cox, 2017). These include:

- Grain size compatibility
    - Influence on equilibrium profile shape
    - Overfill of required nourishment volumes
- Grading curve/sorting

- Colour
- Chemical/mineral composition
- Other criteria such as shape and sediment fall velocity

Ideally, borrow sand for beach nourishment should be similar in grain size (or slightly coarser), composition, angularity, and colour as native beach material specified in Table 2.1 (Carley and Cox, 2017). As discussed in Carley and Cox (2017), borrow material with finer (coarser) grain size than that of the native beach is expected to flatten (steepen) the shape of the natural beach profile with larger (smaller) borrow volumes required to maintain the available dry beach width for public use. Although beaches are dynamic, changes to characteristic profile slopes can influence nearshore biodiversity, characteristic beach state, surf safety, surfing conditions and wave runup behaviour (Carley and Cox, 2017).

When finer borrow material is used, an overfill ratio is applied to make up an equivalent volume of native sand. In the Coastal Engineering Manual (CEM, 2006) borrow sand with a median grain size, D_{50} within ±0.02 mm of native beach material is recommended, equivalent to an overfill ratio of 1.0 to 1.05. However, this is often difficult to obtain in practice, with potentially feasible nourishment projects typically consisting of overfill ratios between 1.1 to 2.0 (e.g., AECOM, 2010, Carley and Cox, 2017). The “Dutch” method of nourishment design, outlined by Verhagen (1992), allows for an overfill ratio of 1.4. A design overfill factor will be determined once the selected sand source has been identified as part of detailed design. Design volumes in the present report use an overfill factor of 1.0 (with sensitivity provided for 1.4 and 2.0) and also note variations in overfill for potential sand sources (Section 3). Required sand nourishment volumes in the *Stage 6 Cost-Benefit Analysis (in draft)* have adopted an overfill factor 1.4 to account for this effect.

The grading curve and proportion of fine sediment is also an important consideration in assessment the suitability of beach nourishment material. Well-sorted sand with a uniformity coefficient (D_{60}/D_{10}) of less than 2 is considered desirable for beach nourishment projects (Mangor et al., 2012) with poorly sorted borrow sediment creating a more compact feel and different drainage properties (Carley and Cox, 2017).

Colour of borrow material should ideally be similar to that of native sand, though this may be difficult to achieve in practice. Over time darker borrow material may lighten due to mixing with native sand and/or bleaching by weather conditions (Carley and Cox, 2017). Borrow material should have a predominantly mineral composition of quartz sand preferably with a low carbonate fraction.

Based on the above recommendations, preferable sediment properties for sand nourishment borrow material for Wamberal Beach are provided in Table 2.2.

Table 2.2: Preferable sand properties for sand nourishment at Wamberal Beach.

Sand properties	Borrow material preferences
Median grain size D_{50} (mm)	0.35 to 0.55 mm (medium grained sand)
Sorting	Well-sorted (uniformity coefficient < 2)
Mineral composition	Quartz sand with low carbonate fraction
Colour	Dull yellow

2.5 Sand nourishment volume requirements

2.5.1 Nourishment volume A) Offset seawall encroachment

This section aims to:

- Assess the merits of sand nourishment requirements to mitigate the impacts on public beach width amenity for each of the proposed seawall concept designs options detailed in *Stage 3 Seawall Concept Design Options (in draft)* (objective A)

A detailed assessment of the impacts of encroachment for each seawall concept option is provided in *Stage 2 Coastal Protection Amenity Assessment (in draft).* Sand volume requirements presented in this section have been determined to mitigate these impacts of seawall encroachment on the beach profile and available beach width, such that an equal level of beach width amenity is achieved across all proposed seawall options (Section 2.2.1).

This volume would be required in addition to nourishment B) outlined in the following section. Required nourishment volumes to mitigate the impacts of seawall encroachment were calculated by:

a) determining the maximum degree of encroachment into the present-day dry beach width area used by the public for each seawall option, and

b) prograding the entire Terrigal-Wamberal embayment nearshore by an equivalent amount to offset this encroachment while maintaining the present shoreline curvature (to avoid creating non-uniformities in the shoreline position around regions of seawall encroachment).

Sand volumes required for mitigating seawall encroachment impacts are presented in Table 2.3. For the broader 2.7 km nourishment region, a total volume of 491,000 m^3 (average of 179 m^3 per metre of shoreline) (Option 1 Basalt) and 528,000 m^3 (average of 193 m^3 per metre of shoreline) (Option 1 Sandstone) is required to mitigate the relatively higher encroachment impacts of the rock revetment structures. These structures have the largest footprint, encroaching furthest into the active beach profile and dry beach user area.

In comparison, vertical structures with a smaller footprint and alignment at the rear of the rock revetment options provide minimal encroachment on available beach width. Set back further than the existing ad-hoc rock protection (which would be removed during seawall construction) vertical seawall options 3 and 4 are expected to slightly enhance amenity by providing some additional beach width availability relative to the present day beach and require no additional volume to offset encroachment impacts. The tiered vertical seawall option with promenade (Option 5) is expected to have a similar level of beach width amenity as present day conditions with only a minor sand volume of 20,000 m^3 (average 7 m^3 per meter of shoreline) required to offset minor beach encroachment. This volume is expected to be covered by excavated sand won during seawall construction. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade (including safe foreshore access following storms when the beach is narrow and otherwise hazardous to traverse).

Table 2.3: Sand volumes requirements to offset seawall encroachment

Seawall Concept Option	Maximum beach encroachment (m) [a]	Total Volume Required for Initial Nourishment Option b) Offset seawall encroachment [b] (average m^3/m)	(m^3 x 10^3)
Option 1: Basalt Rock Revetment	12.0	179 (181)	491 (252)
Option 2: Sandstone Rock Revetment	13.0	193 (195)	528 (270)
Option 3: Vertical seawall	0.0	0	0
Option 4: Vertical Seawall with Rock Toe	0.0	0	0
Option 5: Tiered Vertical Seawall with Promenade	0.5 [c]	7 (7) [c]	20 (10) [c]

[a] Calculated based on the difference in cross-shore position of the +2 m AHD contour of each seawall structure and the toe of the existing foredune/rock protection.
[b] Volumes not in brackets are for 2.7 km Terrigal-Wamberal embayment nourishment region.
Volumes in brackets are for 1.4 km section between lagoon entrances fronting seawall (subject to increased potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration).
All volumes include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD) and apply an overfill factor of 1.0.
Nourishment volumes are for provision of beach amenity only and do not include storm demand.
Nourishment volumes will vary depending on the sediment composition of source material and do not consider excavation sand won during seawall construction.
[c] Stage 2 results indicate Seawall Option 5 has minimal impact on available beach width relative to existing conditions. Minor volumes presented for this option in this report offset what is a relatively negligible degree of maximum encroachment of 0.5 m and will be covered by excavated sand won during seawall construction.

2.5.2 Nourishment volume B) Design recession maintenance

This nourishment volume aims to:

- Maintain an acceptable level of public beach width amenity over the 50-year life of the seawall concept design planning period accounting for underlying recession trends and sea level rise (objective B)

A design recession maintenance volume was calculated to account for both long-term recession (Section 2.4.2) and sea level rise recession (Section 2.4.3) by applying design recession rates and Bruun Rule sea level rise profile adjustments to the pre-July storm beach profile data (Bruun, 1962). This sand nourishment volume is to be undertaken on a periodic basis approximately every 10 years.

Design recession sand volumes to be undertaken nominally every 10 years are provided in Table 2.4, calculated using a 2070 design sea level rise projection of +0.45 m (central value RCP 8.5). A total design recession volume for the 2.7 km Terrigal-Wamberal embayment (excluding Terrigal Haven and Spoon Bay) of 141,000 m^3 (average of 51 m^3 per metre of shoreline) was determined. This volume provides approximately 6 m of added beach width (after nearshore spreading) every 10 years to offset design recession.

Sensitivity of design recession sand volumes to sea level rise projections are presented in Table 2.5, showing volumes for lower (+0.19 m lower bound RCP2.6) and upper (+0.59 m upper bound RCP8.5) bound 2070 sea level rise projections being 110,000 to 159,000 m^3 respectively (-22%/+13% relative to the adopted +0.45 m design sea level rise). This represents the expected range of variability in future maintenance nourishment campaigns.

As previously stated, a beach survey program is considered fundamental to monitor/evaluate nourishment performance and adjust maintenance nourishment volumes as required into the future.

Table 2.4: Design recession sand nourishment volumes undertaken every 10 years*

Section	Representative Profile	Section Length (m)	Nourishment volume B): Design recession maintenance approx. every 10 years [a] (m³/m)	(m³ x 10³)
1	1-8	264	51	14
2	2-8	317	42	13
3	3-7	121	40	5
4	4-11	368	51	19
5	5-6	83	55	5
6	5A-5	333	57	19
7	6-9	231	56	13
8	6-20	208	58	12
9	7-9	200	54	11
10	8-6	148	42	6
11	10-5	468	53	25
Total fronting seawall	-	*1423*	*55 (average)*	*78*
Total embayment	**-**	***2741***	***51 (average)***	***141***

[a] All nourishment volumes calculated include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD) and apply an overfill factor of 1.0.
Nourishment volumes will vary depending on the sediment composition of source material.
Nourishment volumes are for provision of beach amenity only and do not include storm demand.

*Increased risk of more frequent maintenance nourishment for rock revetment structures (Seawall Options 1 and 2) every 5-10 years due to high beach encroachment. Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.

Table 2.5: Design recession nourishment sensitivity to sea level rise projections

Sea level Rise Scenario		Nourishment volume B): Design recession maintenance approx. every 10 years[a]			**Design beach width increase after nearshore spreading (m)**
2070 Sea Level Rise Predictions for NSW Coast (m) Glamore et al. (2015)	Corresponding emissions scenario	(average m³/m)	(m³ x 10³)	Relative difference to design SLR(%)	
0.45 m (Design)	***Central value of RCP 8.5***	***51***	***141***	-	5.9
0.19 m	Lower bound value of RCP 2.6	40	110	-22%	3.6
0.59 m	Upper bound value of RCP 8.5	58	159	+13%	7.0

[a] Volumes for 2.7 km Terrigal-Wamberal embayment nourishment region.

2.5.3 Optional nourishment C) Restoration volume

This optional (dependent on sand availability) nourishment volume aims to:

- Optional upfront nourishment to restore any sand losses over recent decades in the Wamberal Beach embayment associated with historical recession (objective C).

A preliminary restoration volume was determined by subtracting the design restoration profile (described in Section 2.3.2) from the reference profile (described in Section 2.3.1). The difference represents sand requirements to restore the beach to the restoration profile and filling in any eroded sections of beach.

Preliminary restoration nourishment volume for the Terrigal-Wamberal embayment (excluding Terrigal Haven and Spoon Bay) are presented in Table 2.6. A total sand volume of 274,000 m^3 (average of 100 m^3 per metre of shoreline) for the embayment was calculated with key areas of nourishment required in the south at Terrigal Beach (Sections 1 and 2) and in the mid-section of the beach between “The Ruins” (25A/B Ocean View Dr) and Lumeah Ave (Sections 5 to 9). Where the beach has been recently depleted between Wamberal and Terrigal Lagoon (Sections 5 to 9), this option will provide on average an additional 10 m (after nearshore spreading) of beach width relative to 2020 pre-storm conditions. This option provides a total sand volume to the Terrigal-Wamberal embayment equivalent to approximately three decades of historical recession for Wamberal Beach (as quantified by Worley Parsons, 2014).

Smaller nourishment volumes near Terrigal and Wamberal Lagoon entrances (Sections 3 and 10) indicate these areas were relatively accreted in the pre-July storm survey.

It should be noted that the restoration volume will vary depending on how the beach has recovered to an accreted state since the July 2020 event as well as evolving trends in beach recession/accretion into the future. A beach survey program pre and post nourishment campaigns is to be undertaken to refine detailed design volumes and to monitor/evaluate nourishment requirements into the future.

Table 2.6: Preliminary restoration nourishment volumes

Section	Representative Profile	Section Length (m)	Nourishment volume A): Preliminary restoration volume [a]	
			(m^3/m)	(m^3 x 10^3)
1	1-8	264	119	31
2	2-8	317	125	40
3	3-7	121	14	2
4	4-11	368	81	30
5	5-6	83	179	15
6	5A-5	333	161	54
7	6-9	231	135	31
8	6-20	208	138	29
9	7-9	200	113	23
10	8-6	148	20	3
11	10-5	468	37	18
Total fronting seawall	-	*1423*	*135 (average)*	*181*
Total embayment	**-**	***2741***	***100 (average)***	***274***

[a] All nourishment volumes calculated include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD) and apply an overfill factor of 1.0.
To be refined during detailed design with pre-nourishment design reference profile survey
Nourishment volumes are for provision of beach amenity only and do not include storm demand.
Nourishment volumes will vary depending on the sediment composition of source material.

2.5.4 Nourishment and design beach width increase

Design increases in beach width (once the nourished sand is spread throughout the nearshore by waves) and implications for beach amenity of each nourishment objective are summarised in Table 2.7. Significantly larger volumes of sand for objective A are required to mitigate rock revetment Seawall Options 1 and 2, with higher encroachment impacts on the available dry beach width (Table E.1). Such volumes are subject to future viability of larger sand nourishment sources being available at the time of construction. This scale of nourishment would require careful design placement considerations to avoid significant increases in beach width fronting the lagoons which would likely pose additional complexities to lagoon entrance management.

