COASTAL PLANNING AND ADAPTATION – CONCEPTUAL DESIGN REPORT

for Shire of Augusta Margaret River

February 2020

Final Report

SCR1803

Executive Summary

The Prevelly to Gnarabup stretch of the Augusta Margaret River Shire contains the Shire of Augusta Margaret Rivers' only beachside cafe, one of the Shire's most popular swimming beaches, and the Gnarabup jetty and boat ramp. The beach has been progressively eroding with loss of mature dune vegetation, impacting on coastal infrastructure such as stairs, fencing and café decking and threatening sections of the coastal walkway. Previous responses to this erosion have included seasonally closing and adapting beach access points (stairs), minor protective measures (coir logs and sand bags) and adaptation of the café decking during reconstruction.

This report outlines coastal adaptation design options for the coastal walkway, beach access and boat ramp.

A variety of monitoring, survey, photographic and other data has been analysed to develop understanding of the coastal processes.

The coastal behaviour is summarised as follows:

- Relative stability in the nearshore with seasonal shallowing and deepening.
- A high level of variability in the volume of sand on the beach, with week-to-week variability superimposed on seasonal change.
- Seasonal change in beach volumes with the summer and winter pattern of accretion and erosion switching along the coast.
- Relatively low rates and volumes of foredune erosion, but a consistent trend of erosion along the coast. There is a longer-term erosion trend in the vegetation line of 0.3m/yr.
- Higher levels of storm erosion (up to 4m) have been observed with a variable capacity for recovery along the beach.

Coastal Walkway

The Gnarabup Prevelly coastal walkway was initially constructed in 2002 and has provided a serviceable level of amenity for 16 years. Since construction the beach, incipient dunes and foredune have eroded in the order of 4-6 meters. The crest of the relatively steep eroded foredune is immediately adjacent to the limestone coastal walkway in places.

Following an initial review of adaptation options, and stakeholder consultation, three coastal adaptation options have been investigated further for this walkway. These are:

1) *Limestone Coastal Walkway:* Construction of a new compacted limestone coastal path towards the back of the foredune from Gnarabup to Prevelly, at a similar elevation to the existing. The terrain limits the setback from the beach.
2) *Mixed Coastal Walkway:* Construction of a boardwalk towards the back of the foredune at Gnarabup, transitioning to a limestone path at the back of the foredune at Prevelly.
3) *Dune Boardwalk:* Construction of a boardwalk along the ridge-line of the large primary dunes for the southern section of the walkway at Gnarabup, transitioning to a limestone path at the back of the foredune at Prevelly.

A multi-criteria and basic financial analysis has been undertaken of the path options and design concepts and cost estimates are provided in this report.

The multi-criteria analysis clearly favoured options 1 and 2 ahead of option 3. Option 1 was stronger than option 2 on economic criteria (lower capital cost and resilience against bushfire), while option 2 was stronger on environmental criteria (protection of dune vegetation).

Staged construction of a new coastal walkway has been considered. The relocation of a 320m section of the path along the foredune from Gnarabup to Prevelly (Ch140-460m) should be prioritised, together with a focus on managing the dune buffer at the southern approach to the path (Ch120-140m) and a narrow section at Prevelly (Ch640m). In the future, a cutting or crossing of the dune ridge at the Gnarabup carpark may be required. There are economic advantages in managing the dune buffer at the southern end of the coastal walkway to delay construction of what would be, proportionately, the most expensive section of the path.

Beach Access

Beach access points provide a link across the foredune to the beach between the coastal walkways, carparks, parks and Cafes. There are 11 formal access points to the sandy beach along the 1700m section of coast between Gnarabup Headland and Surfers Point. These include timber stairs at the southern end of Gnarabup Beach, retained timber stairs at Prevelly Beach and sand access through dunes at Riflebutts.

People wishing to access the beach from the beach path have an expectation that beach access will be provided at reasonably regular intervals. The removal of eroded timber stairs has resulted in a 275m gap between access points and a substantial increase in people climbing over the path fence and walking down and eroding the dune. Concepts are provided for a local path diversion, retained timber stairs and beach access matting to reinstate access to this popular section of Gnarabup Beach.

The adaptation of timber stairs and ramped access to the beach has also been considered. Ongoing monitoring and maintenance of beach access points is required.

Boat Ramp

Concept designs for reinstatement of the foredune erosion buffer in the areas adjacent to the boat ramp with soft engineering techniques including beach scraping, wrack distribution and sand nourishment are provided, as the potential for relocation of assets in this area is limited. Localised protection has also been considered together with concepts for mitigating scour to the boat ramp abutment.

Coastal adaption concepts are provided and summarized in Table 1 for review by the Shire and the subsequent selection of preferred options for the development of detailed designs.

Table 1 Synopsis of Path Options

	Option 1: Limestone Coastal Walkway	Option 2: Mixed Coastal Walkway	Option 3: Dune Boardwalk
Type	Limestone (620m)	Boardwalk (340m) Limestone (300m)	Boardwalk (375m) Limestone (300m)
Capital Cost	$140,000	$450,000	$630,000
Assumed Design Life (Historic Erosion Rate & 5m storm buffer)	20 years*	25 years	40 years
Potential Reduced Design Life (with accelerated future coastal erosion	<10 years	<15 years	40 years
Environmental	Loss of vegetation in swale (-)	Minimised impacts on vegetation in the swale (+)	
Social	Maintain existing amenity (+) Good beach access (+) Relatively flat path (+)	Higher amenity value (+) Good beach access (+) Relatively flat path (+)	Steeper less accessible path with poor beach access (-) Spectacular views.
Economic	Lowest cost and design life(+)	Moderate cost and design life	Highest cost (-) Longest design life (+)
Potential Staging	1. Management of the Foredune 2. Gnarabup section 3. Prevelly section	1. Management of the Foredune 2. Gnarabup section (without ramped cutting) 3. Prevelly section 4. Gnarabup Cutting	1. Management of the Foredune 2. Gnarabup section 3. Prevelly section

* Requires maintenance of the dune buffer at the southern path approach over this period.

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Limitations of this Report

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Rev	Issues Description	By	Review	Date
A	Draft	[redacted]	[redacted]	15 May 2018
B	Revised Draft	[redacted]	[redacted]	22 May 2018
0	Final Report	[redacted]	[redacted]	10 Feb 2020

1. Introduction

1.1. Background

The Prevelly to Gnarabup stretch of the Augusta Margaret River Shire contains the Shire of Augusta Margaret Rivers' only beachside cafe, one of the Shire's most popular swimming beaches, and the Gnarabup jetty and boat ramp. The beach has been progressively eroding with loss of mature dune vegetation and impact on coastal infrastructure such as stairs, fencing and café decking. As a result of the coastal erosion, the Shire has been seasonally closing and adapting beach access points (stairs) as the beach outflanks the stairs (Figure 1.1).

Following a storm in 2013, the Gnarabup café retaining wall and decking failed requiring adaptation of the deck to accommodate coastal processes. Erosion is threatening an existing coastal walkway and planning and design is required for solutions to manage this walkway and access points in the future.

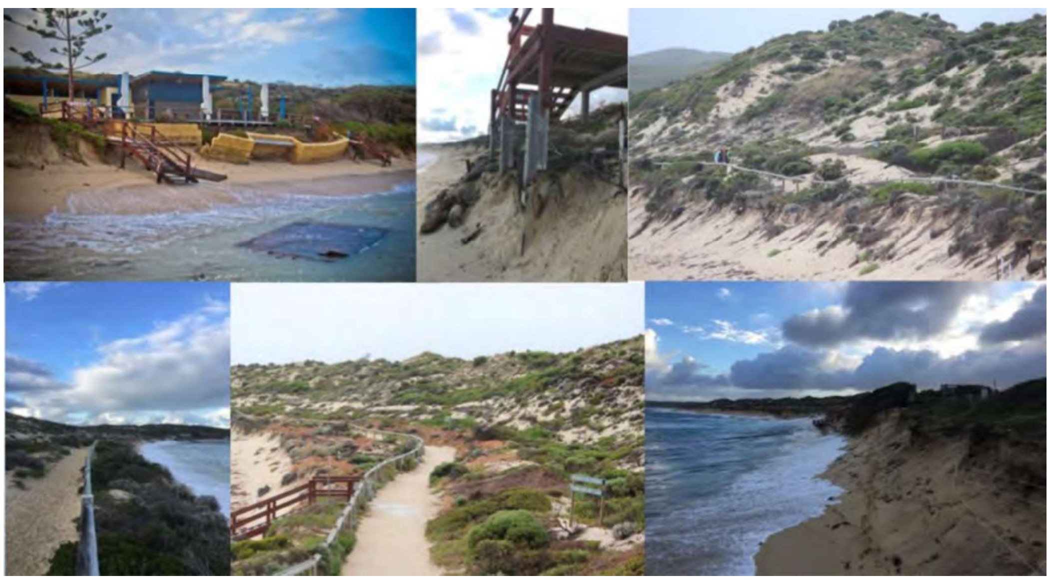


Figure 1.1 Coastal Erosion at Gnarabup

1.2. Scope of Works

Shore Coastal were engaged by the Shire in April 2018 to undertake coastal monitoring and adaptation planning in partnership with Tim Moore (CSC Pty Ltd) and Matt Eliot (Damara WA Pty Ltd).

The scope of works for the coastal planning and adaptation includes:

1. Coastal Monitoring
2. Coastal adaptation design options for Prevelly – Gnarabup coastal walkway and beach access points.
3. Coastal adaptation option detailed design for Prevelly - Gnarabup coastal walkway and beach access points
4. Design of Gnarabup Boat ramp works

This report provides an initial review of monitoring data for the Gnarabup Prevelly beaches (Task 1) but is primarily focused on design options for the coastal walkway and beach access points (Tasks 2 & 3) and the boat ramp (Task 4).

It is noted that the design options for the boat ramp are focussed on the boat ramp abutment, approach and surrounding assets where managing the threat of coastal erosion by relocation is not feasible. Recommendations have not been provided regarding the jetty as this work is being undertaken by others.

The scope was also increased to include a beach and hydrographic survey of Gnarabup-Prevelly, which was completed on 11th May 2018.

Following consideration of the design options and selection of a preferred option by the Shire, detailed design drawings will be developed.

2. Assessment of Coastal Processes

2.1. Coastal Setting

The west-facing coast is dominated by the underlying geology, with approximately 80% of the coast having a rocky backshore. Erosion-resistant hard-rock forms headlands that define the coastal plan form, and are directly exposed to wave action, resulting in irregular, heavily weathered features.

Between the resistant hard-rock headlands, calcarenite is prevalent in the subtidal and backshore areas. This varies from moderately cemented (limestone) through to weakly cemented (partly lithified carbonate sand). The resulting geomorphic structure is determined by the calcarenite strength, reflecting age, and the degree of exposure to wave action:

- Irregular pinnacles and reefs occur intermittently in the subtidal zone;
- Rock platforms occur along much of the Capes Region's west-facing coast. These surfaces have been abraded at approximately present-day sea level, and provide substantial wave sheltering under low to moderate water levels, often holding perched sandy beaches;
- Moderately to highly cemented Tamala limestones occur as pinnacles, stacks and scarps in the backshore, commonly landward of the rock platform's edge by 50-100m, and occasionally covered by coastal sand dunes; and
- Weakly cemented limestones occur as sloping faces, often with tiers that represent differing levels of induration. This structure often occurs above stronger limestone layers, although it may also occur as a separate geomorphic unit.

Despite variation in the limestone, the sedimentary rock coast is almost straight between hard rock headlands, highlighting the effects of abrasion on features that project out from the general line.

Overlying the geological framework are sedimentary features, mainly comprised of marine sands. From Gnarabup to Cape Naturaliste, the sedimentary features are discrete, separated by sections of bare rock. These features mainly occur in areas of relative shelter, including on the seaward margin of limestone rock platforms (the nearshore), on the landward side of the platform (the beach), and in gaps between rock features, including headland controlled embayments and stream-cut gullies. These features are all characteristic 'storage', where the volume of sediment is structurally limited. Although the storage volume may vary with environmental conditions, these features are comparatively insensitive to higher rates of sediment supply, as material exceeding the storage Is transported away rapidly.

Beaches along the Cape's Coast have been developed through four mechanisms that separate them from the high energy transport zone that is prevalent seaward of the hard rock cliffs and reef formations:

1. Where larger headlands are present, bay beaches have typically develop on the lee side, as the shelter provided by the headland locally modifies the wave climate, reducing the northward alongshore transport potential and creating an area of net zero transport (on average);
2. Beaches have developed within inshore lagoons, where rocky seabed and reefs separate the sand mass of the beach from the offshore, except sometimes as a thin veneer of sand;
3. Salients may develop in the sheltered lee behind reefs; and
4. Perched beaches have developed where the rock surface is predominantly above mean sea level, but below storm conditions.

Gnarabup and Prevelly Beaches are lagoon beaches, with local salient behind the Boaties and Bombies reefs (Figure 2.1). Three distinct bay beaches are evident.

Figure 2.1 Overview of Gnarabup Coastal Features

2.2. Metocean

A brief summary of the metocean assessment of Gnarabup by the University of Western Australia (1) is provided in this section together with an analysis of the historic coastal erosion behaviour and rates based on hydrographic survey, topographic survey, beach monitoring by the Shire and assessments of coastline movements from historic aerial photography.

2.2.1. Waves

Directional wave climate has been recorded offshore of Cape Naturaliste since 2010. Figure 2.2 illustrates how the wave climate varies seasonally; with southwesterly swells in autumn, larger west south westerly swells in winter and spring, and lower wave heights in summer.