The initial beach width increases shown in Table 2.7 assume that the entire placement of sand is on the subaerial beach berm and swash zone. Nourishment volume A) for rock revetment structures could potentially increase the beach width immediately after placement by 30 – 55 m. Management of lagoon entrance breakout to alleviate flooding with such a wide beach berm would likely involve additional complexities and require alterations to lagoon entrance management procedures. Such berm conditions may reduce the likelihood of natural breakout during smaller events disturbing lagoon ecological habitats. Nourishment volume A for rock revetment structures would require alternative nearshore placement (e.g. offshore storm bar) or staged subaerial placement to reduce initial impacts on lagoon entrances (see Section 2.4.5).

Without a viable sand source for objective A nourishment, adoption of the rock revetment structures would lead to more frequent narrow beach conditions reducing access along the beach approximately four times more often than present day beach conditions, approximately five times more often than for the tiered vertical seawall with promenade (Seawall Option 5) and approximately twenty times more often than for vertical seawall options (Seawall Options 3 and 4) (based on Stage 2 report findings as shown in Table 2.7).

In comparison, vertical structures with a smaller footprint and alignment at the rear of the rock revetment options provide minimal encroachment on available beach width. Set back further than the existing ad-hoc rock protection (to be removed during seawall construction), vertical seawall options 3 and 4 are expected to enhance beach amenity by providing additional beach width availability relative to the present day beach and require no additional volume to offset encroachment impacts for objective A. Only a design maintenance nourishment (objective B) would be initially required during seawall construction for these options.

The tiered vertical seawall option with promenade (Seawall Option 5) is expected to have a similar level of beach width amenity as present-day conditions, with only a minor sand volume required to offset minor beach encroachment for objective A. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade (including safe foreshore access following storms when the beach is narrow and otherwise hazardous to traverse).

Table 2.7: Estimated increases in beach width associated with sand nourishment volumes

Design Objective	Nourishment Volume	Design beach width increase after nearshore spreading (m)	Initial beach width increase immediately after placement (m) [a]	Estimated average beach width conditions fronting seawall (based on Stage 2 results) & impact on dry beach user area			
				Without Nourishment		Without Nourishment	
				% of time less than 5 m	% of time less than 5 m	% of time less than 5 m	% of time less than 5 m
				Existing beach estimated to spend on average ~3% of time less than a 5 m width (from Stage 2 results)			
A (Offset)	A) Offsetting seawall encroachment volume						
	Seawall Option 1: Basalt Rock Revetment	+12 m	+30-50 m	10 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 2: Sandstone Rock Revetment	+13 m	+35-55 m	13 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 3: Vertical Seawall	-	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 4: Vertical Seawall with Rock Toe	-	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 5: Tiered Seawall with Promenade	<1 m [d]	1-2 m [d]	3%	Maintained beach width + added promenade amenity	3 %	Maintained beach width + added promenade amenity
	TIMING: Upfront						
B (Maintain)	B) Design recession maintenance volume *TIMING: Optional upfront* *Required ongoing approx. every 10 years* [b]	+ 6 m	+ 10 - 15 m	Diminishing beach width over design life (foreshore access maintained via promenade for Seawall Option 5)		Maintained beach width over design life (with added promenade amenity for Seawall Option 5)	
Optional C (Restore)	C) Optional historical recession restoration volume [c] *TIMING: Optional Upfront*	+ 1 to 10 m [c]	+ 3 - 45 m [c]	3%	As per existing beach	~1%	Restored for past ~30 years of historical recession at start of project.

[a] Assumes entire placement on the subaerial beach berm and swash zone. Alternative placements (e.g, offshore storm bar) may also be considered with reduced initial increase in beach width. Will also vary depending on the sediment composition of source material

[b] Increased risk of more frequent maintenance nourishment for rock revetment structures (Seawall Options 1 and 2) every 5-10 years due to high beach encroachment. Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.

[c] Beach width increases vary along the embayment relative to alongshore patterns in the 2020 pre-storm beach profile data, with notably lower beach width increases at lagoon ends of less than 5 m.

[d] Stage 2 results indicate Seawall Option 5 has minimal impact on available beach width relative to existing conditions. Minor volumes presented for this option in this report offset what is a relatively negligible degree of maximum encroachment of 0.5 m and will be covered by excavated sand won during seawall construction

2.5.5 Overfill considerations

Overfill factors are applied to a design nourishment volume to account for the effect of finer borrow sand than the native beach spreading further offshore and requiring additional nourishment volume. Design nourishment volumes for overfill factors 1.0, 1.4 and 2.0 are provided in Table 2.8. An overfill factor of 1.0 represents a sand source with grain size distribution similar to that of native sand on Wamberal Beach. In practice, obtaining an overfill factor close to 1 may be difficult due to limited sand sources available for nourishment. Higher overfill factors represent sand sources with finer sand that spreads to a larger extent offshore, requiring higher nourishment volumes to meet requirements. Overfill factors for potential sands sources for Wamberal are described in Section 3.

Table 2.8: Design nourishment volumes for varying overfill factors 1.0, 1.4 and 2.0

Nourishment option	Total volume required (m3 x 10^3) [a]		
	Overfill 1.0 (d$_{50}$ ~ native sand)	Overfill 1.4 (Slightly finer d$_{50}$ than native sand)	Overfill 2.0 (Moderately finer d$_{50}$ than native sand)
Nourishment volume A) offset seawall encroachment			
Seawall Option 1: Basalt Rock Revetment	491 (252)	687 (353)	981 (504)
Seawall Option 2: Sandstone Rock Revetment	528 (270)	739 (378)	1056 (540)
Seawall Option 3: Vertical Seawall	0	0	0
Seawall Option 4: Vertical Seawall with Rock Toe	0	0	0
Seawall Option 5: Tiered Vertical Seawall with Promenade	20 (10)	28 (14)	40 (20)
Nourishment volume B) design recession every 10 years	141 (78)	198 (109)	283 (156)
Nourishment volume C) preliminary design nourishment volume	274 (181)	384 (253)	549 (362)

[a] Volumes not in brackets are for 2.7 km Terrigal-Wamberal embayment nourishment region.
Volumes in brackets are for 1.4 km section between lagoon entrances fronting seawall (subject to increased potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration).
All volumes include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD).
Nourishment volumes are for provision of beach amenity only and do not include storm demand.
Nourishment volumes do not consider excavation sand won during seawall construction.

2.5.6 Estimated sand won during seawall excavation

Excavated sand won during construction of each of the seawall concept options is provided in Table 2.9. It is noted that a significant amount of ad-hoc material and rock protection exists in the beach substrate where the proposed seawalls would require excavation. All sand excavated during the construction of the proposed seawall must 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. Excavated sand won is provided in Table 2.9 for scenarios with 20%, 50% and 80% of excavated material being screened sand to be placed on the beach seaward of the structure.

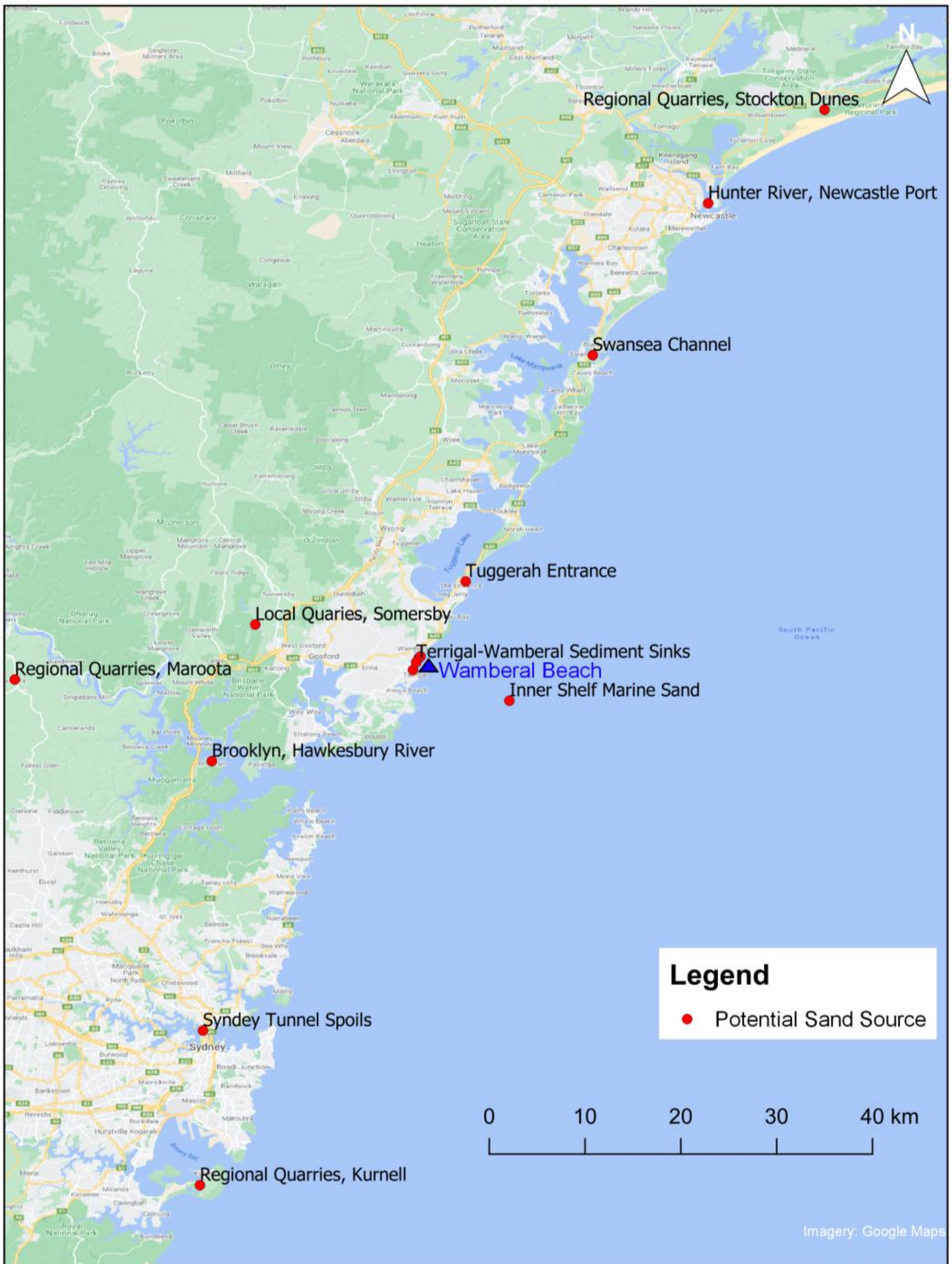
Table 2.9: Estimated sand volume won during seawall construction

Seawall Concept Option	Estimated excavated sand volume won (m3 x 10^3) [a]		
	20% material won	50% material won	80% material won
Seawall Option 1: Basalt Rock Revetment	17	42	67
Seawall Option 2: Sandstone Rock Revetment	17	43	69
Seawall Option 3: Vertical Seawall	1	3	5
Seawall Option 4: Vertical Seawall with Rock Toe	3	7	11
Seawall Option 5: Tiered Vertical Seawall with Promenade	5	13	20

[a] Based on September 2020 MHL drone survey of Wamberal Beach

3 Potential sand sources

A range of potential sand nourishment sources for Wamberal Beach were investigated and assessed as shown in Figure 3.1. These included local and regional quarry sources, transfer of sand from sediment sinks within the Terrigal-Wamberal compartment (lagoon entrances and foredunes), regional port and entrance dredging, offshore inner shelf dredging and Sydney tunnel spoils. These are outlined in the following section.



POTENTIAL SAND NOURISHMENT SOURCES WAMBERAL BEACH

Manly Hydraulics Laboratory

Report MHL2795

Figure 3.1

Figure 3.1.pdf

Potential sand sources for nourishment are outlined considering:

- Location
- Sand composition/suitability
- Estimated resource availability
- Approximate overfill factor
- Method of extraction and delivery to Wamberal Beach
- Indicative unit cost rates ($/m^3): including estimated extraction, delivery and placement costs for Wamberal Beach.

Indicative unit cost rates are for comparison purposes. All sand sources are subject to relevant licensing and environmental approvals to be determined during the detailed design stage of a nourishment campaign.

3.1 Local and regional sand quarries

The closest sand quarries to Wamberal Beach are located approximately 25 km inland on the Somersby Plateau. This region contains areas of leached, friable quartzose sandstone (Hawkesbury Sandstone). A few sand quarries are established in the region and supply fine to medium grained sand from the crushed and processed sandstone bedrock. When contacted, a number of these quarries were unable to supply sand for nourishment purposes to Wamberal Beach due to high regional construction industry demand and limited resource availability.

Potential availability of sand for nourishment was identified at Grants Rd Sands, Somersby, with grading composition and indicative unit cost rates provided in Table 3.1. From a preliminary evaluation of sediment properties, sand from the quarry is considered suitable for sand nourishment purposes but should undergo further assessment and approval of suitability as part of detailed design. Unit costs rates include extraction and delivery to Wamberal Beach (provided by quarry) as well as estimated placement costs. Supply availability from the quarry may vary depending on construction industry demand.