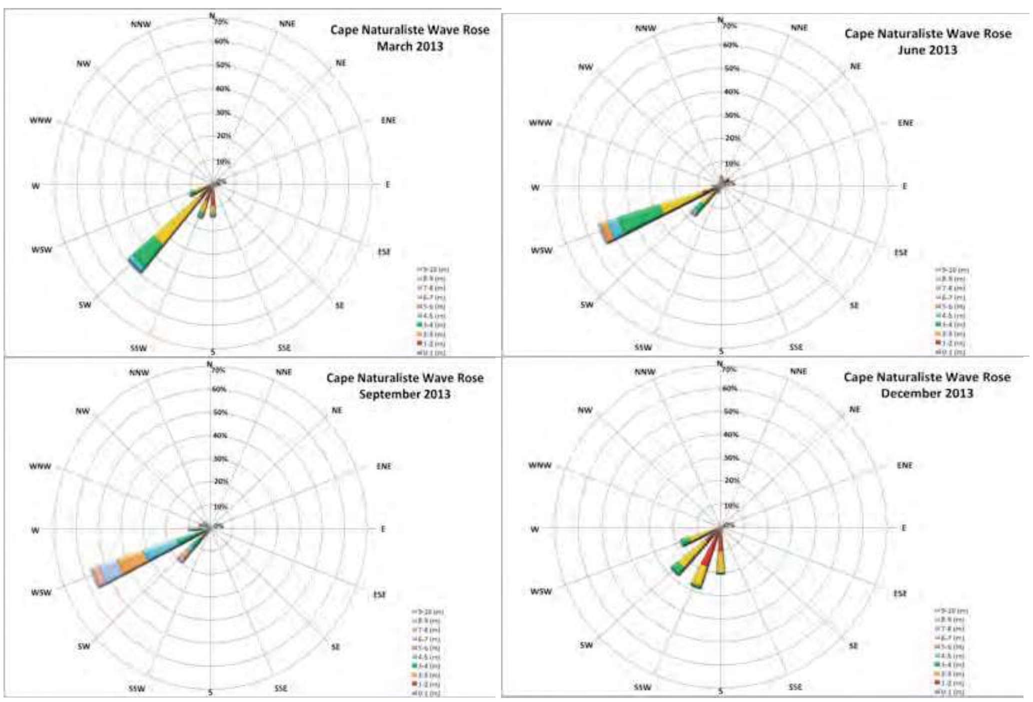


Figure 2.2 Seasonal Variability in Wave Conditions at Cape Naturaliste

As illustrated in Figure 2.1, there are a series of offshore and nearshore reefs and headlands that control the size and direction of the nearshore wave climate and any incident wave energy reaching the beach. UWA undertook a detailed monitoring campaign (1) of the wave climate inside and outside of the lagoon for a 15 month period in 2015/16 to understand the influence of the coastal features on coastal processes.

In summary, the UWA study found that waves within the lagoon (in the lee of the reefs) are strongly influenced by water levels, with more energy penetrating into the lagoon at higher water levels. Wave direction in the lagoon was not recorded so the relationship between offshore wave conditions and wave direction within the lagoon, and the subsequent influence on beach morphology, cannot be established. It is likely that wave direction within the lagoon will be influenced by offshore wave direction, height, period and water levels.

UWA also observed longer period "infragravity" waves in the lagoon, noting

"Similar to many reef environments, the wave dynamics along Gnarabup beach are complex. The interaction and breaking of sea-swell waves (waves with periods< 25 seconds) results in infragravity waves: waves with long periods (25 seconds to 5-10 minutes) which generally have heights less than 0.5 m. The data collection at Gnarabup indicated that infragravity waves often account for ~50% of the total wave energy in the lagoon. Because these waves have low height, but long periods, they do not break like the sea-swell waves but rather reflect from the beach. At Gnarabup, infragravity waves are clearly visible by examining the boat ramp; the infragravity waves are the cause of the "surge" that runs up the boat ramp making launching/retrieving a boat hazardous during moderate and larger swells. The complexity resulting from the significant infragravity energy (which similarly run up the beach face causing the most dune erosion) must be accounted for in any future analysis or numerical modelling"

2.2.2. Water Levels

As with the majority of the southwest, the site experiences semi-diurnal microtidal climate with an astronomic tidal range of just over 1 meter. The water levels are strongly influenced by non-tidal forcing such as wind set up, storm surges, sub-tidal fluctuations, Leeuwin Current.

UWA undertook an analysis of the water levels at the site compared to incident wave height and wave heights within the lagoon. They outlined a strong correlation between wave heights in the lagoon and water levels. This showed that with higher water levels, more wave energy penetrated into the lagoon across the reefs. A time series of water level from Bunbury is shown in Figure 2.3. In particular it shows the high water levels from 2011 to 2013 associated with La Nina that suggests the beach may have been in a relatively depleted state prior to the September 2013 storms. There have been relatively typical water levels in recent years from 2014 to 2017.

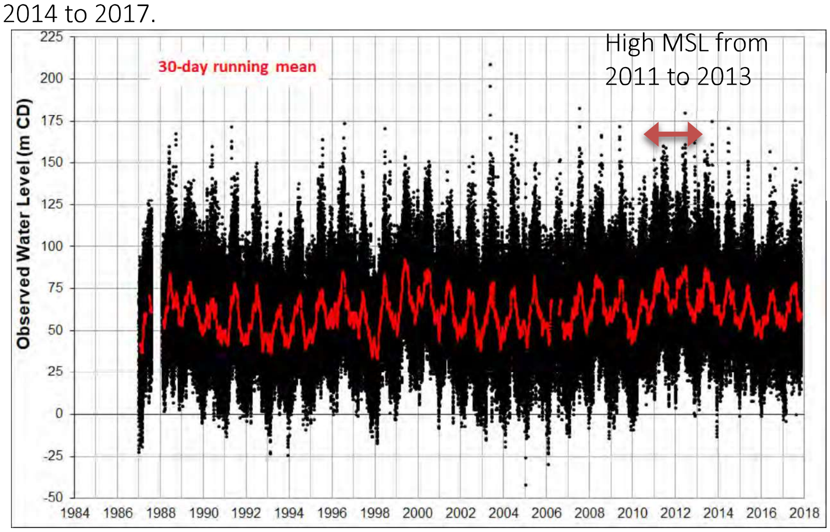


Figure 2.3 Time Series of Water Level from Bunbury Tide Gauge (1986-2017)

2.2.3. Currents

During the monitoring campaign undertaken by UWA a separate more detailed study was also undertaken that measured the direction and speed of currents within the lagoon and around the offshore reefs (Figure 2.4). This illustrated that currents within the lagoon were generally weak (less than 0.3m/s) with stronger currents in the channels between the reefs.

Current direction was also measured and, for this deployment, showed that the onshore offshore current (east/west) was dominant and that there is only a small alongshore (north/south) component to the current in the nearshore. The strongest alongshore currents were measured inshore of the Boaties reef with up to 0.3m/s in a southerly direction. The strongest northerly current was measured in the vicinity of the removed access stairs, but was much lower at only 0.1m/s.

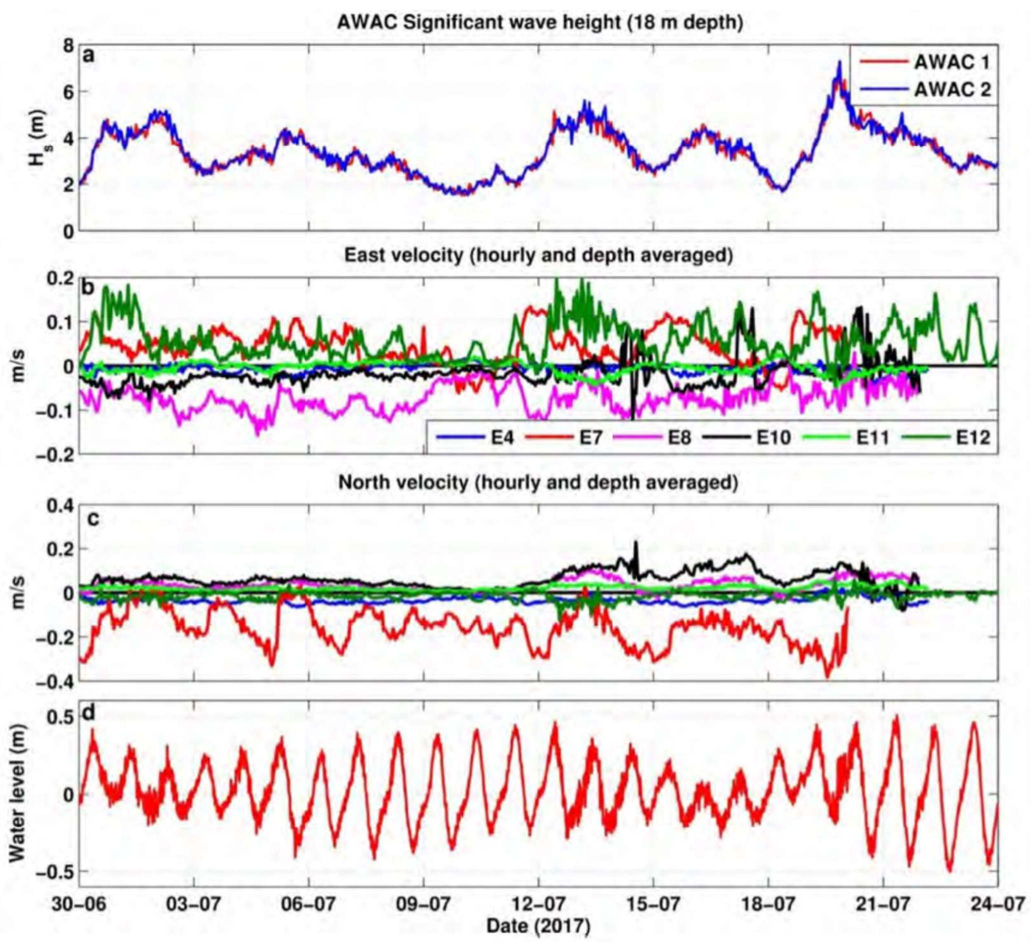


Figure 2.4 Gnarabup Lagoon - Nearshore Wave Heights, Current Velocities and Water Level in July 2017 (UWA)

2.3. Hydrographic and Topographic Survey

2.3.1. Hydrographical Survey Analysis

Historic hydrographical survey data is available for the bay from DoT. This includes a single beam survey from April 1995 and a more detailed multibeam survey from March 2016. These autumn surveys remove the seasonal component of the analysis and allow longer term changes to be identified. A depth difference plot was calculated based on interpolated DEM of this historic survey data (Figure 2.5).

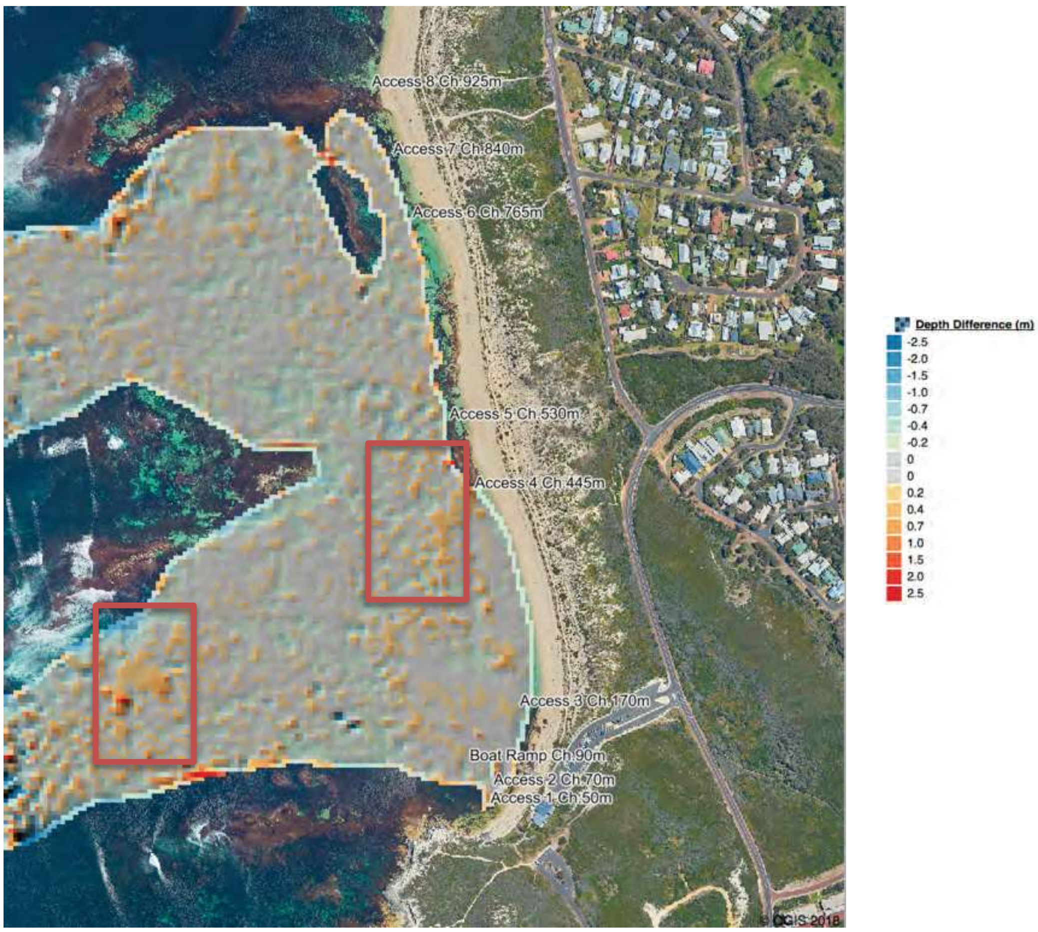


Figure 2.5 Depth Difference Plotting of 1995 to 2016 Hydrographical Survey Data

In the area of interest (the nearshore areas) there has been relatively little change over the 21 year period assessed. However, to the south of Beach Access 4 there is an area of ~2,000m^3 accretion. The analysis suggests minor accretion in nearshore areas, and that material eroded from the beach and foredunes in the September 2013 storms has been moved further offshore or alongshore.

An area of shallowing was also identified in the channel between the southern headland and Boaties Reef. Approximately 1,500m^3 material has accumulated in this area between surveys. This accumulation may be the result of material eroded from the beaches and nearshore being transported offshore in currents between the southern headland and Boaties reef that establish during storm events. This is a possible pathway for loss of material from the system. The change in the offshore areas was surveyed but is not considered in this analysis due to relatively sparse survey data from 1995 in this area.

2.3.2. Topographical Survey Analysis

As part of the UWA monitoring campaign for the Shire, UWA also undertook regular surveys of the beach. The initial assessment looked at changes in survey volume over the period between surveys. Shore Coastal has undertaken a reassessment of this survey data to determine change in surveyed beach volume over successive winter and summer periods. The periods assessed are illustrated in Figure 2.6 and include:

- February 2016 to September 2016 (winter)
- September 2016 to February 2017 (summer)
- February 2017 to August 2017 (winter)

Figure 2.6 Comparison of UWA Surveys February 2016 to September 2016 (left) September 2016 to February 2017 (middle) and February 2017 to August 2017 (right)

The assessment split the bay into 5 areas to determine volumes of material moving along the coast. The splits in the areas were based on approximate boundaries between observed erosion and accretion in each difference plot.

In summary, there does appear to be a weak pattern of erosion and accretion in winter along this stretch of coast, that is reversed during the summer months. The pattern is outlined in Table 2.1.

Table 2.1 Description of Patterns of Erosion and Accretion During Winter and Summer

Section	Summer Pattern	Winter Pattern
Gnarabup Beach South	Accretion	Erosion
Gnarabup/Prevelly "Boatramps" Salient	Erosion	Accretion
Prevelly /Riflebutts "Bombie" Salient	Accretion	Erosion
Riflebutts Beach	Erosion	Accretion
Riflebutts Beach North	Accretion	Erosion

The volumes of erosion and accretion observed are small (maximum 3,000m^3) and generally balanced, suggesting either a closed system or a balance in material entering and leaving the system during the period surveyed. The last period assessed does show an imbalance with net erosion from the system, which may be a result of material moved offshore or alongshore to the north, providing a supply of sand to the perched beach at Surfers Point and the Rivermouth. It should be noted that only a very short period has been assessed so this pattern may only be representative of this period and assessment of a longer period would be needed to establish if a persistent seasonal pattern is present.

2.3.3. Recent Beach and Hydrographical Survey

In May 2018 a beach and hydrographical survey was undertaken to provide a comparison to historic surveys. This survey took cross-sections of the beach and nearshore to approximately 150m offshore of the Gnarabup and Prevelly Beaches (where there is coverage from the DoT March 2016 survey). Figure 2.7 shows a comparison of the recent surveys at chainage 200m along the path.

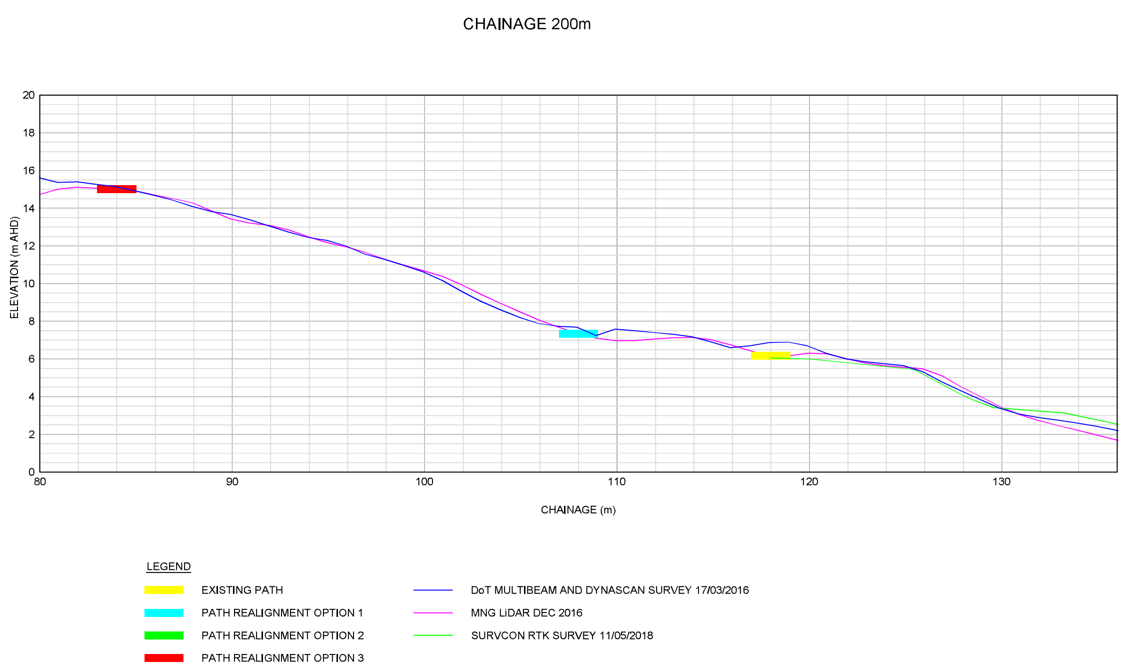


Figure 2.7 Cross-section at Chainage 200m Showing Comparisons of Recent and Historic Hydrographical and Beach Surveys.

The comparison with the DoT March 2016 Hydrosurvey and dynascan survey showed erosion rates of the foredune are approximately 0.3m/yr in this period, which corresponds to the erosion rates determined from other methods. In addition, there was minimal change offshore of the beaches, indicating that the material lost from the beaches was not in the nearshore area.

2.4. Coastline Movements

Coastal demarcation lines have been interpreted from aerial imagery by the Department of Transport for the following years:

- 1943
- 1965
- 1975
- 1991
- 2004

Shore Coastal used more recent aerial imagery to interpret coastal demarcation lines, specifically for the following years:

- 2011
- 2013
- 2017

The coastal demarcation lines have been assessed to determine rates of coastline movement over the period between the years when aerial imagery was available. The plot showing rates of coastline movement have been separated into the lines interpreted by DoT (Figure 2.8) and those interpreted by Shore Coastal (Figure 2.9). This is to reduce the potential for errors in the assessment due to different methods for interpreting the vegetation lines.

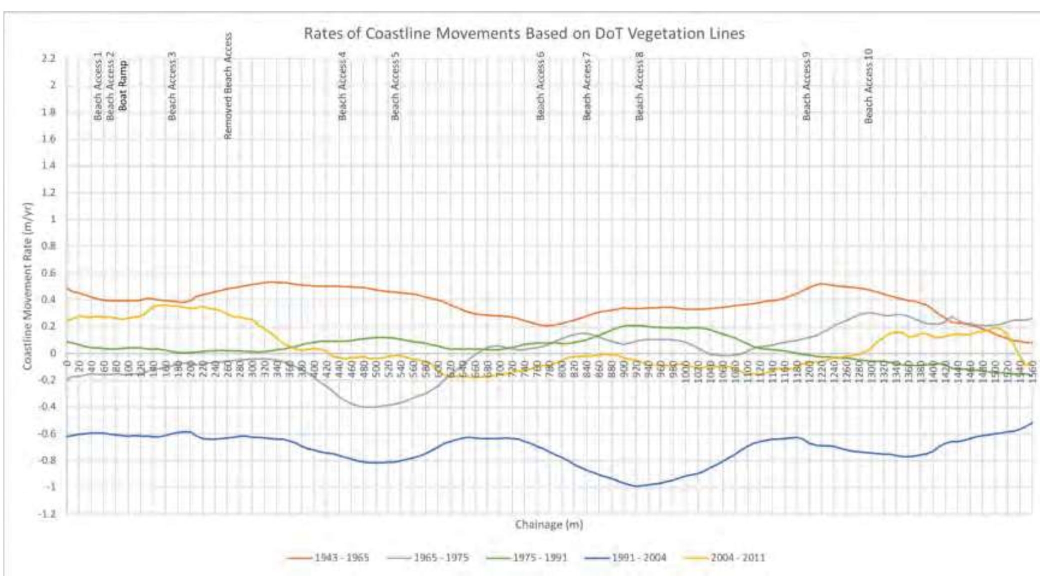


Figure 2.8 Rates of Coastline movement Based on DoT Vegetation Lines

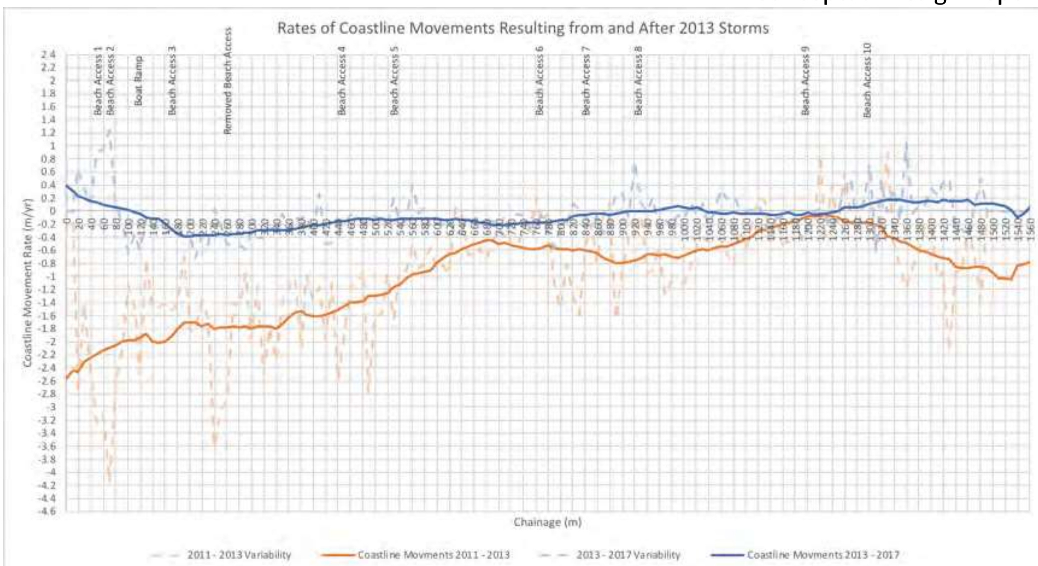


Figure 2.9 Rates of Coastline movement Based on Shore Coastal Vegetation Lines

From interpretation of the DoT vegetation lines, between 1943 and 1965 there appears to have been a period of accretion of on average 0.4m/yr. Between 1965 and 1991 (over 25 years) there appears to have been a period of relative stability with coastline movements generally less than 0.2m/yr on average. Between 1991 and 2004 there appears to have been a period of relatively rapid erosion over the whole bay with erosion rates of between 0.6m/yr and 1m/yr.

Caution should be exercised in interpretation of the coastline movements between the period assessed by DoT and Shore Coastal due to the potential different techniques used in the assessments. However, between the two periods interpreted by DoT and Shore Coastal there appears to have also been relative stability with up to 0.4m/yr accretion along the southern part of the bay.

More recently, between 2011 and 2013 there appears to have been very rapid erosion, particularly in the southern part of the bay (up to approximately chainage 650m on the path) with erosion rates in this period of up to 2.5m/yr. This is likely to be in response to the storms in September/October 2013. Since then there has been relative stability across the bay with, some areas showing minor accretion or erosion (up to 0.4m/yr accretion in front of the White Elephant Café and up to 0.4m/yr erosion between beach access 3 and 4).

This assessment indicates that for the last 50 years the vegetation line has been eroding. The erosion appears to follow a pattern, with general stability of the vegetation line interspersed with periods of rapid erosion every 20 to 25 years. It is likely that the periodic rapid erosion is in response to storm events, such as that experienced in September/October 2013. It also appears that following this rapid erosion there is limited ability for accretion of the vegetation line i.e. material is lost from the system faster than it enters, either through movement offshore or along the coast and out of the bay.

2.5. Conceptual Model of Coastal Processes

The morphology of the Gnarabup beaches is the result of a complex interaction between the coastal features and metocean conditions. The influence of the coastal features is variable and dependent on the metocean conditions experienced. In turn, the morphology of the beaches is dependent on the variable interaction between the coastal features and metocean conditions. It appears that minor differences in metocean conditions can have opposing effects on the beach morphology.

Assessment of UWA detailed deployment during storm events in the 2016 winter indicated a dominant onshore/offshore transport pattern is likely (see Figure 2.10 for deployment locations). These onshore/offshore currents would likely result in rapid response of the beaches to storm events, with sand moved onshore/offshore depending on the water level and availability of sand in the nearshore/beach areas. It is also likely that alongshore transport will be small as the deployment only showed a small alongshore current component. The dominant onshore/offshore transport would likely result in greater variation of the beach than may be observed from seasonal change. It is therefore possible that the variation due to individual storm events will mask any seasonal variation and is the main cause of long-term change discounting the influence of SLR.

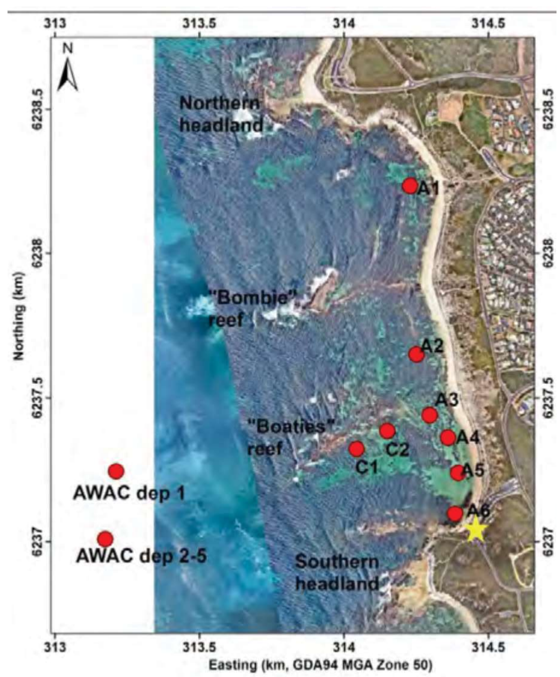


Figure 2.10 Location of acoustic wave gauge (AWAC) and eight pressure sensors (sites A1-6, C1-2) at Gnarabup Beach for the 15 month deployment (1).