Table 3.1: Sand source properties from Grants Rd Sand, Somersby (per comms)

Source	Description
Location	Grants Rd, Somersby Plateau
Sediment composition/suitability	Ripped sandstone – D_{50} of 0.41 mm, approximately 3% silt and 5% gravels.
Approx. annual supply rate	~50,000 m^3 / year (after screening of gravels)
Overfill factor	1.3
Estimated resource availability	Project approval in 2014 for 30 year period of extraction. Supply availability may vary depending on construction industry demand.
Method of extraction/delivery	Ripped sandstone, washed, trucked.
Indicative unit cost (inc. delivery and placement)	$50 / m^3
Quarry Contact	Grants Rd Sand, Somersby

Details of regional sand supply and nourishment suitability from quarries in the Stockton region are provided in the Stockton Coastal Management Program (Royal HaskoningDHV, 2020) and summarised in Table 3.2. Sources from the region are from dry extraction of windblown sand dune deposits in the Stockton Bight, with typical median grain sizes slightly finer than that of native sand material at Wamberal Beach (D_{50} between 0.3 to 0.38 mm) (Royal HaskoningDHV, 2020). An overfill factor of 2.5 was adopted as part of the Stockton CMP for these sand sources and would likely be similar for Wamberal Beach, hence requiring 2-3 times the amount of sand volume. An estimated unit cost of $80/m^3 for delivery and placement to Stockton Beach was adopted in the Stockton CMP. Considering additional haulage to Wamberal this is expected to be in excess of $100/m^3 and notably high compared to other potential sand sources. Additional regional quarries are noted at Maroota and Kurnell and could be further assessed for sand nourishment suitability if this pathway is to be further pursued.

Table 3.2: Regional sand source properties from Stockton Dunes (Royal HaskoningDHV, 2020)

Source	Description
Location	Stockton Bight Quarries
Sediment composition/suitability	Wind-blown sand dune deposits – D_{50} of 0.3-0.38 mm
Approx. annual supply rate	~200,000 m^3 / year
Overfill factor	2 - 3
Estimated resource availability	Supply availability may vary depending on construction industry demand.
Method of extraction/delivery	Dry extraction, trucked.
Indicative unit cost for Wamberal (incl delivery and placement)	>$100 / m^3

Assessment of resource

Supply availability from local and regional sand quarries for beach nourishment are considered relatively limited and expensive due to high regional construction industry demand and limited resource availability.

Grants Rd Sands has sufficient material under their current approvals to supplement nourishment requirements for Wamberal Beach alongside other potential sand sources. Supplementary sand from regional quarries at Stockton is expected to have a high unit cost in comparison to other potential sources.

3.2 Lagoon entrances

The entrances of Wamberal and Terrigal Lagoon are located at the northern and southern ends of the proposed seawall location on Wamberal Beach. The two entrances act as potential sediment sinks within the Terrigal-Wamberal embayment, infilling with native marine sand from the Wamberal Beach system. These entrances are typically closed due to formation of a beach berm fronting the entrance. Council provides berm entrance management and mechanical openings to alleviate flood impacts on low-lying development surrounding the lagoon foreshores. On average between 1976 and 2007, the entrances were mechanically opened 12.6 times per year at Terrigal (average open duration of 8 days after opening) and 2.7 times per year at Wamberal (average open duration of 10 days after opening) (WorleyParsons, 2014).

NSW GOVERNMENT

LAGOON ENTRANCE MARINE SAND INFILL REGIONS

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Report MHL2795
Figure
3.2

Figure 3.2.pdf

Infilled marine sand dominates the seaward entrance regions of Terrigal and Wamberal Lagoon, which become muddier closer towards central regions of the lagoon water body. Typical regions of marine sand infill in each of the entrances were identified via visual inspection of historical satellite imagery and are provided in Figure 3.2. For Terrigal Lagoon this region is contained between the Ocean View Dr bridge to the west, bedrock outcrops along Terrigal Drive to the south and the entrance berm to the east. For Wamberal Lagoon this region extends approximately 300 m upstream into the entrance channel. Sieve analysis of the surficial 0.2 m of marine sands indicate mean grain sizes of 0.125 - 0.4 mm at Terrigal Lagoon and 0.4 mm at Wamberal Lagoon (Albani and Brown, 1976).

Preliminary estimates of available sand volume were undertaken based on 2018 DPIE bathymetry data for each entrance region. This was calculated based on the volume within each of the marine sand infill regions (Figure 3.2) above a representative channel bed level -0.5 m AHD determined from the bathymetry data and assuming that all sediment above this level is marine sand.

For Terrigal Lagoon a total volume of approximately 20,000 m^3 was estimated above -0.5 m AHD in the entrance region. For Wamberal Lagoon a total volume of approximately 23,000 m^3 above -0.5 m AHD in the entrance region was estimated, with notable volumes along the southern bank of the entrance channel. It should be noted that during flood events, these entrance regions will naturally scour and deposit some of this volume, as well as sand from the entrance berm, offshore in the surfzone prior to subsequent infilling and berm regrowth. These volume estimates are preliminary and would be refined with detailed design.

It is noted that catchment infilling rates are much higher than that of marine sand infill, estimated by Worley Parsons (2014) to be approximately 1 million kg of sediment per year for all of the four Gosford coastal lagoons. This is equivalent of 600,000 m^3/year or an average of 150,000 m^3/year per lagoon due to catchment processes. This sediment is not considered suitable for beach nourishment as it is predominately composed of silts and fines.

Lagoon entrance marine sand can be extracted via dredge or dry operation and pumped directly on to the beach, with indicative unit costs of $20 - 40 / m^3 based on similar projects on the NSW coast. A number of NSW coastal lake and lagoon entrances are likewise routinely excavated or dredged in NSW for flood, navigation and/or coastal management purposes (e.g. Narrabeen-Collaroy, Tuggerah Lakes Entrance, Swansea Channel) with sand retained within the littoral system by being transferred to the open coast by truck or sand pumping to alleviate coastal erosion.

To reduce impact on natural water level variability in the lagoons, dredging of the entrance region should not include the entrance berm, with present berm management practices to be continued. Environmental impacts on entrance behaviour of this option are expected to be similar to those naturally induced by large flood events when marine sand in the entrance region is naturally scoured, deposited offshore and re-infills the entrance with time.

Design of lagoon entrance dredging campaigns would need to consider impacts on recreational areas, beach access and amenity at lagoon entrances. The northern side of Terrigal Lagoon entrance near Pacific St, is a major beach access point and popular family recreational area.

Table 3.3: Sand source properties from Wamberal and Terrigal Lagoon entrances

Source	Description
Location	Wamberal and Terrigal Lagoon Entrances
Sediment composition/suitability	Marine sand from within the Terrigal-Wamberal system
Overfill factor	1.0 (native sand)
Estimated volume available	43,000 m^3 (20,000 at Terrigal and 23,000 at Wamberal) based on sand volume above a representative channel bed level of -0.5 m AHD level.
Method of extraction/delivery	Dredge or dry operation, pumped directly to beach
Indicative unit cost	\$20 - 40 / m^3

Assessment of resource

Sand from this source is located within the Terrigal-Wamberal embayment such that this option provides sand redistribution (movement of sand within a system) rather than nourishment (addition of sand to the compartment). Regions of sand extraction from lagoon entrance sand will naturally infill with time following removal, particularly with dry weather conditions and low catchment outflows, and require repeat entrance dredging campaigns to return the sand to the beach. A similar program is undertaken at Tuggerah Lakes entrance and Narrabeen Lagoon.

3.3 Active foredune management

North of Wamberal Lagoon entrance lies an extensive dune system with crest levels of +20 to +30 m AHD. Preliminary analysis of historical beach profile data from 1941 to present was undertaken to quantify the degree of foredune growth in the region between Wamberal Lagoon and the rock shelf 500 m to the north as shown in Figure 3.3. Foredune volumes (volume above +4 m AHD and landward of the +10 m AHD on seaward face of dunes) were found to be have steadily accreted on average 40-60 m^3/m over the past 50 years. This foredune growth equates to approximately 25,000 m^3 for the region shown in Figure 3.3 and does not account for likely additional growth in the extensive dune system further landward and potentially further north. Active foredune management program could potentially be undertaken to cap the growth of the incipient foredune in this region to a design foredune profile and use this sand to replenish the beach berm elsewhere within the embayment. Foredune management mechanisms would require careful consideration as to minimise potential ecological impacts.

Table 3.4: Sand source properties from Wamberal and Terrigal Lagoon entrances.

Source	Description
Location	Wamberal and Terrigal Lagoon Entrances
Sediment composition/suitability	Wind-blown marine sand from within the Terrigal-Wamberal system with slightly higher proportion of fine sands than beach berm.
Overfill factor	1.5 - 3 (native sand wind-blown)
Estimated volume available	25,000 m^3
Method of extraction/delivery	Dry excavation / trucking alongshore
Indicative unit cost	\$15 - 30 / m^3

Figure 3.3:Region of incipient foredune growth north of Wamberal Lagoon

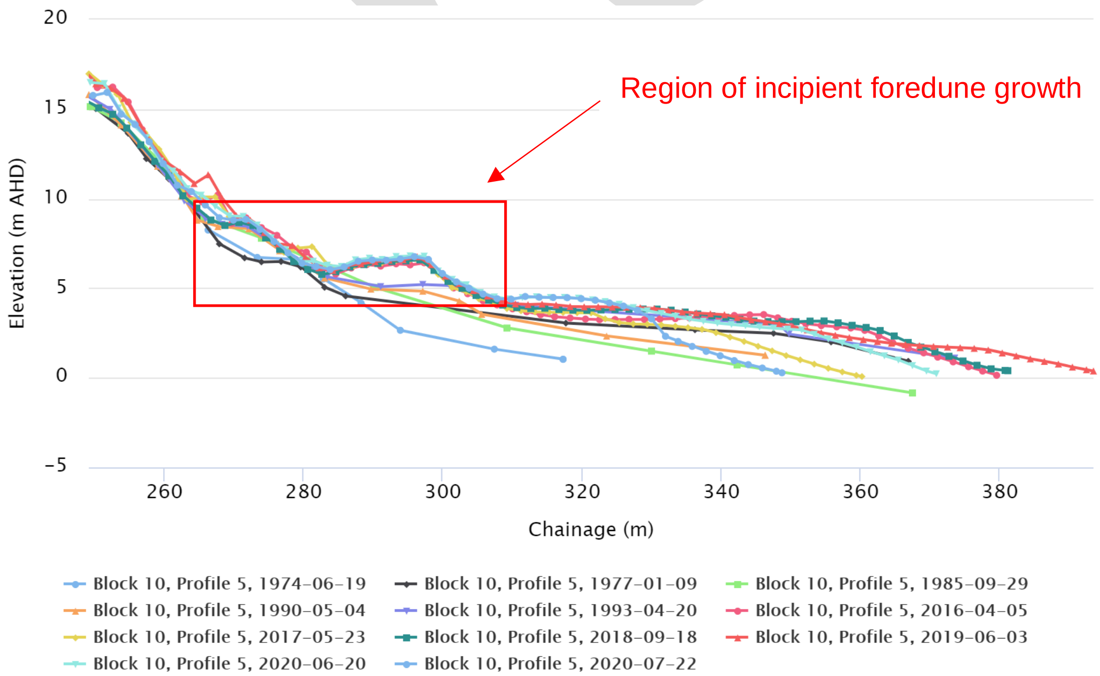

Figure 3.4: Foredune growth at Profile 10-5 north of Wamberal Lagoon.

Figure generated using the NSW Beach Profile Database (DPIE, developed by WRL UNSW). www.nswbpd.wrl.unsw.edu.au

Assessment of resource

Sand from this source is located within the Terrigal-Wamberal embayment such that this option provides sand redistribution (movement of sand within a system) rather than nourishment (addition of sand to the compartment). Windblown sand build-up is likely to continue in the future with repeated foredune management required under this option. Available sand volumes are relatively low and will require supplementary sources. Windblown sand in the foredunes is generally finer than that of the beach berm, requiring additional volume (overfill) than other potential sources. Detailed environmental impact assessment of this sand source would be required to address any potential impacts on the Wamberal Lagoon Nature Reserve dune system and would require approval from National Park and Wildlife Services who are responsible for managing the Nature Reserve.

3.4 Port and navigation dredging

Regional ports and marinas require dredging during expansion works and ongoing maintenance to remain operating. The closest major port to Wamberal Beach is the Port of Newcastle. The current dredging regime for the Port of Newcastle sees up to 30,000 m^3/y of dredged material placed in the nearshore zone of Stockton Beach (Royal HaskoningDHV, 2020). Under the current regime, dredged material from the Port of Newcastle is considered exhausted by Stockton Beach nourishment requirements.

The Stockton CMP also noted potential future opportunities with improved for the Port of Newcastle dredging capacity in the order of 112,000 m^3/y as well as additional dredging areas of the South and North Arm of the Hunter River (subject to required approvals) with potentially significant volumes in the order of several million cubic metres (Royal HaskoningDHV, 2020). Unit cost estimates shown in Table 3.5 for Cutter Suction Dredging, barging and placement at Wamberal Beach are relatively high given the approximate 70 km haulage distance. Costs may be reduced when undertaken as part of a larger scale regional nourishment campaign(s) to reduce mobilisation costs. Consultation with Port of Newcastle is warranted to further investigate these opportunities as more information becomes available.

Table 3.5: Sand source properties from Hunter River. From Royal HaskoningDHV (2020) with unit cost estimates for hopper barging to Wamberal Beach.

Source	Description
Location	Hunter River South and North Arm
Sediment composition/suitability	Clean medium grained marine sand
Overfill factor	Unknown
Estimated volume available	Potentially significant up to the order of several million m^3
Method of extraction/delivery	Cutter Suction Dredge / Barge / Nearshore placement
Indicative unit cost	\$60 - 120 / m^3 with potential for cheaper costs if undertaken as part of a regional nourishment campaign.

The NSW Bar to Beach Program (MHL2432, 2016) provides a comprehensive summary of the opportunities linking dredging operations with coastal hazards mitigation and beach amenity improvements along the NSW coastline. The report noted that a well-structured Program has significant potential to maximise the value of dredging operations to best utilise limited sand resources while enabling regional growth through improved safe and sustainable access to our coastal waterways and harbours for the benefit of NSW communities.

The report identified Brooklyn Marina in the Hawkesbury River estuary as a potential sand source for Wamberal Beach nourishment with approximately 100,000 m^3 of available sand. The marina is situated approximately 20 km south of Wamberal Beach. For delivery and placement, unit cost rates (indexed to present values using a rate of 4%) varied between approximately \$23 to \$43 / m^3 depending on the size of Hopper dredge adopted. Dredge material is expected to be clean marine sand with less than 10% fines.

Table 3.6: Sand source properties from Brooklyn, Hawkesbury River. From MHL2432 (2016).

Source	Description
Location	Brooklyn, Hawkesbury River
Sediment composition/suitability	Clean marine sand with less than 10% fines.
Overfill factor	Unknown
Estimated volume available	100,000 m^3
Method of extraction/delivery	Hopper dredge and pumping
Indicative unit cost	\$25 - 45 / m^3

The Swansea Channel is periodically dredged by NSW DPIE Crown Lands to maintain safe navigation of vessels into Lake Macquarie. Records from 1970 indicate a total of around 700,000 m^3 of sand has been dredged in the Swansea Channel in the last 45 years, removing typically 10,000 - 50,000 m^3 every one to five years with some isolated major dredging campaigns on the order of 100,000 m^3 (Morgan et al., 2014). Dredged material is either pumped directly to Blacksmiths Beach or stockpiled at the Belmont Sand Stockpile site at Pelican (Royal HaskoningDHV, 2020).

Mean grainsize of stockpiled dredge spoils are reported by Royal HaskoningDHV (2020) and range from 0.21 – 0.41 mm depending on the section of channel that is dredged. Unit cost for delivery via hopper barge and placement at Wamberal Beach 47km south of Swansea Channel is estimated at \$40-80/m^3.

Dredge material at Tuggerah Lakes entrance was identified but not considered as a potential source given its required placement on The Entrance Beach South and North Entrance.

Table 3.7: Sand source properties from Swansea Channel.

Source	Description
Location	Swansea Channel, Lake Macquarie
Sediment composition/suitability	Fine to medium grained marine sand.
Overfill factor	2
Estimated volume available	10,000 - 50,000 m^3 every 1-5 years with more infrequent major dredging on the order of 100,000 m^3.
Method of extraction/delivery	Hopper dredge/pumping
Indicative unit cost	\$45 - 80 / m^3

Assessment of resource

Future opportunities indicate potential for large-scale sand volumes (several million m^3) from dredging in the North and South Arm of the Hunter River. Haulage to Wamberal via barge is expected to be relatively expensive compared to other options given the distance. Costs may be reduced if this source was used to make undertake a broader-scale regional nourishment campaign. A regional nourishment program, such as the NSW Bar to Beach Program, is considered a highly beneficial and cost-effective means of nourishment for Wamberal Beach as well as additional erosion hotspots along the NSW coast. Material at other entrances such as Swansea Channel and Tuggerah Lakes entrance is likely to be exhausted by local sand requirements closer to the source.

3.5 Offshore dredging of inner shelf sand

The NSW coastline contains numerous marine sand deposits located in 20 – 80 m water depth on the inner continental shelf as shown in Figure 3.5 (termed inner shelf sand sheets). Inner shelf sand deposits are estimated to cover approximately 8000 km^2 of which around 70% are located north of Sydney (Roy, 2001). The Sydney Coastal Councils Group Beach Sand Nourishment Scoping Study documented a number of marine sand deposits located in the Sydney Region (AECOM, 2010).

Of particular significance to Wamberal Beach are applications for a mineral exploration licences, submitted by Sydney Marine Sand Pty Ltd (under the Commonwealth of Australia Offshore Minerals Act, 1994) for exploration of marine sand deposits in regions offshore of Wamberal Beach (Sydney Marine Sand Pty Ltd, 2012). Applications have been submitted in 2006 and 2012 with areas shown in Figure 3.6. The latest application in 2012 covered an area of 150 km^2 located in 50 to 80 m water depth offshore between Wamberal Beach on the Central Coast and Warriewood on Sydney's Northern Beaches (Sydney Marine Sand Pty Ltd, 2012).

Limited seabed sediment samples of the inner shelf deposit from Geoscience Australia's MARine Sediment (MARS) database show typically >98% sand composition with <2% mud and minimal gravel. Images collected of the seabed by Sydney Marine Sand Pty Ltd (2012) show typical soft sediment habitats with fine to medium grained sandy seabed with coarser shell fragments. Potential sand volumes from inner shelf marine deposits are significant, estimated by AECOM (2012) to be in the order of 10 million m^3, and suitable for large-scale regional nourishment campaigns.

Sand extraction methods for inner shelf marine deposits and nourishment placement methods are noted by AECOM (2012) and Carley and Cox (2017) and include:

- Trailer Suction Hopper Dredge extraction of inner shelf sand at targeted offshore depths & locations associated with low environmental impact on adjacent beaches and ecology. Trailer Suction Hopper Dredges are suited to operating in high wave energy environments and inner shelf water depths whilst minimising dredge plume generation.
- Haulage to approximately 20 m water depth.
- Nearshore placement in shallow water depths either via:
    - transfer pipelines connected to a spreader pontoon, or
    - bottom dump and retrieval of a smaller Trailer Suction Hopper Dredge to transfer

    and bottom bump in shallow depths, or
  - rainbowing of dredged material into shallower water depths
- Subaerial beach placement via pumping ashore and profiling

Noting that a major proportion of the cost is mobilisation/demobilisation of an international dredger, unit cost estimates of offshore dredging for Wamberal Beach are $10-30/m^3, with potentially cheaper costs (<$10/m^3) if undertaken as part of a broader regional nourishment campaign to share the mobilisation/demobilisation costs. Recent large-scale (several million m^3) offshore dredging with nearshore placement on the Gold Coast was achieved for as little as $3-5/m^3 (per comms).

Details of other exploration licences and mining lease applications in the regional area off Sydney and areas of the Central Coast are described in AECOM (2010). Despite being common practice in other states (e.g., Gold Coast, QLD) and countries, extraction of offshore sand for beach nourishment has not been undertaken in NSW due to community and Government concerns regarding potential environmental impacts (Carley and Cox, 2017).

Table 3.8: Sand source properties from offshore dredging. From AECOM (2012) and Carley and Cox (2017).

Source	Description
Location	Inner continental shelf marine sand deposits 50-80m water depth
Sediment composition/suitability	Clean fine to medium grained marine sand.
Overfill factor	1 - 2
Estimated volume available	Likely significant - on the order of 10 million m^3
Method of extraction/delivery	Trailer Suction Hopper Dredge and nearshore placement
Indicative unit cost	$10 - 30 / m^3 with potentially cheaper costs (<$10/m3) if undertaken as part of a broader regional nourishment campaign

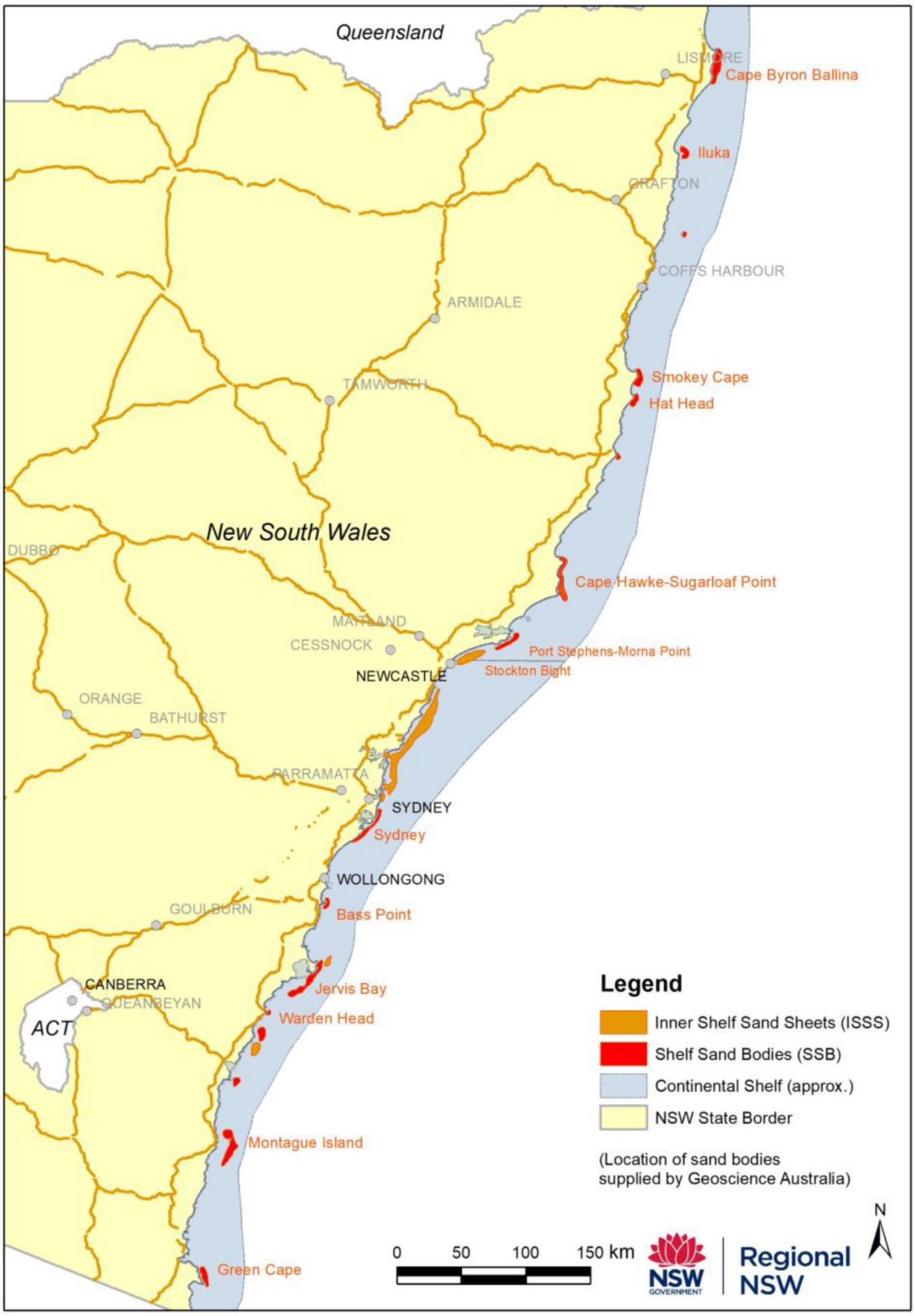

Figure 3.5: NSW marine sand bodies location map (adapted from NSW Trade & Investment, 2016)

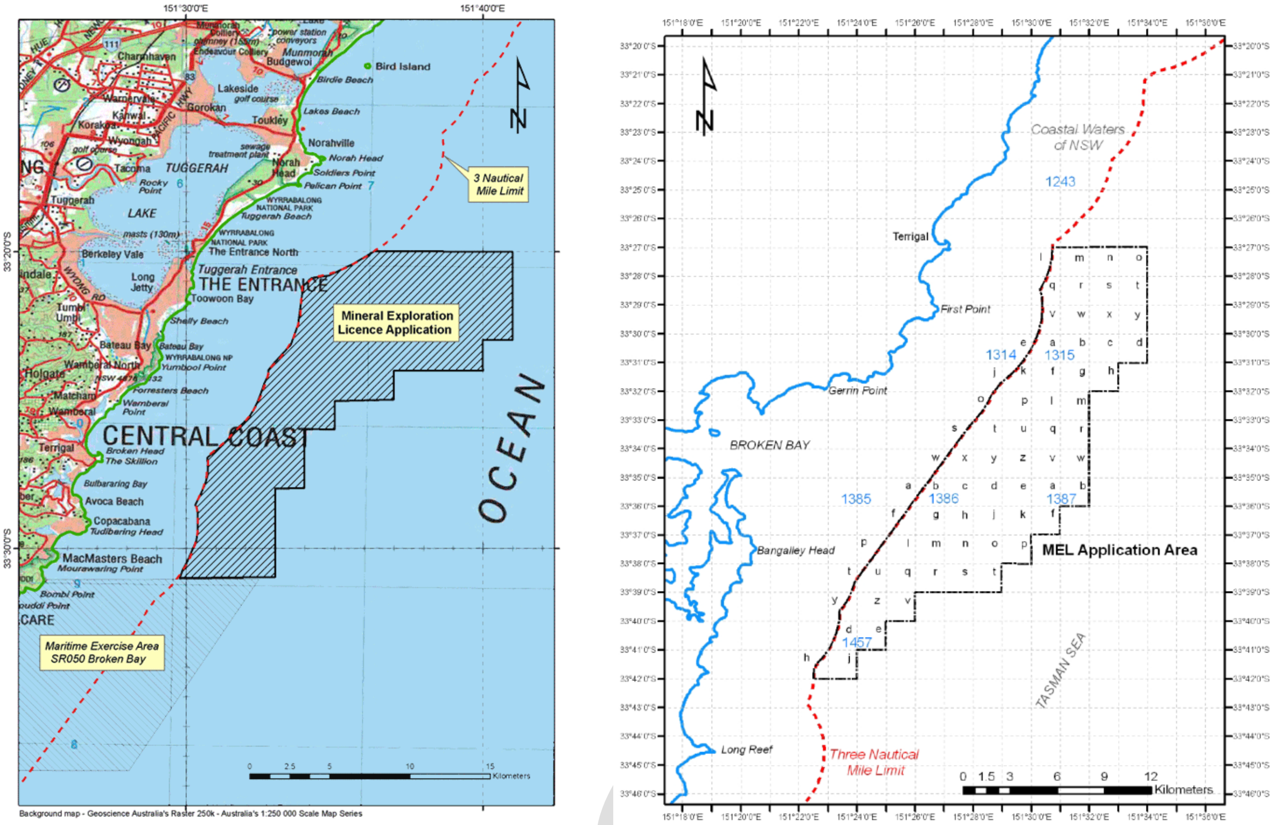

Figure 3.6: Sydney Marine Sand Pty Ltd. Exploration Licence Applications offshore of Wamberal Beach. Applications from 2006 (left) and 2012 (right) (Sydney Marine Sand Pty Ltd, 2012)

Assessment of resource

Offshore dredging of inner shelf marine deposits has significant potential for sand nourishment in NSW. Unit cost rates are relatively low in comparison to other sources and can be significantly reduced if undertaken as part of a broader regional nourishment project involving multiple beneficiaries and cost-sharing opportunities.