Assessment of the historic coastline movement data shows there has been periodic recession of the vegetation line, which are most likely due to storm events, with limited recovery in between. This has resulted in an overall erosive trend, which can be averaged out at between 0.15 and 0.3m/year over the last 50 years.

From the assessment of the topographic beach surveys there appears to have been a weak pattern of erosion and accumulation over the winter period, which is reversed in the summer period. This pattern is largely in balance, suggesting a closed system or volumes of material entering and exiting the system are balanced in the short term. However, as outlined above the variation due to storm events may mask any seasonal variation, and the limited recovery observed between storm events suggests there may be an overall net loss of material.

The influence of the seasonal cycle is likely to be important in determining where storm events have the greatest impact in terms of erosion. For example, if the erosion event occurs at the end of winter, the beaches in front of the White Elephant Café are likely to be in a depleted state and any storm event would initially have the largest impact here. It is also possible that, with the subsequent seasonal fluctuations of sediment within this system, the erosion would balance out across the bay with relative recovery in the area impacted the worst and progressive erosion in those areas that initially experienced lower erosion rates during the storm event.

It is possible that during higher water levels more wave energy reaches the salient in the lee of the reefs setting up currents away from these formations. During lower water levels there may be comparatively more wave energy entering through the channels between the reefs than over the top of the reefs, which may result in stronger currents towards the salient formations.

Based on the width of buffers to the path and the recent historic erosion rate, the existing path is already vulnerable to damage from coastal processes. With climate change erosive events may become more frequent, while sea level rise may also increase the erosive effect of events.

A conceptual model of coastal processes is provided in Figure 2.11, which identifies key landforms including Gnarabup Beach (1), Boaties Salient (2), Prevelly Beach (3), Bombie Salient (4) and Riflebutts Beach (5), with Q1 representing incoming sand and Q2 loss of sand from the local sediment cell, smaller arrows represent loss of sand through offshore transport due to currents between the reefs.

Figure 2.11 Conceptual Model of Gnarabup Beach

2.6. Coastal Response to Climate Change

The impact of climate change and sea level rise (SLR) on the beaches will vary according to local topography.

As discussed above, Gnarabup and Prevelly Beaches are lagoon beaches, with local salient behind the Boaties and Bombies reefs. These beaches have reduced seaward transport due to a nearshore area that is predominantly rock, possibly with a nearly flat, thin veneer of overlying sand. Under energetic wave conditions, the beach may retreat and flatten, with 'permanent' retreat if beach sediment is dragged offshore, typically through wave-driven rip currents. Such loss may be offset by gradual recovery from offshore or alongshore supply of sediment, but this typically occurs slowly on a pocket beach.

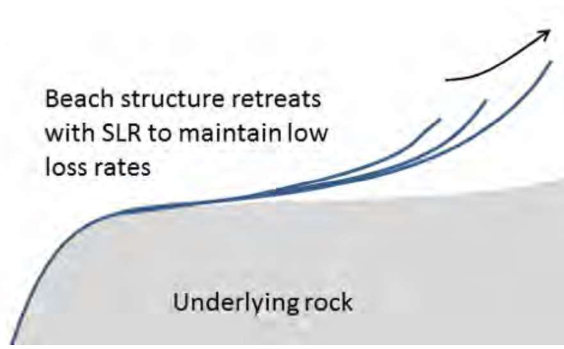


Figure 2.12 Behaviour of Beach Structure with SLR

The notional response of a lagoon beach to sea level rise is determined by the ratio of the horizontal active sediment zone to its vertical height. The dimensional constraints provided by the lagoon structure determine that this ratio is less than occurs on the open coast, which is the basis for the Bruun Rule.

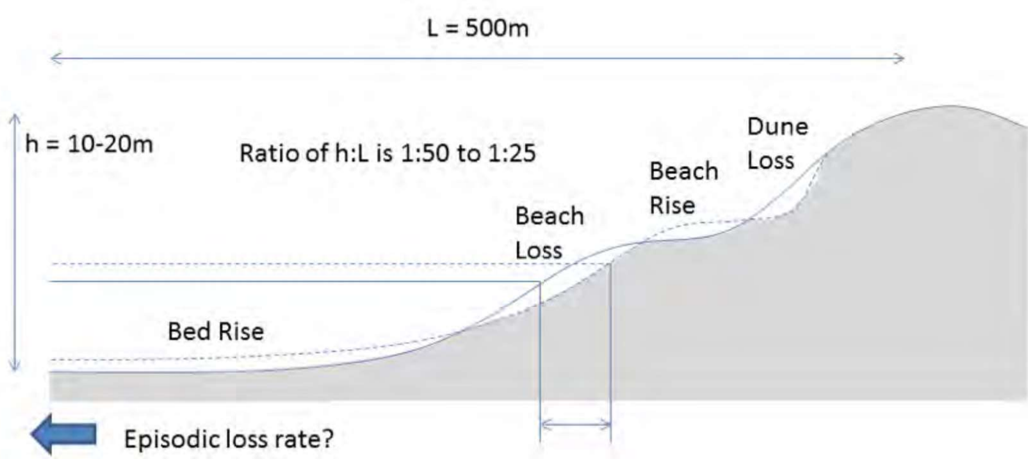


Figure 2.13 Dimensional Response of Beach to SLR

Long-term behaviour of the lagoon beach differs from the theoretical response to sea level rise due to both the smaller ratio of response and the greater importance of storm-events to provide permanent cross-shore sediment transfer. This means that storms act as the main mechanism to drive change towards an 'equilibrium' position, rather than providing short-term cycles of erosion-recovery overlying a long-term trend.

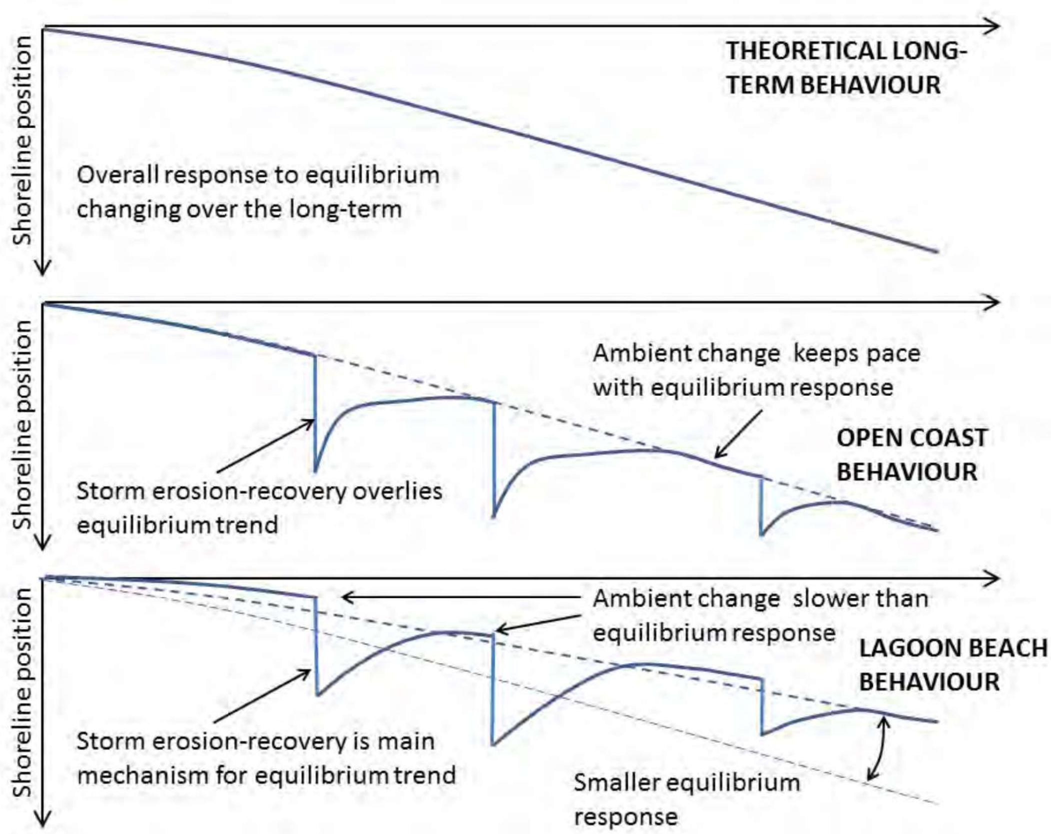


Figure 2.14 Long-term Response to SLR

As Gnarabup and Prevelly Beaches contain a number of smaller landform features, mechanisms which may change the volume or distribution of beach sediments include:

- Bruun-type Response (nearshore: beach balance)
- External supply / loss (from outside lagoon)
- Episodic loss (rip currents)
- Transfer to adjacent beach cells (north to Prevelly Beach)
- Dune & beach growth or loss
- Loss of shelter (applicable to salients)

Available evidence from the beach behaviour suggests that the lagoon components of the beach are comparatively insensitive to changing conditions, but that enhanced response is likely to be experienced at the two salients. This has been considered in the development of coastal adaptation options.

3. Coastal Adaptation Concepts

Planning for adaptation of coastal infrastructure must consider the mechanisms by which coastal structures are affected by coastal processes, as well as the full range of adaptations options.

There are two main causes of the loss of structural foundation to infrastructure sited on or adjacent to the Gnarabup Beach.

- ***Normal annual variations in beach levels****:* Winter storms typically create high energy waves which cause erosion, with a resultant dropping of beach levels. Subsequent spring weather typically brings accretion of sand with the resultant rise in beach levels (to their typical summer levels). Combined with the above, localised severe beach erosion occurs with localised seaweed build up. Diffraction of wave action occurs around the piles of seaweed causing severe longitudinal erosion. The annual variation in levels is in the order of 1.5m (comparison of the UWA (2017) survey).

- ***Erosion of the western (seaward) face of the primary dunes:*** Wave action, combined with trafficking by members of the public is eroding the primary dunes, resulting in unstable slopes which then collapse. There is no seasonal re-building of the dune. The effect is that the western face of the primary dune moves inland.

Coastal adaptation concepts for Gnarabup require consideration of three categories of infrastructure built within coastal influence

1) **"SACRIFICIAL"** INFRASTRUCTURE: LOW VALUE, LOW IMPACT

Infrastructure which is easily replaced at relatively low cost. E.g. garden beds, low value paths. Loss of these items would have no, or low impact on commercial operations.

Such infrastructure is designed assuming these items would need to be removed and/or replaced and may be undermined in a design event. For example, flexible paths such as crushed limestone would be preferable to concrete.

Clean-up and/or a maintenance program needs to be planned at time of design/construction.

2) **"ACCOMMODATION":** CONSTRUCTION METHODS TO WITHSTAND LOSS OF FOUNDATION –

Founding structures at a level below that where disturbance and loss of material may be caused by wave action. Once the beach/dune has been eroded away the structure remains suspended above, because its support system was founded below the design eroded level.

This system lends itself well to structures that are designed to be founded on point loads such as stumps, such as decks, stairs and landings.

An important consideration with this method is that once the beach has eroded to the anticipated design levels, the structures are left suspended. It may be some time until the eroded beach returns and, as with the case of ongoing dune erosion, it may never return. Given these parameters it becomes necessary to have systems in place that accommodate these large variations in beach/dune level. For example, stairs may need to be constructed so that the beach step-off is buried during times of high beach levels to ensure it is useable when the beach is eroded.

3) **"PROTECTION"** SYSTEMS: PROTECTION OF FOUNDATION FROM COASTAL EFFECTS

Physical barrier(s) are constructed to prevent eroding effects of waves from damaging infrastructure that is located behind the "protection".

These systems must be founded below the level of erosion by wave action in order to protect the foundation to the structures behind, and may include sea walls, sand filled geotextile bags, contiguous stone pitching or sheet piling. Protection systems must be founded well below the design eroded level of the beach. These systems tend to have relatively high capital costs, and are often intrusive to beach users. Well researched design is important.

Alternatively, the physical barrier itself may be sacrificial in that it absorbs the wave energy that might otherwise impact/damage the infrastructure to be protected. For example, sand/seaweed may be placed at the base of dunes which supports stairs that might otherwise be eroded during winter storms. A maintenance program needs to be implemented to ensure the sacrificial protection is maintained and then replaced once it has done its job.

3. Gnarabup – Prevelly Coastal Walkway

3.1. Existing Coastal Walkway

The Gnarabup Prevelly coastal walkway was constructed over a number of stages between August 2002 and June 2004, along the crest of the foredune. The path at the southern end was constructed with a 'spreader truck' as a compacted limestone walkway, with a short section near the boat ramp installed as a concrete path (Figure 3.1). Based on site and aerial photography sections of this path were constructed within 2 meters of the foredune crest. However, at the time the seaward face of the foredune was relatively flat and incipient dunes, which are an indicator of a relatively stable or accreting beach, are evident in site and aerial photos seaward of the foredune.

In the 16 years since the construction of the walkway, erosion of the beach, incipient dunes and the front face of the foredunes has occurred. The crest of the eroded and steep foredune is now immediately adjacent to the coastal walkway in some locations along the southern section of the path.

Figure 3.1 Coastal Walkway during construction in 2002 (L) and following installation of concrete path and fencing in 2003 (R).

Subsequent stages of the coastal walkway construction north towards Rifflebuts Reserve were constructed as compacted limestone further from the coast, with short sections of path providing a number of beach access points along the path. This northern section of the path requires maintenance of wind blows sand across the path but does not have the same issues with coastal erosion due to increased setback and the relative stability of the adjacent beach in recent years.