Despite its significant potential and adoption in other states/countries, offshore dredging is currently not undertaken in NSW, with proposals for offshore sand mining ventures not progressing due to community and Government concerns of potential environmental impacts (Carley and Cox, 2017). Potential environmental impacts listed by Carley and Cox (2017) include physical (changes to wave refraction, beach impacts and burial of shipwrecks and reefs) and ecological impacts (habitat disturbances, burial of reefs). Careful project design can assist to mitigate these impacts including recolonisation of disturbed habitats in extraction and placement areas.

3.6 Sydney tunnel spoil opportunities

The Stockton CMP noted potential sand nourishment sourcing from spoil material generated from Sydney Metropolitan tunnel projects including the Sydney Metro (Metro West), Western Harbour Tunnel and WestConnex Stage 3b (Royal HaskoningDHV, 2020). These major infrastructure works are expected to generate several million m^3 of sand potentially suitable for nourishment via operation of tunnelling equipment (roadheader or tunnel boring machine) (Royal HaskoningDHV, 2020).

The Stockton CMP documents tunnel spoil material from these projects with grainsize distributions containing around 10% fines and up to cobble size diameters (Royal HaskoningDHV, 2020). The study noted that spoil could be washed and screened prior to subaerial beach placement or alternatively placed in the nearshore without washing and screening.

Approval pathways in the Stockton CMP consider a government agency obtaining a 'concept approval' for use of tunnel spoils as beach nourishment and other significant future sand sourcing opportunities (Royal HaskoningDHV, 2020). The 'concept approval' pathway is documented in Section 5 of the Stockton CMP.

Table 3.9: Sand source properties from Sydney tunnel spoils. Based on information from Royal HaskoningDHV (2020)

Source	Description
Location	Sydney Metropolitan area
Sediment composition/suitability	Tunnel spoil material - Poorly sorted sand with 10% fines and presence of cobbles
Overfill factor	Unknown
Estimated volume available	Potentially significant - on the order of several million m^3
Method of extraction/delivery	Tunnel equipment / trucking to Wamberal. Either washed and screened or placed in nearshore.
Indicative unit cost	Potentially less than \$10/m^3

Assessment of resource

Sediment composition of Sydney Tunnel spoils remain largely unknown and requires further investigation to determine suitability for sand nourishment. If suitable, this option provides a likely low-cost nourishment source with potentially high volumes available, provided the timing can be synchronised.

3.7 Environmental impacts of sand nourishment

Potential environmental impacts of sand nourishment are summarised by Carley and Cox (2017) and are listed in Table 3.10. Environmental impacts of sand nourishment can be reduced through careful project design of nourishment campaigns and environmental impact assessments. Methods to reduce environmental impacts will vary depending on the nature of the nourishment project adopted and can include testing of source sand composition, turbidity control measures, project design studies to determine benign extraction and placement techniques (e.g., methods, pattern, depth, location, etc), adoption of buffer zones to vulnerable habitats, regular monitoring, revegetation of disturbed habitats and close partnership with local environmental groups and experienced organisations to achieve environmental outcomes. Environmental impact assessment and licencing approvals are required to be undertaken in the detailed design of an adopted sand nourishment program.

Table 3.10: Potential environmental impacts of sand nourishment. From Carley and Cox (2017).

Zone of Beach	Potential environmental impacts
Subaerial	Disturbances of native biota inhabiting beach sands and associated foraging species. Disruption to nesting and breeding areas Burial of beach habitats Changes to native beach sediment composition and properties Alteration of beach from natural state Impacts on lagoon entrances and coastal flooding Impacts on adjacent beaches and ecological communities
Subaqueous	Changes to wave refraction Changes in nearshore bathymetry and wave action Changes to surf conditions and beach safety depending on placement Burial of shipwrecks, seagrass beds and reefs Increased turbidity Disturbances to reef habitats and seagrass bed ecology
Borrow area	Removal of benthic vegetation and organisms in sediment (recolonisation dependent on extraction method adopted) Increased turbidity and water quality impacts Infilling of offshore extraction areas Impacts on vulnerable habitats within buffer zones
Other	Impacts of equipment used in beach nourishment including noise, air pollution/carbon emissions, ship movements and potential spills Contamination of source material (eg heavy metals, weeds etc)

3.8 Policy and Legal Context

Policy and legal frameworks that may apply to sand nourishment projects are outlined by Carley and Cox (2017). An excerpt from this report is provided below:

A range of Commonwealth and NSW Acts may apply to any proposal to extract sand for beach nourishment. These may include:

Commonwealth

- Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)
- Telecommunications and Other Legislation Amendment (Protection of Submarine Cables and Other Measures) Act 2005

NSW

- Coastal Management Act 2016
- Offshore Minerals Act 1999 No 42
- Environmental Planning and Assessment Act 1979 (EP&A Act)
- Marine Estate Management Act 2014 No 72 and Marine Estate Management Regulation 2009

Other NSW Acts

- Protection of the Environment Operations Act 1997
- Threatened Species Conservation Act 1995
- Fisheries Management Act 1994
- Crown Lands Management Act 2016
- National Parks and Wildlife Act 1974

NSW Legislation

(NSW) Offshore Minerals Act 1999 No 42

Sand or marine aggregate is a mineral under Section 22 of the (NSW) Offshore Minerals Act 1999. An entity is required to hold a mining licence under Part 2.4 of the Act in order to recover marine aggregate from the seabed within the 3 nautical mile limit.

(NSW) Marine Estate Management Act 2014 No 72

The Marine Estate Management Act 2014 No 72 contains the following clauses which prohibit sand mining within marine parks and aquatic reserves except in limited circumstances such as "conservation purposes":

Division 6 Development and activities within marine parks and aquatic reserves 54 Mining in marine parks and aquatic reserves prohibited

(1) It is unlawful to prospect or mine for minerals in a marine park or an aquatic reserve.

(2) The Offshore Minerals Act 1999, the Mining Act 1992, the Petroleum (Onshore) Act 1991 and the Petroleum (Offshore) Act 1982 do not apply to or in respect of any area within a marine park or an aquatic reserve.

(3) This section does not apply to or in respect of any licence, permit, authorisation or

lease in force under any of those Acts:

(a) in relation to a marine park—as at 1 August 1997, and Note. Section 18 of the Marine Parks Act 1997 (the predecessor of this provision in relation to marine parks) commenced on 1 August 1997.

(b) in relation to an aquatic reserve—as at 31 March 2002. Note. Section 197B of the Fisheries Management Act 1994 (the predecessor of this provision in relation to aquatic reserves) commenced on 31 March 2002. However, no renewal or extension of such a licence, permit, authorisation or lease may be granted after those dates except as expressly authorised by an Act of Parliament.

(4) This section does not apply to or in respect of sand extraction within a marine park for conservation purposes or for the purpose of preventing the risk of serious injury to a person or harm to the environment that is carried out in accordance with a consent granted under this section and any other authorisation required under any other Act.

(5) The relevant Ministers may grant consent (with or without conditions) to the carrying out of sand extraction within a marine park but only if satisfied that the sand extraction is for a purpose referred to in subsection (4).

(6) In deciding whether to grant consent, the relevant Ministers must have regard to the assessment criteria (if any) prescribed by the regulations.

In Clause (4) above "sand extraction within a marine park for conservation purposes" could be construed as sand extracted for beach nourishment. Ministerial consent for this would consider assessment criteria under the Marine Estate Management Regulation 2009.

NSW Policy

As stated above, while the Offshore Minerals Act was gazetted on 31 March 2000, no regulations have been gazetted or promulgated that will allow an entity to apply for a mining licence off the NSW coast.

Beach Scraping

Beach scraping could be undertaken under State Environmental Planning Policy (Infrastructure) 2007 as a foreshore management activity. It would generally be undertaken under Part 5 matter with the local government authority being both the proponent and approval authority. Depending on the scale of the works, generally a Review of Environmental Factors (REF) or Statement of Environmental Effects (SEE) would be undertaken as part of the approval. A range of other assessments and permits may be required in NSW depending on the specific work location, including:

- Crown Lands;
- Aboriginal Cultural Heritage Assessment/Surveys and/or Aboriginal Heritage Impact Permit;
- Permit for destruction of marine vegetation;
- Species Impact Statement.

Current prohibition on offshore minerals extraction are noted by AECOM (2010):

> *There is currently a prohibition on offshore minerals extraction due to the effect of the Offshore Minerals Act 1999 (NSW). It would require an amendment to Schedule 2 of the Offshore Minerals Act 1999 and the introduction of companion regulations to enable a mining licence to be issued over an area of sand within the State Government 3Nm limit to enable sand to be recovered for beach nourishment purposes. Changes of this nature would require considerable discussions with Government at the highest levels.*

4 Summary and recommendations

This report provides the outcomes of Stage 4 of the Wamberal Terminal Coastal Protection Assessment, namely the investigation of sand nourishment options to be undertaken in association with terminal protection design at Wamberal Beach (CZMP, 2017). Sand nourishment has been investigated for the primary purpose of maintaining public beach amenity for the Wamberal/Terrigal embayment over the life of the terminal protection structure, considering underlying long-term recession rates, sea level rise and seawall encroachment. The report includes an outline of sand nourishment requirements for Wamberal Beach and investigation of potential sand sources including indicative unit cost estimates.

Sand nourishment as structural protection for un-piled beachfront structures has not been considered in the sand nourishment investigation given the adoption of terminal protection outlined in the certified Gosford Beaches CZMP (2017). This has previously been reported primarily due to the lack of readily available sand sources (potential sources subject to future legislative and planning viability) required for large-scale nourishment to sufficiently mitigate the prevailing storm erosion hazard without terminal protection. Large-scale nourishment also poses a number of complexities including implications on flooding and lagoon entrance management, broader embayment-wide environmental impacts on existing nearshore environments, seabed habitats and reefs, as well as ongoing commitments to maintaining a sufficient storm erosion buffer.

The design objectives of sand nourishment are outlined in Section 2.1. It is important to note that it is unrealistic to expect a nourishment program to maintain a consistent beach width given the dynamic nature of high-energy sandy beaches such as Wamberal Beach. Nourished beaches will continue to naturally fluctuate and evolve due to temporal changes in wave conditions, storm erosion and accretion cycles, beach rotation and other coastal drivers. Beach nourishment seeks to address longer-term deficiencies in public beach amenity over periods of years to decades.

Establishment of a beach monitoring program is considered fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works. This would benefit from the provision of subaqueous and subaerial beach surveying on a regular basis and before/after major events similar to that undertaken on the Gold Coast and at Narrabeen-Collaroy Beach (Strauss et al., 2017; Turner et al., 2016).

To enhance sand nourishment longevity, nourishment should ideally be undertaken for the 2.7 km Terrigal-Wamberal embayment between the rock shelf at the southern end of Terrigal Beach near Ash St to the rock shelf approximately 500 m north of Wamberal Lagoon (excluding Terrigal Haven and Spoon Bay). This however is subject to sand availability at the time of the nourishment campaign. Smaller sand nourishment targeting the 1.4 km region fronting the seawall (between Terrigal and Wamberal Lagoon Entrances) is still considered beneficial to enhancing beach amenity, albeit with higher potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration for larger volumes. Sand volume requirements have been provided for both these regions. Design parameters for nourishment are provided including long-term recession rates, sea level rise, cross-shore and alongshore spatial considerations, placement considerations, native sand characteristics and borrow sand compatibility criteria.