Figure 3.2 Coastal Walkway Stage 2 & 3 Constructed in 2004.

3.2. Coastal Buffers to Path

Assessment of the latest aerial image shows how the buffers between the vegetation line and the path vary between the White Elephant and Riflebutts (Figure 3.3).

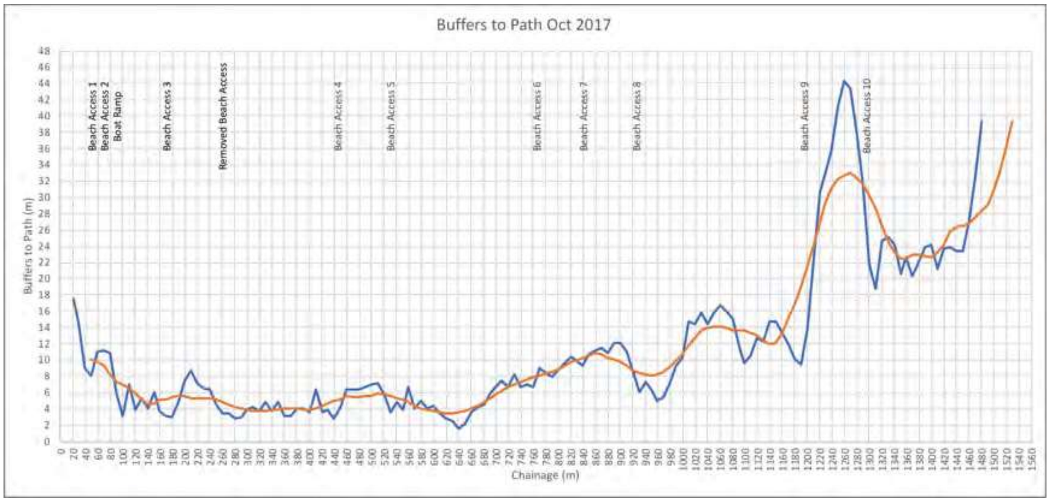


Figure 3.3 Distance Between October 2017 Vegetation line and Path

Figure 3.4 Photo Illustrating Narrow Buffer to Path

This illustrates that buffers to the path to the north of the boat ramp up to the Boaties Salient are small (between 0m and 6m wide). This is in an area that has experienced relatively rapid erosion of the vegetation line in recent history. Further north the dune buffers increase in width and the vegetation line has been relatively stable over the last 10 to 20 years. This assessment only considers the width of buffer between the vegetation line and the path and does not consider the volume of material within the dunes, which may also influence the erosion buffer to the path and the length of time before it becomes vulnerable to erosion.

3.3. Stakeholder Engagement

A stakeholder meeting for this project was held on 19/05/17. This included representatives from Shore Coastal, Shire offices, elected members, local resident groups, sea rescue and coastal dune care groups. The agenda included:

- Presentation at the Shire office and background.
- Site walkthrough Gnarabup area.
- Discussion of coastal adaptation options for the coastal walkway and agree outcomes.

Table 3.1 Stakeholder Discussion of Path Types

	Option 1 Limestone	Option 2 Boardwalk	Option 3 Mixed
Social	- Maintains existing level of amenity - Good underfoot in hot weather, unless sand covering path (+) - Allows wide range of access unless sand covering path (walking, bikes, prams) (+). - Low visual impact (+) - Lower public perception of path (-)	- Improved level of amenity (+) - Conflicts due to 'constraints' of path for passing (-) - Heat of structure on bare feet (-) - Access for emergency vehicles (-) - Falling off edge of boardwalk (-) - Higher public perception of path (+) - Aim higher with investment in infrastructure (+) - Detracts from natural feel of the path (-)	-Boardwalk in areas more prone to covering with sand (+).
Environmental	- People stray into dune vegetation when passing (-). - Path not as obviously delineated, people may stray from intended path alignment more often (-)	- Protection of dune vegetation (+) - Structure may be damaged during storm and end up on the beach if not set far enough back in dunes (-) - Allows dune to move underneath boardwalk with minimal intervention (+)	-Protection of dune vegetation in sensitive areas (+).
Economic	- Maintenance of sand on path (-) - Allows access for maintenance vehicles. (+)	-Capital cost of structure to allow for desired level of amenity and maintenance. (-) -Structure maintenance (-) -Insurance (-)	-Design and maintenance of transitions (-).

Table 3.2 Stakeholder Discussion on Path Alignment

	Option 1 Coastal Offset (30m)	**Option 2 Dune Swale**
Social	- Undulating path (-) - May be closer to coast in some areas (+) - Requires more access and better defined access from path to beach	-Potentially flatter grade on path (+) May be further to coast in some areas affecting views (-)
Environmental	- Greater disturbance to dune to construct (-) - May require cutting at southern end (-)	-Less disturbance to dune (+) -Path within swale may impact dune vegetation particularly if limestone path. This area has good vegetation growth due to protection and ponding of water. -May require cutting at southern end (-).
Economic	-Consistent setback from coast (+) -Maintenance of sand on path (-) -Marginally higher cost of construction (-) -Need to align around coastal rock in places (-) - Potentially significantly higher cost as boardwalk more suitable. - More challenging but possible to use limestone, likely to require stairs	-Variable setback from coast (-) -Maintenance of sand on path (-) - Initial construction cost likely to be less as limestone path more feasible

Figure 3.5 Site Meeting

3.4. Concept Adaptation Options

The proximity of the vegetation line to the coastal walkway was outlined in Figure 3.3. As discussed previously, the observed coastal behaviour is complex with an underlying historic erosion rate in the order of 0.15 to 0.30m/yr. However, aerial photographs suggest foredune erosion of 4 meters can occur in a stormy year, with variable rates of recovery. Sections of the southern end of the path remain vulnerable to immediate storm damage from year to year, in particularly from Ch100-700m, a 600m section of the path from the Gnarabup carpark north to Prevelly.

Following an initial review of adaptation options, and stakeholder consultation, three coastal adaptation options have been investigated further for this walkway (refer Attachment 1). These are:

1) *Limestone Coastal Walkway:* Construction of a new compacted limestone coastal path towards the back of the foredune from Gnarabup to Prevelly, at a similar elevation to the existing. The terrain limits the setback from the beach.
2) *Mixed Coastal Walkway:* Construction of a boardwalk towards the back of the foredune at Gnarabup, transitioning to a limestone path at the back of the foredune at Prevelly.
3) *Dune Boardwalk:* Construction of a boardwalk along the ridge-line of the large primary dunes for the southern section of the walkway at Gnarabup, transitioning to a limestone path at the back of the foredune at Prevelly.

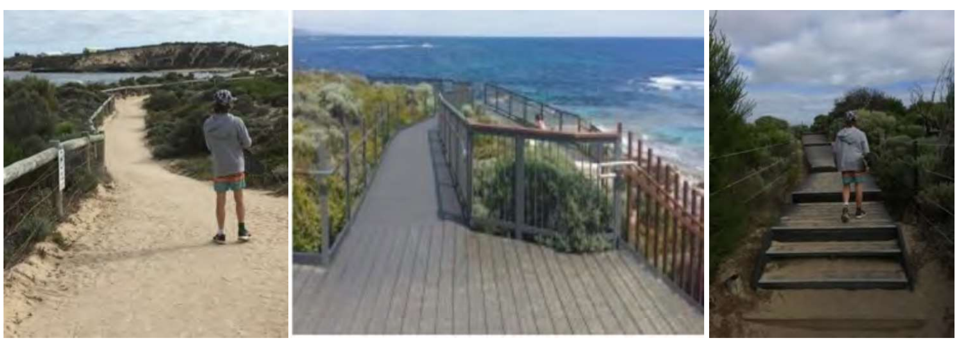


Figure 3.6 Walkways types including compacted limestone, boardwalks and boardwalks over dunes incorporating stairs.

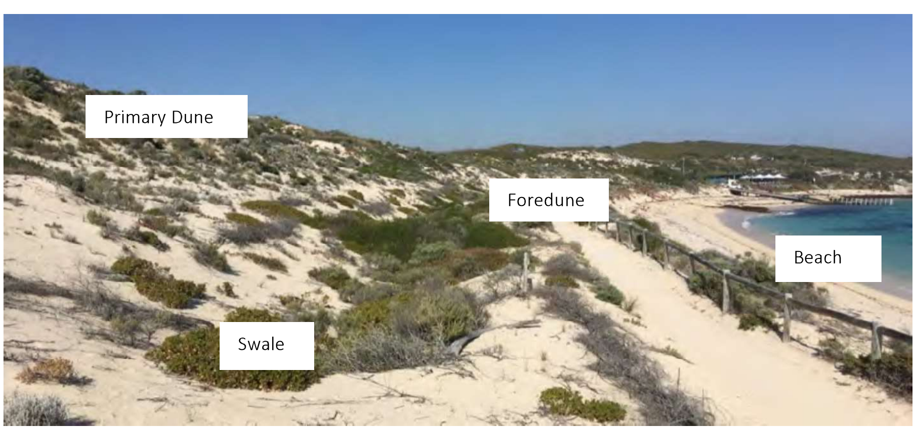


Figure 3.7 Coastal Dune Morphology

3.4.1. *Limestone Coastal Walkway (Option 1)*

The first adaptation option considered is the construction of a new limestone coastal walkway on the foredune. A potential alignment has been identified using available aerial photography, survey and site inspections. This alignment seeks to balance:

- Setback from the seaward face of the foredune, which is directly related to the design life of any new coastal walkway.
- Constructability and accessibility of the walkway (i.e. avoiding steep terrain).
- Future maintenance of the walkway, in particular the ongoing clearing of wind-blown sand from the new walkway, as is required for the existing walkway.
- The extent of vegetation clearing required.

The construction of a new walkway would require removal or relocation of the limestone in the existing path to prevent this material washing onto the beach in a storm. The alignment is constrained by the terrain, in particular the variability in the surface level of the foredune and the steep western face of the primary dune (Figure 3.7). This option assumed the following:

a) Utilise the existing access to the path at the southern end (Ch120-140m) on its current alignment, which is seaward of the dune ridge that runs along the edge of the carpark. This is a pinch-point where the path is within 10m of the vegetation line. This assumes protective works to the foredune (sand nourishment) would be maintained for this section.

b) The path alignment crosses the dune swale behind the beach access stairs to establish an alignment along the back of the swale (Ch140-200m).

c) The next section of the path (Ch200-400m) is challenging as the buffers to the path are low, recent erosion rates are relatively high, the foredune is relatively narrow (12m), the swale is relatively heavily vegetated, and the grade of the adjacent primary dune is steep. The disturbance of vegetation and more substantial earthworks are required to install this 200m section of path with reasonable buffers and acceptable ongoing maintenance.

d) North of Ch400m, the next 60m of the path to Ch460m, is aligned along the back of the swale with the flatter primary dune allowing less disturbance of vegetation and less earthworks.

e) North of Ch460m, the next 160m of the path to Ch620m follows a wide, flat vegetated swale which allows the path to be located up to 30m from the coast.

f) North of Ch620m, the next 140m of the path to Ch760m (Georgette Way access) is aligned along the back of the swale but may require some retaining structures such as limestone blocks due to the terrain.

g) Existing path to Riflebutts. There are no proposed changes to the path alignment north of Georgette Way to Riflebutts Reserve. However, the foredune 100m north of the Narda Ave access track should be monitored and the path re-aligned in this section in the future if required.

Figure 3.8 Limestone Path Alignment (Option 1) along Back of Swale

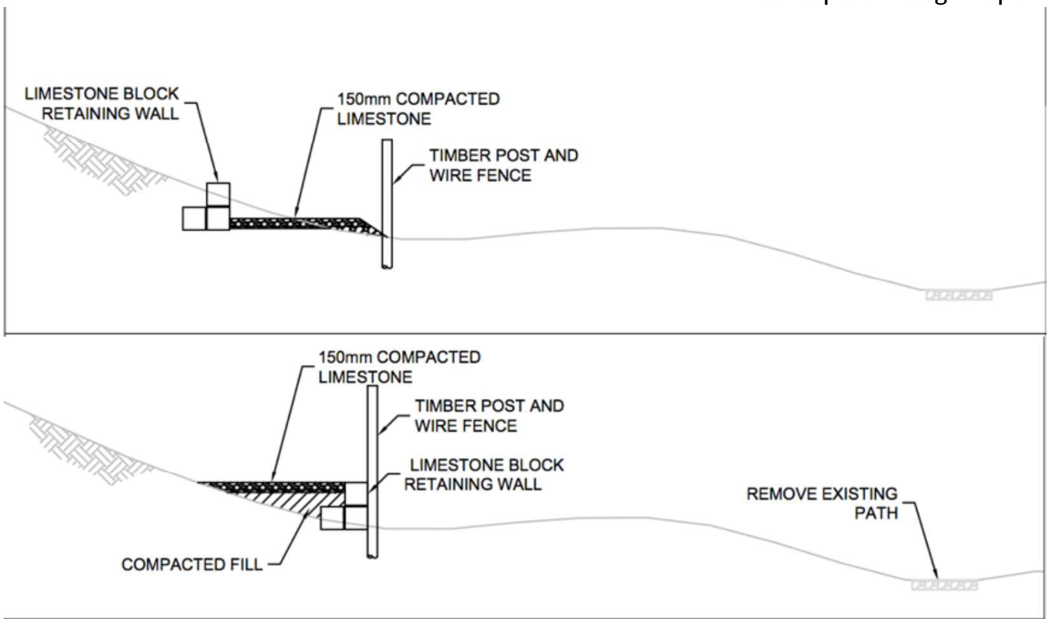


Figure 3.9 Typical Concept Sections for Limestone Path with Retaining Structure (Option 1)

3.4.2. Limestone path with cutting through dune to carpark (Option 1a)

This option is similar to option 1, except that it involves cutting through the dune ridge to the carpark with associated earthworks and retaining walls. This is included as a separate option because this high cost section may be able to be postponed to a later stage if the coastal protection works adjacent to the boat ramp are extended to protect the southern end of the existing path.

From chainage 200 onwards this option is the same as option 1.

Figure 3.10 Options 1a and 2a cross the Dune Ridge adjacent to the Carpark

3.4.3. Mixed Limestone/Boardwalk Coastal Walkway (Option 2)

The second adaptation option considered is the construction of a mixed limestone/boardwalk coastal walkway. This will allow the use of lower cost limestone in flatter areas and a boardwalk in the southern section wherever the west face of the primary dune is steep and in areas of the swale where vegetation is more established. This option assumes the following:

a) Existing southern access path. Utilise the path at the southern end (Ch120-140m) is on its current alignment, which is seaward of the dune ridge that runs along the edge of the carpark. This is a pinch-point where the path is within 10m of the vegetation line. It is assumed protective works to the foredune will be maintained for this section.

b) Transition to new alignment (Ch140-200m)320-460. The path alignment crosses the dune swale behind the beach access stairs to establish an alignment along the back of the swale. It is proposed to initially construct this section of the path as limestone, due to its proximity to the eroding dune scarp. (refer option 2b)

c) Boardwalk (Ch200-320m) It is proposed to construct a boardwalk along the rear of the swale. This is a high use area where a limestone path would otherwise require disturbance to vegetation and some retaining structures to accommodate the relatively steep terrain.

d) Boardwalk (Ch320-460m) The topography here is less challenging than in the previous section, but the design still allows for a boardwalk to minimise environmental impact.

e) Limestone path (Ch460-620m) North of Ch460m, the next 160m of the path to Ch620m follows a wide, flat vegetated swale which allows for construction of a limestone path to be located up to 30m from the coast.

f) Limestone path (Ch620-760) The next 140m of the path to Ch760m (Georgette St access) is also assumed to be a limestone path aligned along the back of the swale. Some retaining may be required in this section, but it is not considered sufficient to justify utilising a boardwalk.

g) Existing path to Riflebutts. As per options 1, there are no proposed changes to the path alignment north of Georgette St to Riflebutts Reserve. However, the foredune 100m north of Narda Ave should monitored and the path re-aligned in this section in the future if required.

There is a new access to the path at the southern end (Ch120m-Ch200m). This requires construction of a relatively high cost ramped boardwalk over the dune ridge that runs along the edge of the carpark, or a cutting through the dune ridge. This is to ensure the southern access to the path does not become a pinch-point.

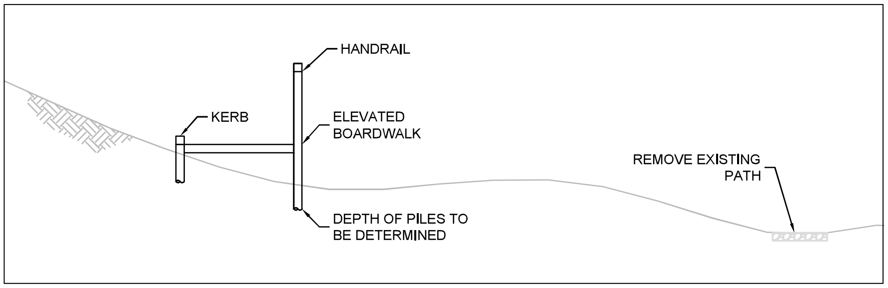


Figure 3.11 Typical Concept Sections for Coastal Boardwalk (Option 2)

3.4.4. Boardwalk with ramp over dune ridge to carpark (Option 2a)

This option is similar to option 2, except that it involves of a relatively high cost ramped boardwalk over the dune ridge that runs along the edge of the carpark. This is included as a separate option because this high cost section may be able to be postponed to a later stage if the coastal protection works adjacent to the boat ramp are extended to protect the southern end of the existing path.

From chainage 200 onwards this option is the same as option 2.

3.4.5. Dune Boardwalk (Option 3)

The third adaptation option considered is construction of an approximately 375m long boardwalk along the ridge or crest of the primary dune from the Gnarabup carpark to the Wallcliffe Rd access path at Ch400m. The boardwalk could then drop down to closer to the coast, similar to the mixed option.

The higher elevation boardwalk is only proposed for the southern section of the walkway (Ch 100-400) because:

- The southern section is most vulnerable to coastal erosion, with the terrain limiting the distance the path can be relocated eastward in the other options
- The dunes in the southern section have the most suitable terrain for construction of a boardwalk. Further north, the dune terrain means construction of a boardwalk would be more expensive and have a greater environmental impact.
- A path along the dunes in the southern section would not interfere with privacy of landowners. Further north, a path along the dunes would look directly down onto houses in Mitchell Drive.

This option assumes the existing coastal walkway is removed and replaced with a boardwalk along the ridge of the primary dune. Beach access would be limited to the southern end of the Gnarabup beach and north of the Wallcliffe Rd access track.

From chainage ~440m northwards, the proposed path would be the same as Options 1 & 2.

Figure 3.12 Option 3 - Nominal Alignment of Dune Ridge Path for Option 3

3.5. Analysis of Path Options

3.5.1. Design Life for Coastal Erosion

The design life of the path options, assuming coastal erosion as the mode of failure, is based on the minimum coastal setback and the assumed future erosion rate. The coastal setbacks to the three path options are outlined in Table 3.3. The following is noted:

- The southern end of the path adjacent to the Gnarabup Carpark is a 'pinch-point' for all options. This is immediately adjacent to the area requiring coastal protection, which in the longer term may require this coastal protection to progressively extend further north.
- Minimum buffers for all Options 1 & 2 are 10m at Ch650m (Prevelly Beach), where exposed rock constrains the path alignment to the foredune seaward of the exposed rock.
- The average buffers to erosion for Options 1 & 2 are in the order of 15m.
- The average buffer to erosion for Option 3 is in the order of 40m.

Table 3.3 Path Setbacks from Foredune

	Distance from 2017 Vegetation Line (m)			
Chainage	Existing Path (m)	Option 1	Option 2	Option 3
150	6	6	16	22
200	8	17	18	42
250	5	15	16	45
300	4	14	16	41
350	5	11	14	39
400	4	13	13	13
450	5	18	18	18
500	7	21	21	21
550	5	28	28	28
600	5	17	17	17
650	3	10	10	10
700	7	12	12	12
750	6	11	11	11
Min Buffer – Gnarabup (m)	5	11[1]	13	22
Min Buffer – Prevelly (m)	3	10	10	10
Average Buffer (m)	5.4	14.8	16.2	37.8

Note: 1. The minimum buffer for Option 1 is 6 meters at the entrance to the path at the southern end. However, it is assumes this erosion buffer will be managed by sand nourishment and other protection measures, leaving the minimum unprotected buffer of 11 meters at Ch350m.

Estimates have been made of the design life for each option, allowing for an ongoing minimum 5-meter buffer to the path to accommodate slope instability and storm erosion and an ongoing erosion rate of 0.3m/yr. Estimates have also been made allowing for an accelerated erosion rate of 0.6m/yr due to sea level rise.

Table 3.4 Coastal Walkway - Design Life for Coastal Erosion

Future Coastal Behaviour (Assumed)	Existing Path (yrs.)	Option 1 (yrs.)	Option 2 (yrs.)	Option 3 (yrs.)
Gnarabup				
Historic Erosion Rate Continues (0.3m/yr.)	17	37	43	73
Accelerated Erosion Rate (0.6m/yr.)	8	18	22	37
Historic Erosion Rate + 5m storm buffer	***0***	***20***	***27***	***57***
Accelerated Erosion Rate + 5m storm buffer	0	10	13	28
Prevelly				
Historic Erosion Rate Continues (0.3m/yr.)	10	33	33	33
Accelerated Erosion Rate (0.6m/yr.)	5	17	17	17
Historic Erosion Rate + 5m storm buffer	*0*	*17*	*17*	*17*
Accelerated Erosion Rate + 5m storm buffer	0	8	8	8

Note: Option 1 assumed the erosion buffer at the entrance to the path will be managed.

The following should be noted:

- The design life for Option 1 at Gnarabup Beach is 3yrs without proactive management at the pinch-point at the path approach, If, however, this foredune is effectively managed, a design life of up to 20 years may be feasible.
- For Prevelly, the assumed design life of the all path options is 17 years, at the pinch-point where the path runs seaward of exposed rock in the foredune.
- Reduced design lives for all options can be expected with an accelerated future erosion rate.

Figure 3.13 Gnarabup Beach April 2013. Note Incipient Dunes in front of recently removed Beach Access.

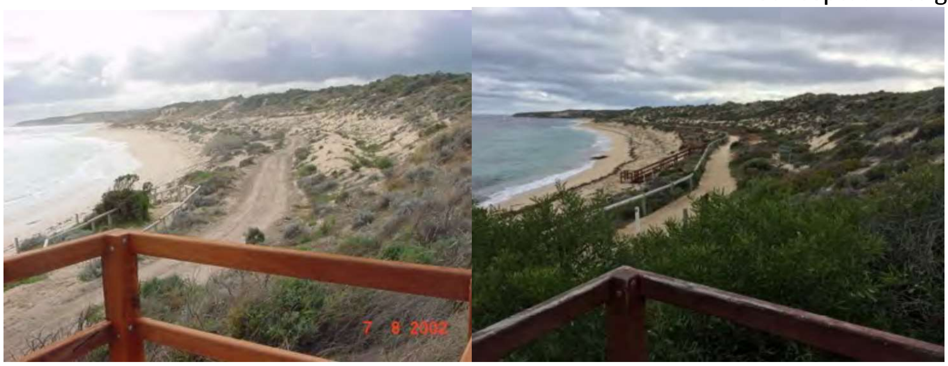


Figure 3.14 Coastal Walkway following construction in 2002 (L) and 16 years later in 2018 (R).

3.5.2. *Multi Criteria Analysis*

A multi-criteria analysis of the path options has been undertaken with consideration of the following:

- Coastal exposure: vulnerability to storm erosion and longer-term erosion, which is related to design life.
- Environmental: impacts on dune vegetation and habitats.
- Social: Amenity for users, amenity in the landscape, impacts on coastal residents and beach access.
- Economic: Capital and maintenance costs and resilience to bushfire.

Whilst the multi-criteria analysis is a subjective assessment, it identifies the limestone (Option 1) or mixed (Option 2) coastal walkways as preferred. Whilst the dune boardwalk scores highly for coastal exposure, as it is setback about 40m from the beach, this has a negative impact in terms of beach access. Additionally, the accessibility of the path is relatively poor as the terrain of the dune ridge results in a steeper, and more variable path grade and the capital cost is expected to be high.

The mixed coastal walkway scores marginally higher than the limestone walkway due to reduced storm exposure with the raised boardwalk over the dune ridge near the carpark and less impact on dune vegetation. However, there is a higher economic cost and reduced resilience to bushfire than the limestone walkway.

Table 3.5 Multi-Criteria Assessment of Path Options

Strategic Consideration	1. Limestone Coastal Walkway	2. Mixed Coastal Walkway	3. Dune Boardwalk
Coastal Exposure: Storm erosion (short term)	3	5	5
Coastal Exposure: Long term erosion	3.5	3.5	4.5
Environmental: Dune Vegetation	2	4	3
Social: Amenity for users	3	4	4
Social: Amenity in landscape	4	4	3
Social: Impact on coastal residents	4	4	3
Social: Beach Access	4	4	2
Social: Accessibility of Path	3.5	4	2.5
Economic: Capital Cost	4.5	3	1.5
Economic: Resilience to bushfire	4.5	2	2
Economic: Maintenance Cost	3	3	3
	39	40.5	33.5

Note: 5: Very good, 4: Good, 3: Fair, 2: Poor, 1: Very Poor.

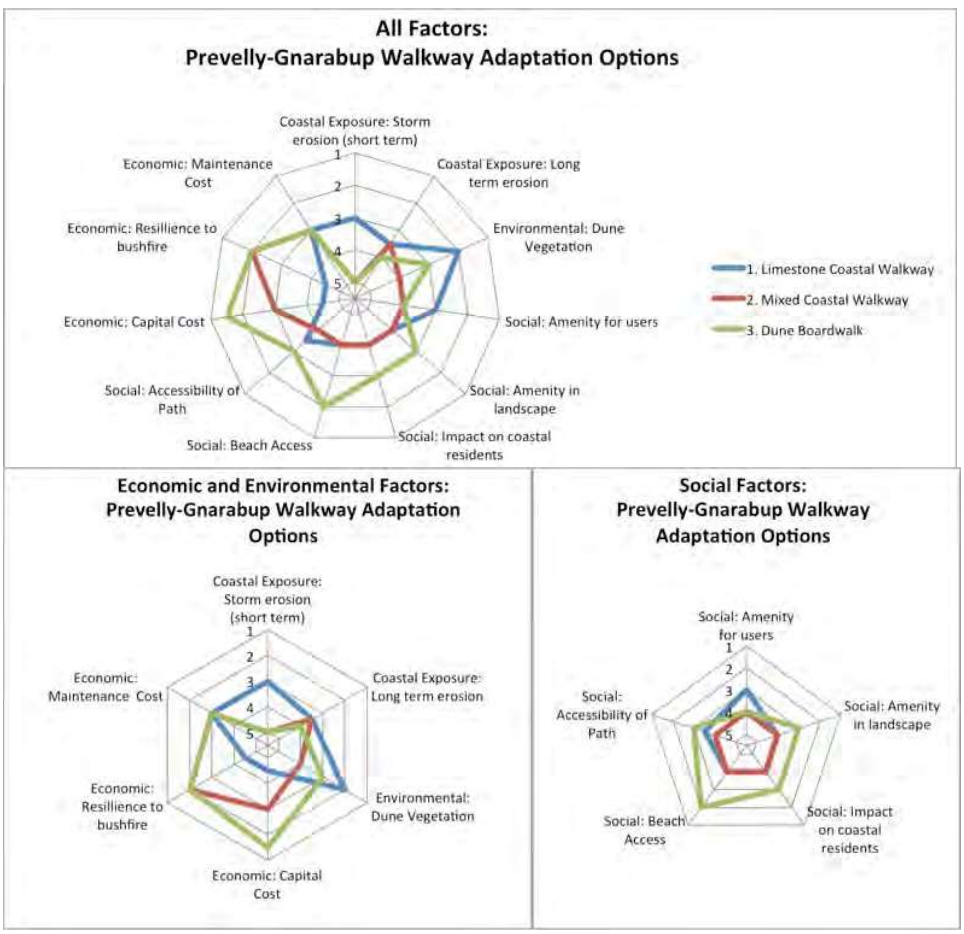


Figure 3.15 Multi-Criteria Assessment of Path Options

3.5.3. Cost Estimates

The assumed capital cost and design life for Coastal walkway options are outlined in Table 4.6.