Required nourishment volumes to meet each of the design objectives are provided in Table 4.1 including design beach width increases after nearshore spreading and estimated impacts on beach amenity (based on Stage 2 results). Excavation sand won during seawall construction should be used to contribute toward nourishment requirements and has also been estimated in the report.

To address objective A, sand volume requirements were calculated to mitigate or offset the impacts of seawall encroachment on the present-day dry beach width available for public use. Seawall concept options from the *Stage 3 Seawall Concept Design Options (in draft)* were assessed. Sand volume requirements to meet objective A are provided in Table 4.1 and are considered an upfront nourishment requirement to be undertaken with seawall construction.

Significantly larger volumes of sand for objective A are required to mitigate rock revetment Seawall Options 1 and 2, with higher encroachment impacts on the available dry beach width (Table 4.1). Such volumes are subject to future viability of larger sand nourishment sources being available at the time of construction. This scale of nourishment would require careful design placement considerations to avoid significant increases in beach width fronting the lagoons which would likely pose additional complexities to lagoon entrance management.

Without nourishment for objective A, the rock revetment structures would lead to more frequent narrow beach conditions reducing access along the beach approximately four times more often than present day beach conditions, approximately five times more often than for the tiered vertical seawall with promenade (Seawall Option 5) and approximately twenty times more often than for vertical seawall options (Seawall Options 3 and 4) (based on Stage 2 report findings).

In comparison, vertical structures with a smaller footprint and alignment at the rear of the rock revetment options provide minimal encroachment on available beach width. Set back further than the existing ad-hoc rock protection (to be removed during seawall construction), vertical Seawall Options 3 and 4 are expected to enhance beach amenity by providing additional beach width availability relative to the present day beach (refer to Stage 2 report) and require no additional volume to offset encroachment impacts for objective A (Table 4.1).

The tiered vertical seawall option with promenade (Seawall Option 5) is expected to have a similar level of beach width amenity as present-day conditions (refer to Stage 2 report). Nourishment requirements for objective A for Seawall Option 5 in Table 4.1 are minor and offset what is a relatively negligible degree of maximum encroachment of 0.5 m for this option. This volume is expected to be covered by excavated sand won during seawall construction. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade (including safe foreshore access following storms when the beach is narrow and otherwise hazardous to traverse).

To address objective B, a design recession maintenance nourishment volume was calculated to account for both long-term recession of -0.2 m/year (Worley Parsons, 2014) and sea level rise recession of -0.39 m over the next 50 years (central value RCP 8.5 2070 projection). A total design recession maintenance volume (B) to be applied nominally every 10 years is provided in Table 4.1. This volume provides approximately 6 m of added beach width (after nearshore spreading) every 10 years to offset design recession. Sensitivity to upper and lower bound estimates of sea level rise resulted in -22%/+13% variations to calculated design recession volumes representing the expected range of variability in future maintenance nourishment campaigns. Without nourishment volume A, there is likely to be increased risk of more frequent maintenance nourishment (volume B) for Seawall Options 1 and 2 every 5-10 years, due to the high encroachment of the rock revetment structures into the active beach.

Table 4.1: Summary of design nourishment volumes

Design Objective	Nourishment Volume	Total volume required [a]		Design beach width increase after nearshore spreading (m)	Estimated average beach width conditions fronting seawall (based on Stage 2 results) & impact on dry beach user area			
					Without Nourishment		With Nourishment	
		$m^3 \times 10^3$	Average m^3 / m		% of time less than 5 m	Impact on existing dry beach user area	% of time less than 5 m	Impact on existing dry beach user area
					Existing beach estimated to spend on average ~3% of time less than a 5 m width (from Stage 2 results)			
A (Offset)	A) Offsetting seawall encroachment volume							
	Seawall Option 1: Basalt Rock Revetment	491 (252)	179 (181)	+12 m	10 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 2: Sandstone Rock Revetment	528 (270)	193 (195)	+13 m	13 %	Reduced beach width	3 %	Maintained beach width
	Seawall Option 3: Vertical Seawall	0 (0)	0 (0)	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 4: Vertical Seawall with Rock Toe	0 (0)	0 (0)	-	1 %	Improved beach width	1 %	Improved beach width
	Seawall Option 5: Tiered Seawall with Promenade	20 (10) [d]	7 (7) [d]	<1 m [d]	3 %	Maintained beach width + added promenade amenity	3 %	Maintained beach width + added promenade amenity
	TIMING: Upfront							
B (Maintain)	B) Design recession maintenance volume *TIMING: Optional upfront* *Required ongoing approx. every 10 years* [b]	141 (78)	51 (55)	+ 6 m	Diminishing beach width over design life (foreshore access maintained via promenade for Seawall Option 5)		Maintained beach width over design life (with added promenade amenity for Seawall Option 5)	
Optional C (Restore)	C) Optional historical recession restoration volume [c] *TIMING: Optional Upfront*	274 (181)	100 (135)	+ 1 to 10 m	3%	As per existing beach	~1%	Restored for past ~30 years of historical recession at start of project.

[a] Volumes not in brackets are for 2.7 km Terrigal-Wamberal embayment nourishment region.
Volumes in brackets are for 1.4 km section between lagoon entrances fronting seawall (subject to increased potential for alongshore spreading, reduced longevity and initial non-uniform shoreline configuration for larger volumes).
All volumes include the subaerial and subaqueous beach from the dune toe (+4 m AHD) to design depth of closure (-12 m AHD) and apply an overfill factor of 1.0.
Nourishment volumes are for provision of beach amenity only and do not include storm demand.
Nourishment volumes will vary depending on the sediment composition of source material and do not consider excavation sand won during seawall construction.
[b] Increased risk of more frequent maintenance nourishment for rock revetment structures (Seawall Options 1 and 2) every 5-10 years due to high beach encroachment. Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.
[c] To be refined during detailed design with pre-nourishment design reference profile survey.
[d] Stage 2 results indicate Seawall Option 5 has minimal impact on available beach width relative to existing conditions. Minor volumes presented for this option in this report offset what is a relatively negligible degree of maximum encroachment of 0.5 m and will be covered by excavated sand won during seawall construction.

An optional nourishment (objective C) has been investigated to restore sand losses over recent decades due to historical recession at Wamberal Beach. This was calculated by adopting a design restoration profile for Wamberal Beach that provides a maximum level of beach width amenity within the natural envelope of beach profile variability in the last 20 years. The amount of nourishment volume required to achieve the design restoration profile was calculated based on a reference profile prior to the July 2020 storm event. A preliminary sand volume for objective C is provided in Table 4.1. Key areas requiring restoration nourishment identified include the south end of the embayment at Terrigal Beach (Sections 1 and 2) and in the mid-section of the beach between "The Ruins" (25A/B Ocean View Dr) and Lumeah Ave (Sections 5 to 9). Where the beach has been recently depleted between Wamberal and Terrigal Lagoon (Sections 5 to 9), this option will provide on average an additional 10 m (after nearshore spreading) of beach width relative to 2020 pre-storm conditions. This option provides a total sand volume to the Terrigal-Wamberal embayment equivalent to approximately three decades of historical recession for Wamberal Beach (as quantified by Worley Parsons, 2014).

A summary of nourishment feasibility for seawall options is provided in Table 4.2. Larger volumes are subject to future viability of larger sand nourishment sources being available at the time of the nourishment campaign, as well as potential added complexities around lagoon entrance management depending on design placement. Given the feasibility of sand nourishment requirements, present day beach width amenity is likely to be maintained for Seawall Options 3 to 5, and reduced amenity would be expected for Seawall Options 1 and 2. Beach user amenity for Seawall Option 5 is likely to be further enhanced by improved foreshore access and additional amenity values offered by the promenade. Seawall Options 3-5 require minimal upfront nourishment to maintain the existing beach user area (utilising excavated sand won during seawall construction for Option 5).

A range of potential sand sources for nourishment were investigated and assessed including local and regional quarry sources, sand transfer from sediment sinks within the Terrigal-Wamberal compartment (including sand transfer from lagoon entrances and foredunes), regional port and estuary entrance sources, offshore inner shelf sources and Sydney tunnel project spoils. Preliminary assessment of potential sand sources has taken into consideration:

- Sediment composition and compatibility for nourishment at Wamberal Beach
- Resource availability
- Potential constraints including legislation, licensing, environmental and social implications
- Indicative unit cost estimates ($\$/m^3$) for extraction, delivery and placement at Wamberal Beach

A summary of recommended sand sources for nourishment of Wamberal Beach is provided in Table 4.3 Overall, there are a number of feasible sources of sand to nourish Wamberal Beach, however, few of these (all subject to future viability and availability at the time of works) offer sufficient capacity to cater for upfront nourishment requirements in excess of around 50,000 m^3. This is insufficient for upfront nourishment requirements for Seawall Options 1 and 2. Minimal upfront nourishment requirements for Seawall Options 3 to 5 are considered advantageous in this regard, being less dependent on the availability of larger sand sources at the time of construction.

Table 4.2: Summary of nourishment feasibility for seawall options

Seawall option	Nourishment volume A) offsetting seawall encroachment	Nourishment volume B) design recession maintenance [a]	Optional nourishment volume C)	Relative impact on present-day beach width availability
Seawall Option 1: Basalt Rock Revetment	Subject to future viability of larger sand sources available at time of construction Potential lagoon entrance management complexities depending on design placement	✓ (Optional upfront & required ongoing every 5-10 years[b])	Subject to future viability of larger sand sources available at time of construction (Optional upfront)	Moderate to high adverse impact without Nourishment A
Seawall Option 2: Sandstone Rock Revetment	Subject to future viability of larger sand sources available at time of construction Potential lagoon entrance management complexities depending on design placement	✓ (Optional upfront & required ongoing every 5-10 years[b])		Moderate to high adverse impact without Nourishment A
Seawall Option 3: Vertical Seawall	Not Required	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact
Seawall Option 4: Vertical Seawall with Rock Toe	Not Required	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact
Seawall Option 5: Tiered Vertical Seawall with Promenade	✓ (Upfront – covered by excavated sand won during construction)	✓ (Optional upfront & required ongoing every ~10 years)		Low to beneficial impact + added promenade amenity

[a] Establishment of a beach monitoring program is fundamental to assist with design and optimisation of a nourishment campaign as well as determining triggers and volumes for repeat nourishment works.
[b] Increased risk of more frequent maintenance nourishment due to high beach encroachment.

Table 4.3: Summary of preliminary sand source assessment

Location	Total Resource Available	Estimated Overfill Factor [a]	Indicative unit cost ($/m^3)	Constraints / Comments	Recommendation
Local Quarries - Grants Rd Sand	~50,000 m^3/y	1.3	50	• Supply limited due to high regional construction industry demand and limited resource availability • Volume requires supplementing from other sources	Further investigation recommended.
Regional Quarries - Stockton	~200,000 m^3/y	2 - 3	>100	• High cost due to haulage • Supply limited due to high regional construction industry demand and limited resource availability	Not recommended. (high cost)
Wamberal and Terrigal Lagoon Entrance	43,000 m^3 (20,000 at Terrigal and 23,000 at Wamberal)	1	20 - 40	• Requires repeat entrance clearance program to maintain. • Volume requires supplementing from other sources • Maintains transfer of sand within Terrigal-Wamberal sediment compartment (i.e. beach replenishment) • Variable volumes and sediment quality dependent on dredge campaign. • Impacts on recreational area and amenity at entrances	Further investigation recommended.
Active foredune management	25,000 m^3	1.5 - 3	15 - 30	• Requires repeat foredune maintenance program • Disturbances to foredune ecology in Wamberal Lagoon Nature Reserve • Volume requires supplementing from other sources • Maintains transfer of sand within Terrigal-Wamberal sediment compartment (i.e. beach replenishment)	Subject to detailed EIA in consultation with NPWS.
Hunter River (South and North Arm)	Several million m^3	Unknown. Fine to medium grained sand	60 - 120	• High cost due to haulage • Potentially cheaper if undertaken as part of broader regional nourishment program	Subject to future viability. (potential high cost due to haulage)
Brooklyn, Hawkesbury River	100,000 m^3	Unknown. Fine to medium grained sand	23 - 43	• Potentially cheaper if undertaken as part of broader regional nourishment program	Not recommended. (sand required in source compartment)
Swansea Channel	10,000 - 50,000 m^3 every 1-5 years with infrequent major dredging	2	45 – 80	• Likely exhausted by local sand requirements closer to the source	Not recommended. (sand required in source compartment)
Tuggerah Entrance	30,000 -80,000 m^3/y every 1-2 years	Unknown. Fine to medium grained sand	40 - 60	• Likely exhausted by local sand requirements closer to the source	Not recommended. (sand required in source compartment)
Offshore dredging	Order of 10 million m^3	1 – 1.5	10 - 30	• Environmental concerns of Government and community • Potentially cheaper costs (<$10/m3) if undertaken as part of a broader regional nourishment campaign	Subject to future viability. Further investigation recommended.
Sydney tunnel spoils	Several million m^3	Unknown	<10	• Low cost option • Sand compatibility of spoils for nourishment purposes requires further investigation	Subject to future viability. Further investigation recommended.

[a] Factor applied to design volume to account for additional nourishment due to finer borrow sand grain size composition than that of native beach.