Staged Construction

Staged construction of a new coastal walkway has been considered:

- A 320m section of the path along the foredune from Gnarabup to Prevelly (Ch140-460m) should be prioritised, together with a focus on managing the dune buffer at the southern approach to the path (Ch120-140m).
- The limestone path north of Ch460 should be considered in the next stage subject to management and monitoring of the narrow section at Prevelly (Ch640m).
- There are economic advantages in managing the dune buffer at the southern end of the coastal walkway to delay construction of what would be, proportionately, the most expensive section of the path.

Option 1 assumes the dune buffer at the southern end of the path is managed by sand nourishment or other soft engineering options (no cutting). Option 2 assumes a cutting or crossing of the dune ridge at the Gnarabup carpark is installed (with cutting) (Figure 3.16). Staged construction could consider two further options which are outlined in the detailed cost estimates:

- Option 1 could initially installed without a cutting, with planning and budgeting for installation of a limestone cutting with associated retaining walls at a later date. This would require an additional budget amount of $26,800 for Option 1.
- Option 2 could initially be installed with a short limestone path diversion at the southern end. The boardwalk cutting/ramp over the dune ridge near the Gnarabup carpark could then be installed at a later date if the management of the dune buffer is not feasible. This would reduce the initial cost for Option 2 by $27,275

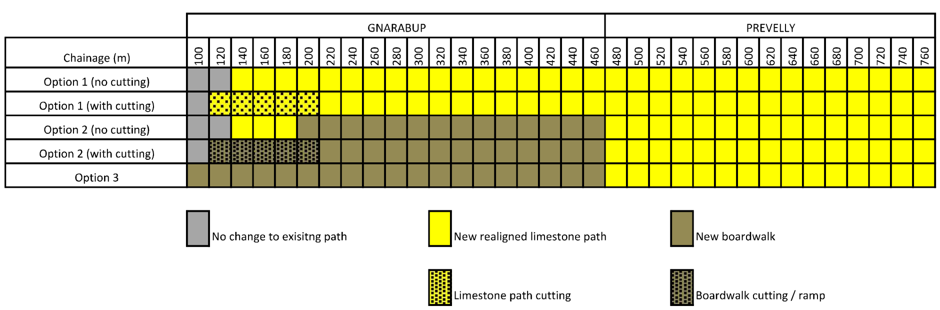


Figure 3.16 Staged Construction of Walkway

3.5.4. Financial Analysis

A basic financial analysis has been undertaken on potential build sequences for the three options considered, considering simple depreciation costs and interest costs. The assumed capital costs and design life for the paths are outlined in Table 3.6, with further detail in Attachment 2.

Table 3.6 **Assumed Capital Costs and Design Life for Path options**

Option	Description	Capital Cost ($ ExGST)	Assumed Design Life
1. Limestone coastal path	Coastal walkway (620m) from Gnarabup carpark to Georgette Way access track. Foredune at existing southern approach managed and some retaining structures required.	$140,000	10 years
2. Mixed coastal path	Coastal walkway (640m) from Gnarabup carpark to Georgette Way, with southern 340m as a boardwalk and northern 300m as a limestone path. Includes a new southern approach over dune ridge at Gnarabup carpark.	$450,000	25 years
3.Dune boardwalk	Dune boardwalk (375m) from Gnarabup carpark to Wallcliffe Rd access track, and 300m limestone coastal walkway to Georgette Way access track.	$630,000	40 years

The design life for the coastal walkways is limited by coastal erosion. The assumed design life for dune boardwalk in this analysis is 40 years. The analysis looked at average costs over 40 years, with the coastal walkways replaced when eroded. Where construction of an option was deferred, the value of that construction was reduced using a 5% interest rate for a Net Present Value calculation. NPV factors were only applied to capital costs. 5% was used as the assumed interest rate for interest costs, and interest costs were applied to the NPV capital cost of each asset.

Table 3.7 **Financial Analysis of Path Options**

Build Sequence	Average Depreciation and Interest
A) Dune boardwalk now	$47,000/year
B) Mixed path, then dune boardwalk	$33,000/year
C) Limestone path, then mixed path, then boardwalk.	$28,000/year

This basic analysis was indicative only. This analysis does, however, indicate:

- there are financial advantages to the Shire in constructing the lower cost coastal walkway options option 1 and option 2, despite their reduced design life, due to reduced costs associated with depreciation and interest costs of borrowing for the more expensive sections crossing the dune ridge to the car park.
- the cost per year of each of the options also indicated it is worth investing in foredune stabilisation works (beach scaping, nourishment, brushing) to limit erosion, even with the knowledge these works will delay rather than avoid the need for the construction of a new coastal walkway or dune boardwalk at some time in the future.
- Maintenance costs of the new structures require consideration in the design.

4. Beach Access

4.1. Existing Beach Access

Gnarabup -Prevelly Beaches are highly valued by the community as natural places for swimming, walking, surfing and other activities. Beach access points provide a link across the foredune between the coastal walkways, carparks, parks and Cafes to the beach. There are 11 formal access points to the sandy beach along the 1700m section of coast between Gnarabup Headland and Surfers Point (Attachment 1). These include:

- Timber stairs at the southern end of Gnarabup Beach. These provide access across a relatively steep, eroding foredune to the beach.
- Retained timber stairs at Prevelly Beach. These provide access across a wider, flatter and lower foredune to the beach
- Sand access through dunes at Riflebutts. These provide access though the foredune to the beach.

Figure 4.1 Beach Access Types including Timber Stairs (L), Retained Timber (C) and Sand Access (R).

The following is also noted in regard to the beach access:

- The southernmost set of timber stairs south of the boat ramp (Ch20m) was removed following damage during the September 2013 storms, with the adjacent stairs providing reasonable access to this section of the beach.
- The boat ramp is used for informal pedestrian access to the beach, and depending upon sand levels, can restrict access along the beach.
- A second set of timber stairs at Gnarabup Beach (Ch260m) was removed in 2017 following progressive erosion of the beach and foredune. This created a relatively wide (275m) gap between beach access 3 & 4 in a popular part of the beach. This has required ongoing management of informal beach access points as people access the beach from the coastal walkway across the foredune.
- The majority of beach access points inspected in May-2018 provided reasonable access to the beach at the time for relatively able bodied persons, with some undercutting of the crushed limestone at Access 4.
- There are no universal access points to the beach.
- There is access to the coastal walkway for machinery via the Spindrift Access (Ch900m) and Beach Access 5 is relatively wide and accessible with placement of sand or temporary ramps.
- There is no access south of the ramp for large machinery, although smaller plant may be able to track under the back of the ramp. Machinery was craned into this area to remove the failed limestone wall following the September 2013 storms.

Table 4.1 Prevelly Gnarabup Beach Access

ID	Bay	Distance along Beach (m)	Distance from Adjacent Access (m)	Type of Access	Function
1	1. Gnarabup	50	50	Timber stairs	Access from café area to sheltered swimming beach and pontoon south of ramp.
2		70	20	Timber stairs	
3		170	100	Timber stairs	Access from main carpark to swimming beach
4		445	275	Crushed limestone	
5	2. Prevelly	530	75	Retained timber	Access from coastal walkway
6		765	235	Retained timber	Access from Narda Ave carpark
7		840	85	Retained timber	Access from coastal walkway
8		925	85	Retained timber	Access from Georgette St carpark
9	3. Rifflebuts	1195	265	Sand	Access from coastal walkway
10		1295	100	Sand	Access from coastal walkway
11		1470	175	Sand	Access from Rifflebuts Reserve

Note: 1. Boat ramp at Ch90m provided informal access to the beach.
2. Beach access (timber stairs) at Ch260m removed in 2017 due to coastal erosion.

4.2. Concept Adaptation Options

People wishing to access the beach from the beach path have an expectation that beach access will be provided at reasonably regular intervals. The removal of "removed access Ch 260" has resulted in a substantial increase in people climbing over the path fence and walking down the dune AND climbing from the beach up the face of the dune, north of the removed stairs. This trafficking increases the inland migration of the foredune.

There are essentially two practical methods available whereby pedestrians can access the beach from the beach path.

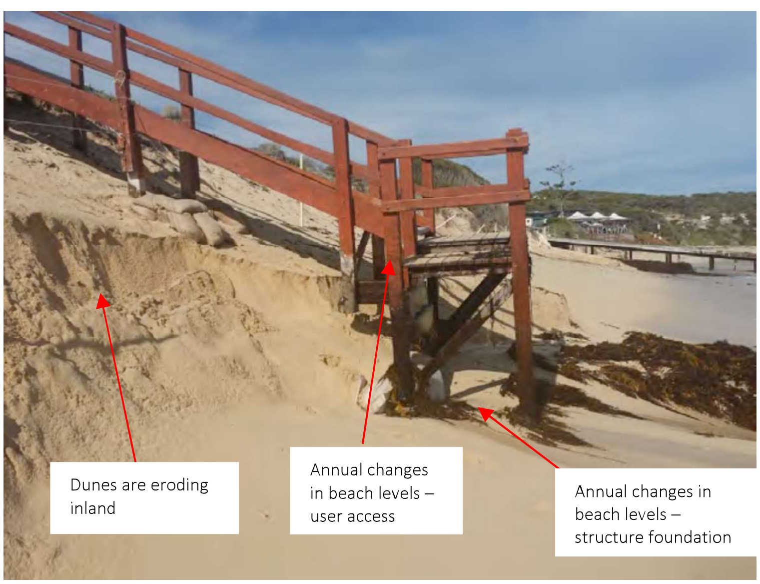
4.2.1. STAIRS

An access stair system is created that allows beach users to egress from the beach path onto the beach, and back to the path from the beach.

Stairs require a stable foundation in order to remain structurally sound. In other words, the base of the stairs needs to remain unchanged. This can be achieved either through:

- "Protection", i.e. provide a system to ensure the foundation is protected from the effects of wave erosion (this system was used for some years for the stairs at "Removed Access chainage 260", but eventual demolition was necessary) or
- "Accommodation" which is the more common method, generally in the form of lengthening the support members so that they are founded BELOW a level where the beach level erodes to (the "design level").

Design must accommodate BOTH the annual beach levels AND the movement of the primary dune inland, for beach access as well as for the structural foundation. Selection of levels will be affected by the design life for which the stairs are to be serviceable (five years, ten years etc).



STAIRS
Beach access structures need to account for the annual change in beach levels AND the one-way movement inland of the primary dune. The three options are:

SACRIFICIAL (not practical for stairs)
ACCOMMODATE (preferred)
PROTECTION

Figure 4.2 Gnarabup Beach Access Stairs

4.2.2. WALK THROUGH BEACH ACCESS

This simple system is more forgiving and has lower capital costs and is more "forgiving" than stairs.

Access pathways may require some stabilisation and/or retaining to the sides of the path.

Design and construction needs to be location sensitive, i.e.:

- Minimal grade from the beach path onto the beach which is a function of difference in levels (therefore minimal difference is preferred) and distance from path to beach – the longer this distance the shallower the grade.
- Best sited where changes in beach levels (annually and in the future) are known to be (or expected to be) minimal.

The portion of the access path that is founded where beach levels are subject to annual level changes (as much as 1.5m per year) requires consideration and a maintenance plan/program. There are several options available for this area where people step from the beach access path unaffected by level changes, onto the beach, such as:

- compacted limestone,
- treads (timber or recycled plastic/timber composite)
- treads chained together
- no formalised treatment
- paved (only where level changes are negligible)

Each option has advantages/disadvantages, it becomes a choice between capital costs/maintenance costs/serviceability under varying conditions.

<u>WALK THROUGH BEACH ACCESS</u>
Requires a maintenance program for interface between: path unaffected/path affected by beach level changes.

Low capital cost.
Requires judicious choice of location.

Figure 4.3 Walk Through Beach Access

Whilst the majority of beach access points inspected in May-2018 provided reasonable access to the beach at the time for relatively able, bodied persons, the high levels of beach variability limit access at certain times of the year. In particular:

- The level of the beach berm varies seasonally, and from week to week, by up to 1.5m. This restricts access from the lower platform of the timber stairs to the beach.
- Erosion of the foredune progressively undermining support posts for timber stairs.
- Steep grades at Access 4 due to foredune erosion, lowering of beach levels and erosion by foot traffic.
- Local accretion and erosion at retained timber stairs due to wind-blown sand and foot traffic.

Adaptation options for beach access are summarised in Table 4.2 and shown on Figure 4.4.