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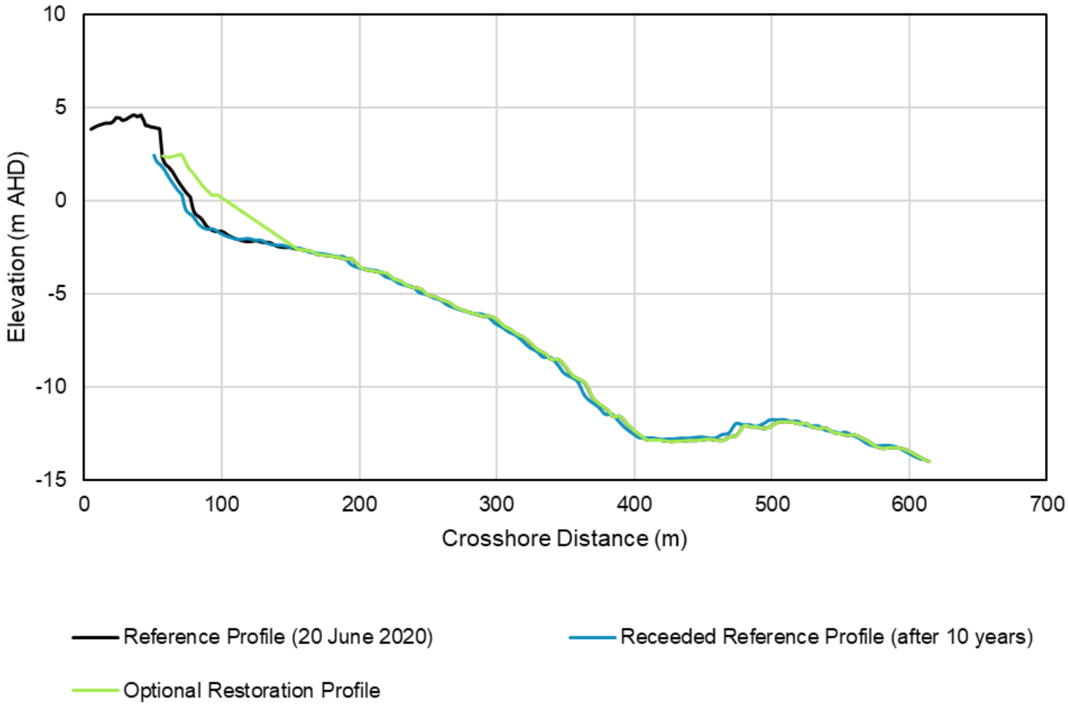
Appendix A Beach profiles used for nourishment calculations

Section 1 Profile 1-8



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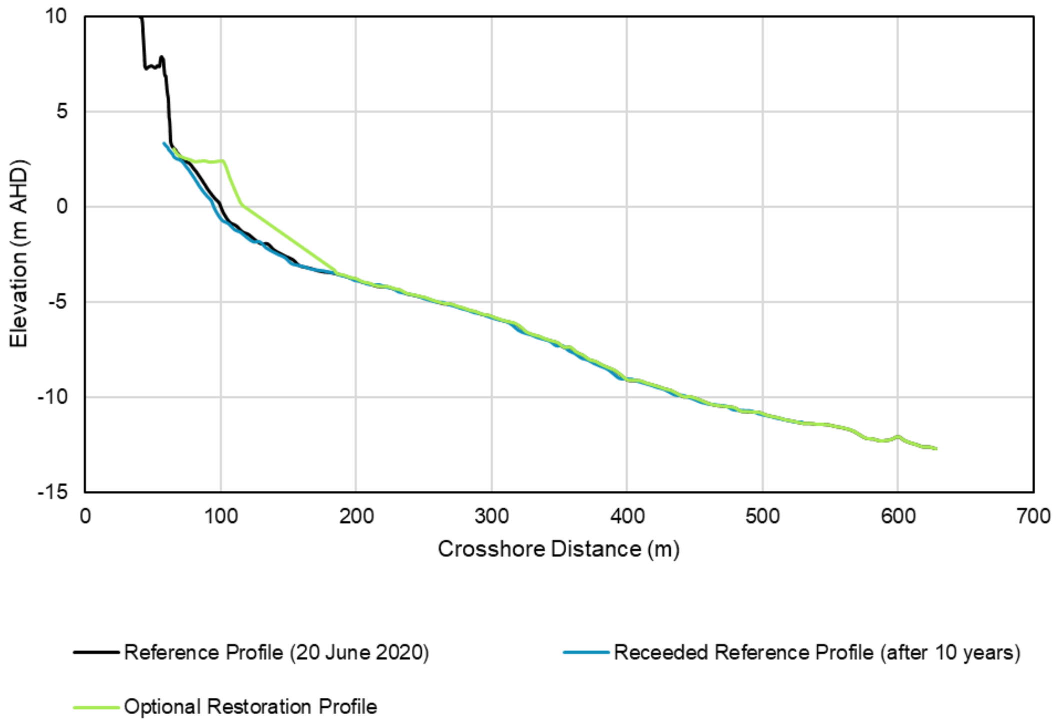

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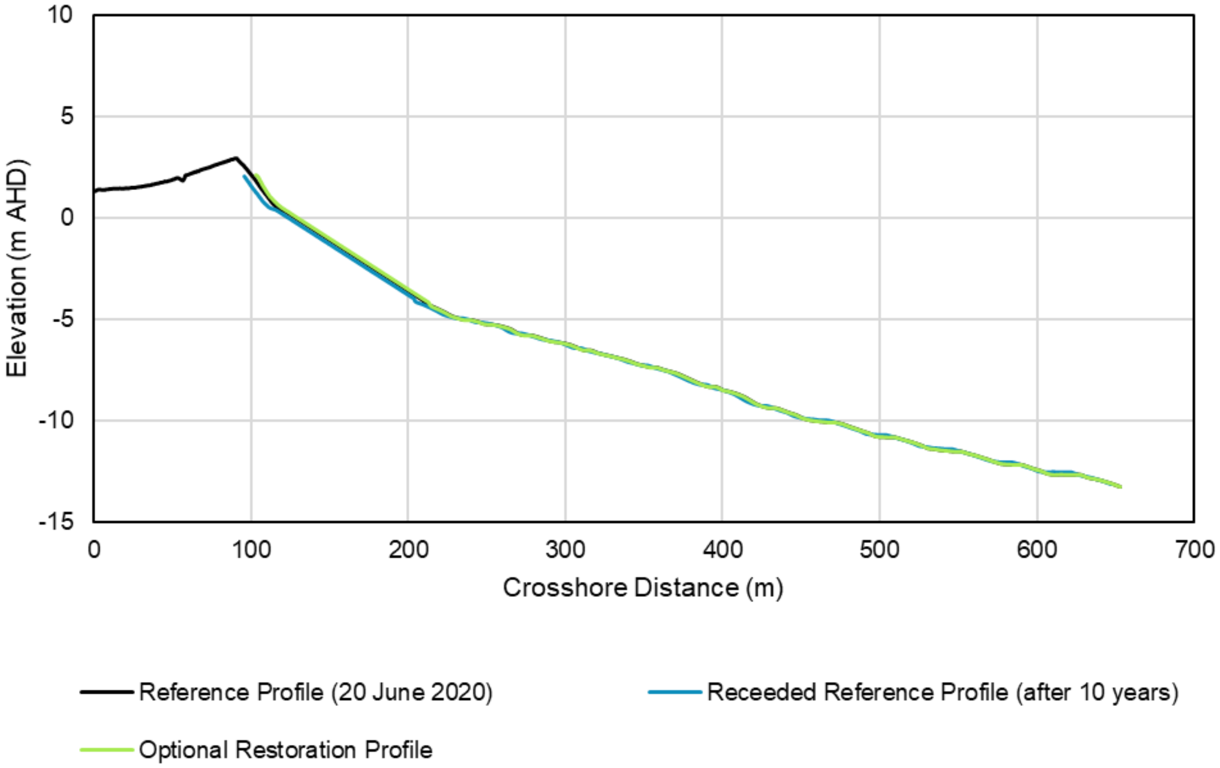
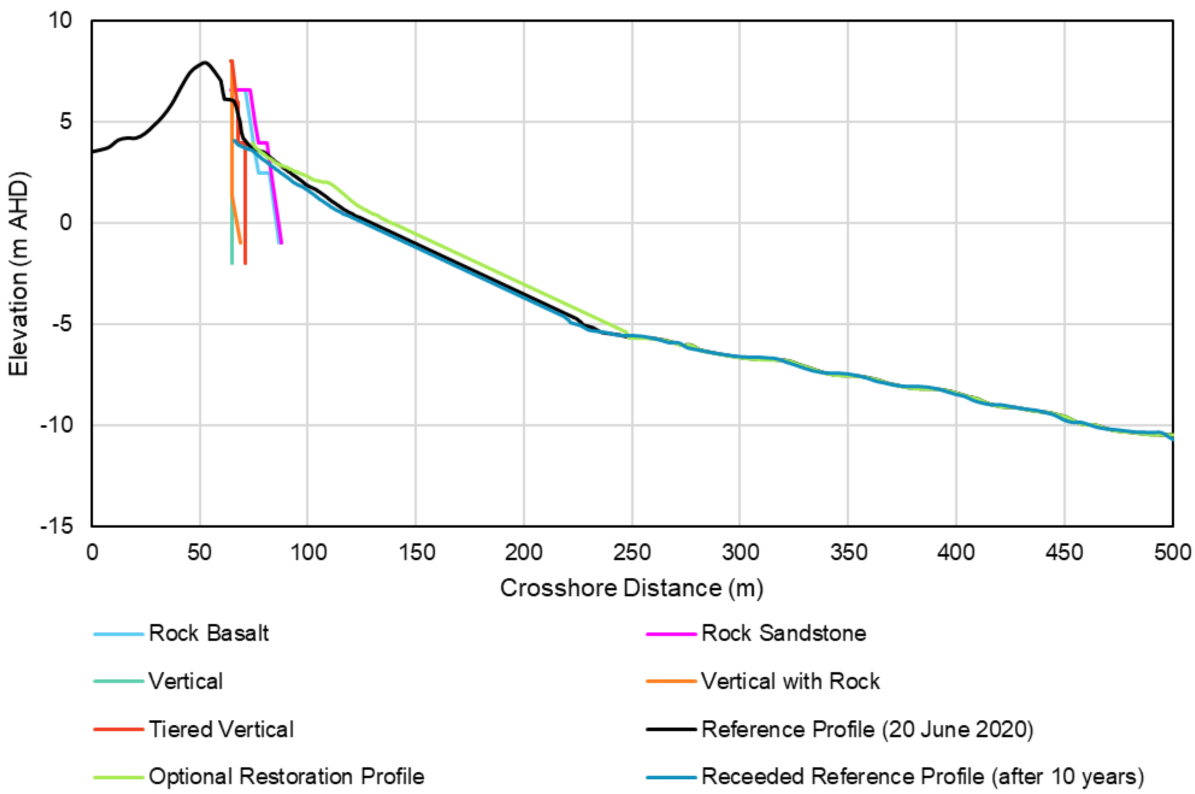


Section 4 Profile 4-11



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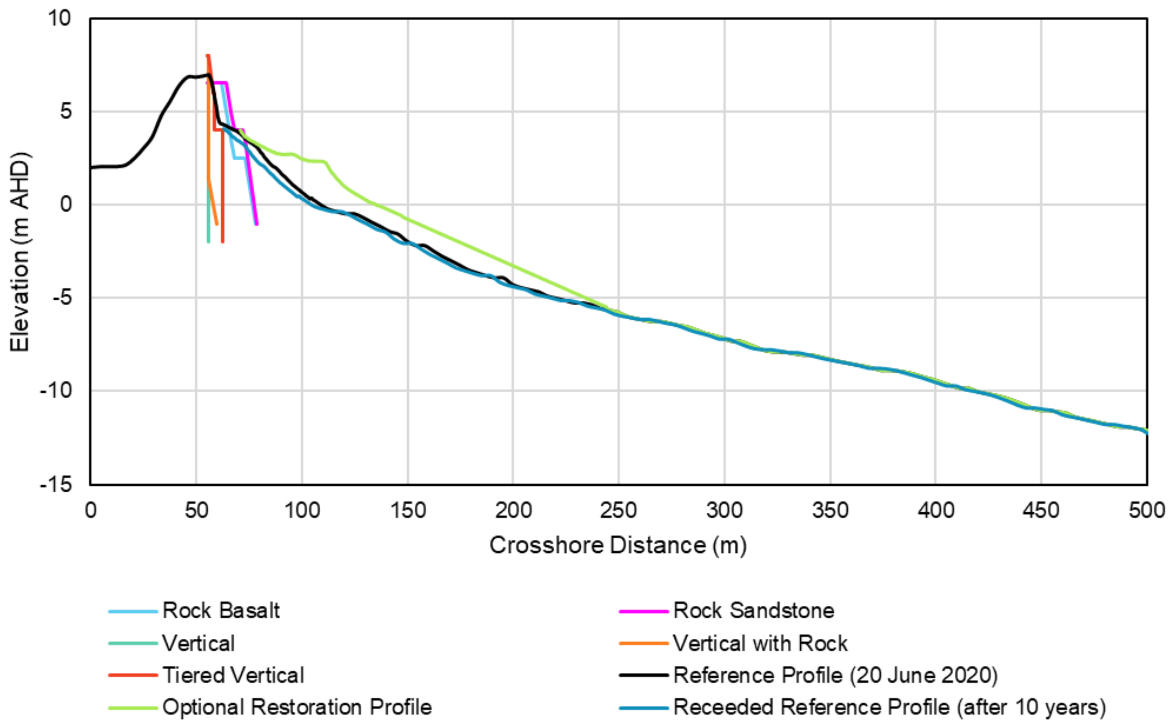

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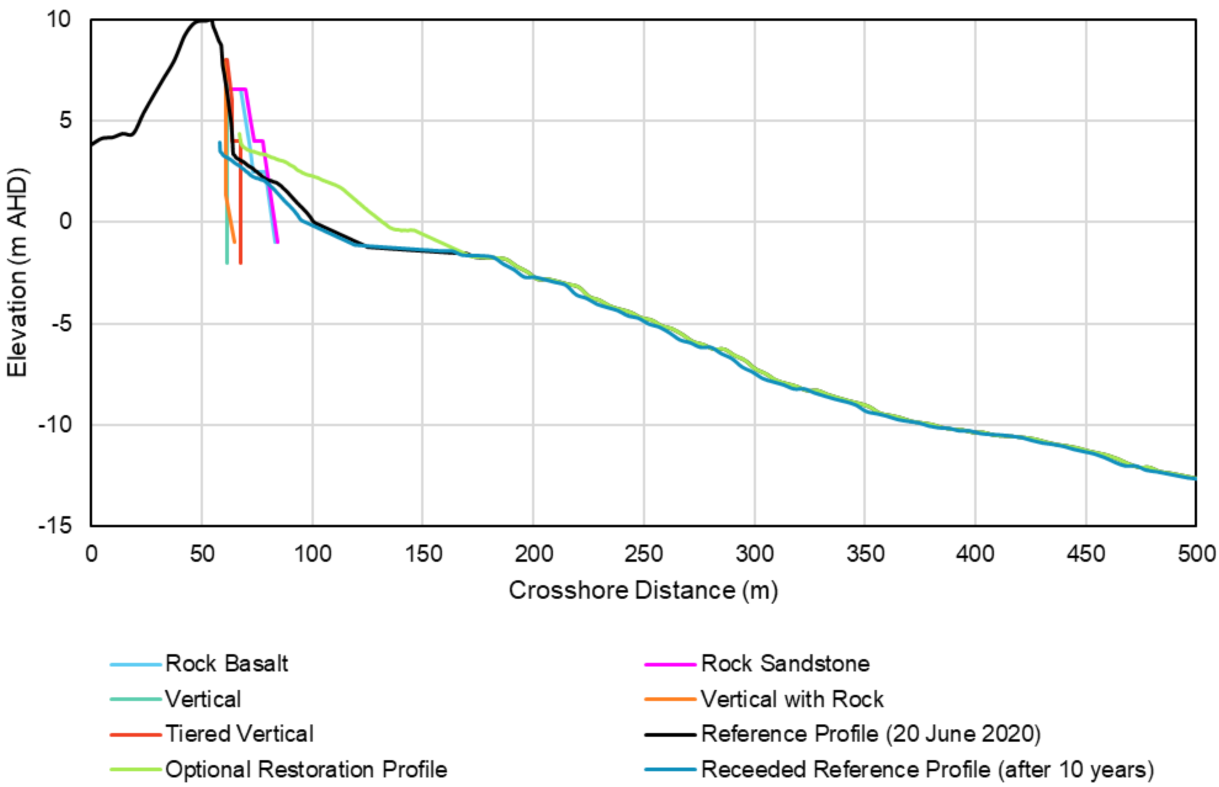

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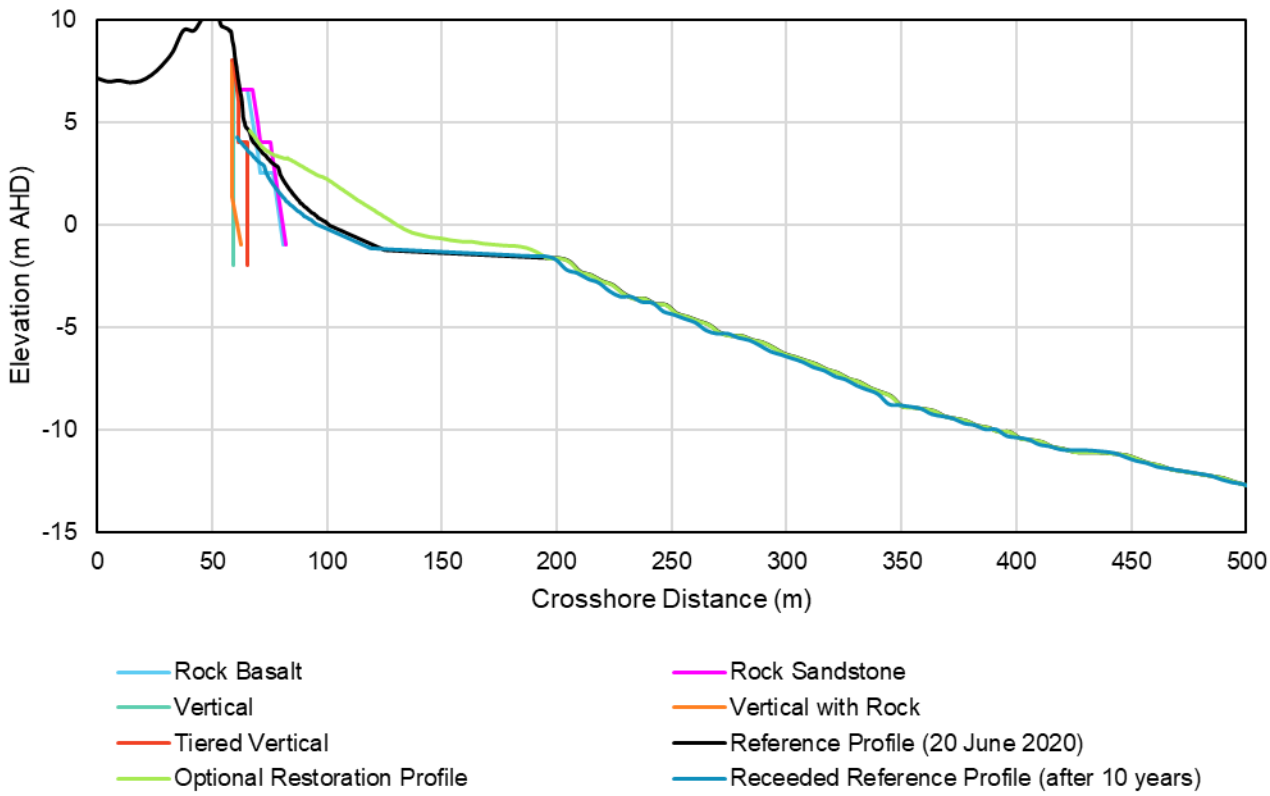

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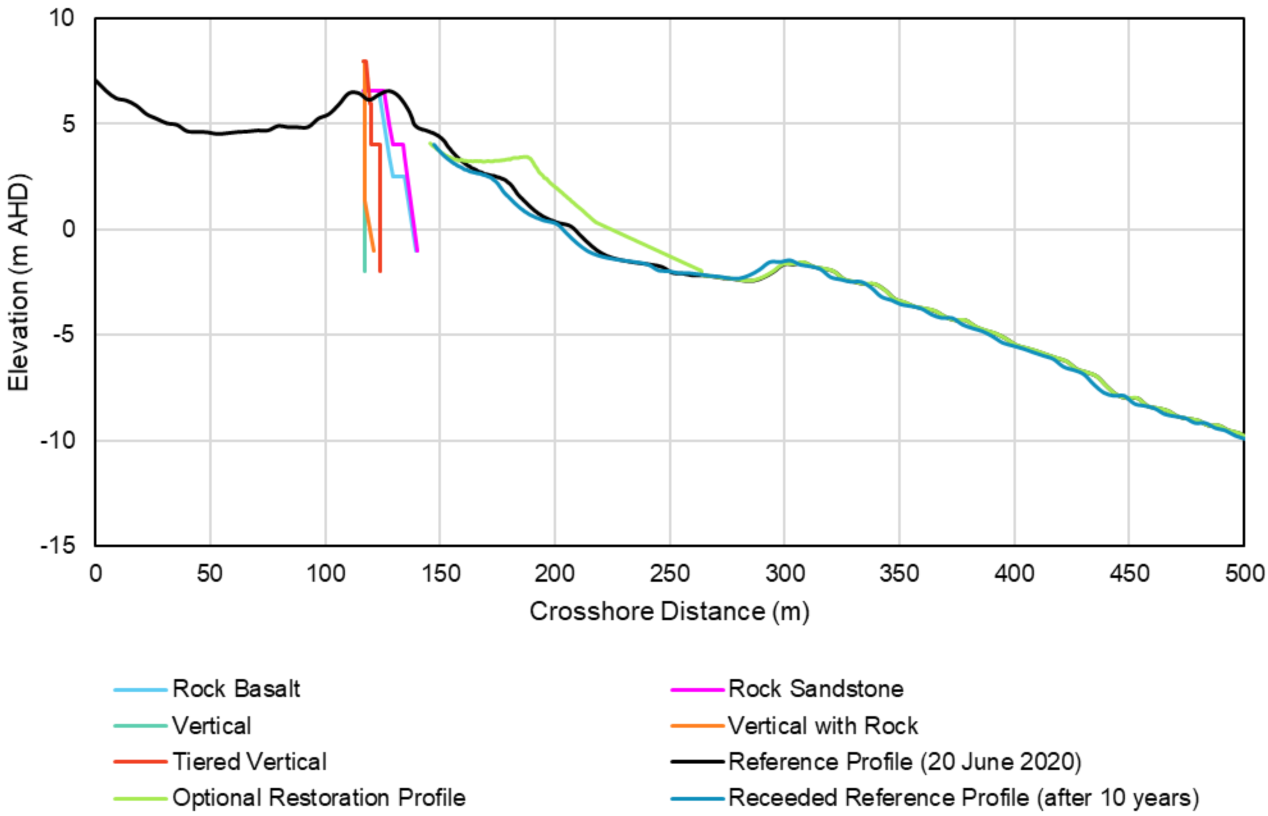
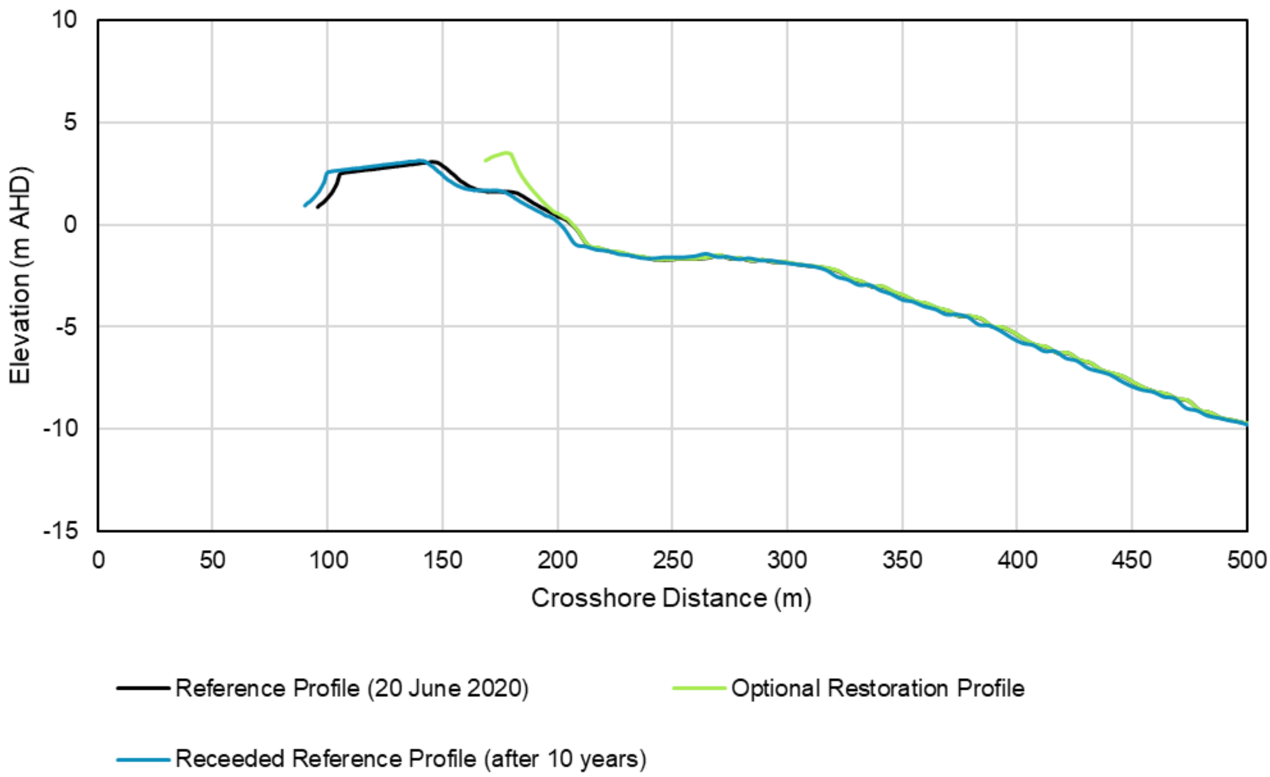


Section 10 Profile 8-6



Section 11 Profile 10-5