Table 4.2 Beach Access Adaptation Options

ID	Bay	Type of Access	Adaptation Options
1	1. Gnarabup	Timber stairs	Continue to monitor beach levels and foredune erosion. Design generic stair extensions for Beach Access 1, 2 & 3, with additional support for posts in Access 3. Allow for relocation in longer term. Potential for ramped access in southern corner to be considered.
2		Timber stairs	
3		Timber stairs	
4		Crushed limestone	Consider replacing with retained timber. Trial new beach access to the south (Ch260m) where timber stair removed. May requires local coastal walkway setback and retained timber stairs.
5	2. Prevelly	Retained timber	Continue to monitor and maintain, with additional brushing in places where wind-blown sand moving onto path. Trial seasonal beach matting to manage erosion by foot traffic as base of retained timber stairs.
6		Retained timber	
7		Retained timber	
8		Retained timber	
9	3. Rifflebuts	Sand	Continue to monitor and maintain. Trial seasonal beach matting to improve accessibility from Rifflebuts Reserve (Beach Access 11).
10		Sand	
11		Sand	

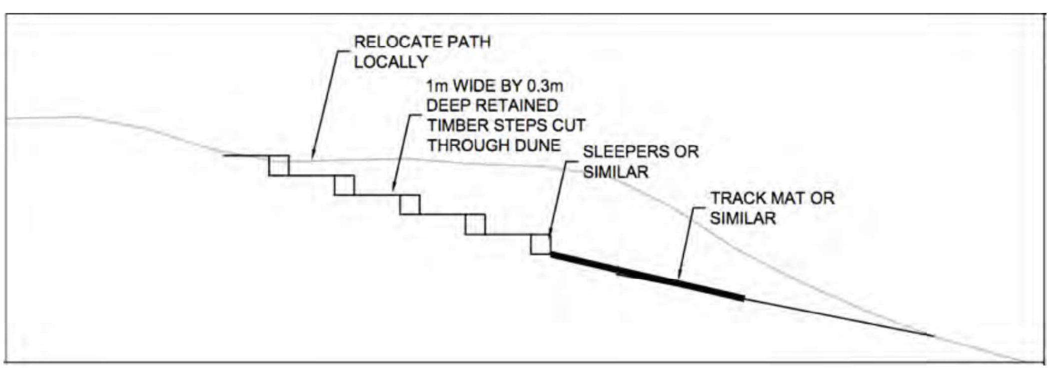


Figure 4.4 Beach Access Concept

Table 4.3 **Indicative Cost of Beach Access Options**

Option	Capital Cost
Timber Stairs[1]	$50,000 to $100,000
Retained timber[2]	$10,000
Crushed Limestone[3]	<$1,000
Sand[3]	<$1,000

1. Cost based on construction of existing beach access stairs at Gnarabup
2. Indicative cost based on similar structures throughout the Shire.
3. Nominal estimate

5. Gnarabup Boat Ramp Area

5.1. Existing Coastal Erosion

The southern end of Gnarabup Beach was subject to erosion in the September 2013 storms. South of the boat ramp the beach has recovered, however the recovery north of the boat ramp has been limited. Foredune erosion and high rates of variability of the level of the beach berm continues. Whilst the rates of foredune erosion are relatively low (0.3m/yr) there are very narrow buffers to infrastructure (carparks, concrete paths, boat ramp approach, Café) that cannot readily be relocated due to the high limestone cliff to the south.

The southern corner of the beach (Ch0-50m) has foredune erosion scarps from the September 2013 storms, although with the removal of the beach access stairs there is limited infrastructure immediately behind the dune.

Adaptation of the White Elephant Café deck with deeper piles following the September 2013 storms allows the adjacent foredune (Ch50-70m) to be lower and wider, as it is not required to provide support to the adjacent structure. This foredune is stabilised with vegetation and protected from foot traffic by fencing.

Adjacent to the boat ramp (Ch70-120m) the relatively high crest level of the foredune (6.0mAHD) creates instability in the face of foredune with minor erosion of the toe. The foredune is steep, unstable (with a rock overhang south of the ramp), unvegetated and difficult to stabilise with lower cost techniques (i.e. brushing and fencing). This is also the area with the lowest buffers (<5m) to higher value infrastructure that cannot readily be relocated, including the southern end of the coastal walkway.

The boat ramp abutment (Ch90m) includes two 'wing wall' constructed from boat ramp slabs supported by steel piles, and some additional limestone rock armour. Variable beach levels are exacerbated by wave reflection from the vertical walls of the abutment. Scour and erosion in front of the ramp abutment has caused undermining in recent years. Installation of lower cost coir logs and monitoring of beach levels have successfully managed this in the short term.

The foredune north to Beach Access 3 (Ch120-170m) is also unstable and in an area where relocation of the southern end of the coastal walkway is feasible but at a relatively high costs. However, buffers in this area are relatively higher than immediately to the south.

Figure 5.1 Gnarabup Beach South of Boat Ramp (Ch0-90m)

Figure 5.2 Gnarabup Beach North of Boat Ramp (Ch90-170m)

5.2. Concept Adaptation Options

The interface between the suspended portion of the boat ramp and the carpark approaches is known as the abutment. Effectively it is a retaining wall that serves two functions:

- Provides support for the boa tramp
- Provides retaining for the carpark approaches foundation.

The Gnarabup boat ramp abutment is constructed from concrete panels held in place by steel piles.

BOATRAMP
Needs to account for the annual change in beach levels AND the one- way movement inland of the primary dune. The three options are:

SACRIFICIAL (irrelevant)

ACCOMODATION (impractical)

PROTECTION (necessary)

Figure 5.3 Gnarabup Boat Ramp Abutment

Coastal adaptation options are limited to accommodation (structural modifications) and protection. The adaptation of the White Elephant deck and beach access stairs following the September 2013 storms provides a benchmark example of modifying a structure to allow for future erosion of the foredune and beach. In particular the modified structures supported independently of the foredune.

However, the boat ramp access at the adjacent carpark and concrete paths requires improved coastal protection to protect these structures from the damage that would be caused by require support by the foredune and will be damaged with further erosion of the foredune supporting them. This requires the Shire to consider a greater level of intervention and maintenance of this section of coast.

The foredunes immediately adjacent to the boat ramp (Ch70-120m) require sand to increase the erosion buffer to the paths and boat ramp access. Options include:

- *Beach scaping:* Relocating sand from the beach to the foredune when the beach berm is relatively high. This is simply redistributing material in the beach profile from the beach berm to the foredune using tracked machinery. This is a relatively low cost technique, but care needs to be taken that removing material from the beach does not increase the erosion of material placed in the foredune.
- *Wrack distribution:* The relocation of wrack stranded on the beach to the foredune, and mixing this material with sand, can increase the erosion buffer of the foredune and increase the durability of this buffer. This is a relatively low cost technique but

can limit the volume of sand removed from the beach during beach scraping. Care needs to be taken to ensure the volume of placed wrack does not affect the amenity of the foredunes.

- *Sand nourishment:* Import of sand from an external source using trucks and placement of material in the dune with a loader or similar. Sand should be of similar size, distribution and colour to the existing foredune material.
- *Brushing and Fencing:* Use typical techniques once the grade of the foredune has been moderated.
- Toe Stabilisation with flexible structures: Placement of lower cost structures such as coir logs or geotextile sand containers at the toe of the foredunes to assist stabilising the upper slope. High levels of variability in the beach berm mean this option requires ongoing monitoring and maintenance to ensure its effectiveness.

In the early stages inexpensive, low key protection is recommended. This may also postpone the need to move the start of the beach path to go through the dunes, as the protection could be designed to defend that area of the path as well as the boat ramp.

Recent survey in 2016/17 (UWA, 2017) has allowed the volume of material lost from the foredune annually to be quantified. Whilst further analysis is required to confirm volumes, this indicates that less than $1m^3/m$ is lost annually from the foredune. Sand nourishment would therefore be a relatively low cost operation with total quantities being less than $100m^3$ annually to nourish the 50m section of coast (<$3,000/year).

The following requires consideration:

- Machine access to the beach is required.
- Suitability, availability and cost of imported sand.
- Implementation would be seasonal and depend on beach levels, anticipated high erosion events, available sand and wrack supplies.
- Ongoing funding sources required.
- A feedback study to be conducted as to the cost/efficacy of this level of protection.
- Be prepared to increase the level of protection to, for example, sand filled geotextile bags (appropriately placed).

Depending upon the success of these ‘soft engineering’ techniques, the construction of a length of revetment (seawall) may be required in the longer term. This would preferably follow relocation of the southern section of the coastal walkway, so that protection of one asset (carpark) does not result in the erosion of another (coastal walkway). The design of a seawall would need to consider:

- the variability of the level of the beach berm.
- the wave energy the structure would be subject to.
- the type of material used (rock armour, geotextile sand containers)
- the length of the structure
- impacts on the beach (wave reflection, reduction in beach widths) and visual amenity.
- end effects (i.e. potential increase erosions immediately north or south of the seawall).

Coastal adaptation concepts for the boat ramp abutment include:

- Mitigation of scour impacts through:
    - Maintenance or monitoring of coir logs.
    - Beach scraping and wrack redistribution.
    - Geotextile sand containers.
- Mitigation of end impacts through:
    - Reinstatement of the foredune buffers as per above.
    - Increase extent of rock armour protection provided material is retained through use of filter rock and geofabric.

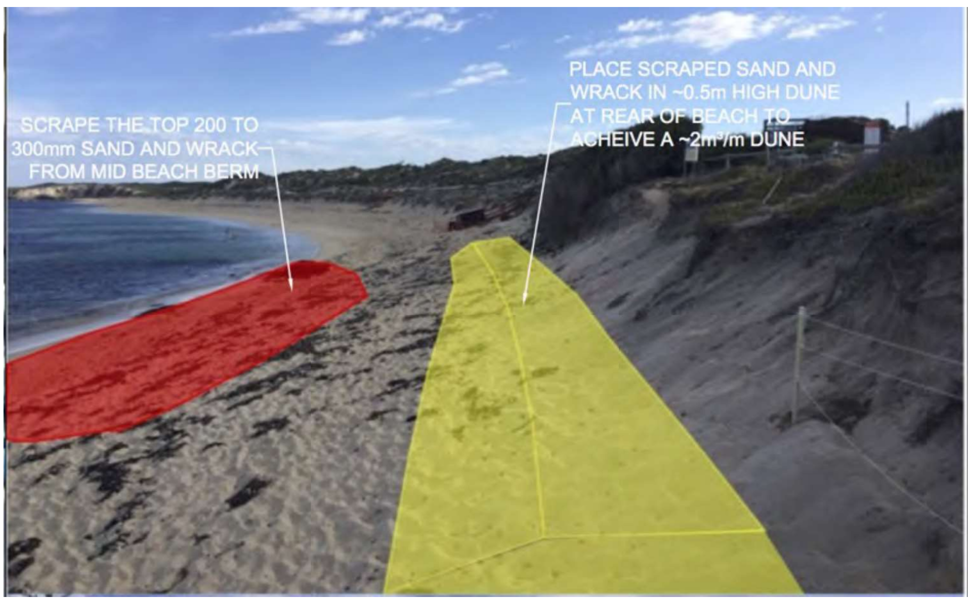


Figure 5.4 Beach Scaping Concept

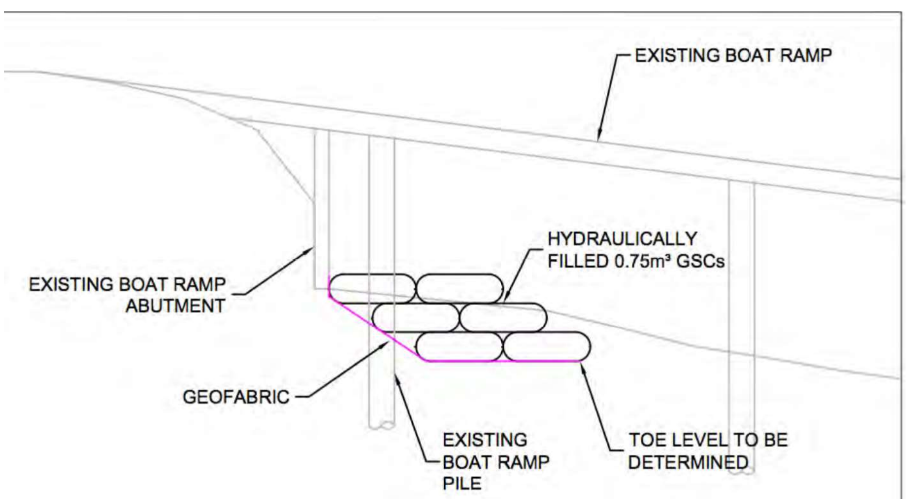


Figure 5.5 Geotextile Sand Container Scour Protection Concept

5.3. Sand Sources

Sand sources for beach renourishment have been briefly reviewed. This included two Shire pits at Forest Grove and Redgate Rd, and a commercial pit from Kaloorup in the City of Bunbury. The following is noted:

- The Gnarabup beach material is a coarse sand with a high shell content and a cream/brown colour. The foredune material is slightly finer as it is the wind-blown component but has similar composition to the beach sand.
- The Forrest Grove material is a grit with a brown colour that is unlikely to be suitable.
- Sand from Redgate Rd is a medium/fine sand with a white colour but is from a pit that is not operational and may require screening of rocks. The adjacent Redgate lime sand pit is likely to have similar material that has been screened.
- The Kaloorup sand is a medium white sand that is finer and marginally different colour to the existing dune sand but may be a suitable material for nourishment of the foredune in small quantities.

In summary, it is likely to be difficult to find material that is a close match for grain size, composition and colour to the existing dune sand. However, sources are available that could be considered for dune nourishment provided the colour is acceptable to the Shire and quantities allow for potential higher rates of erosion of imported material.

Figure 5.6 Sand Sources for Beach Nourishment

Indicative costing of the coastal adaptation options for the boat ramp area are outlined in Table 5.1

Table 5.1 **Indicative Costing of Boat Ramp Coastal Adaptation Options**

Option	Capital Cost
Beach Scraping[1]	$2,000
Sand Nourishment[2]	$21,000
Install GSCs as scour protection to ramp abutment[3]	$5,000
Install additional rock and extend wingwalls[3]	$5,000

1. Frequency of works likely to be annual
2. Sand nourishment assumes establishment of a 4m wide buffer with a 1:2 (V:H) slope from crest of foredune to beach
3. Initial capital cost only, likely to require ongoing beach scraping/sand nourishment as well.

6. Recommendations

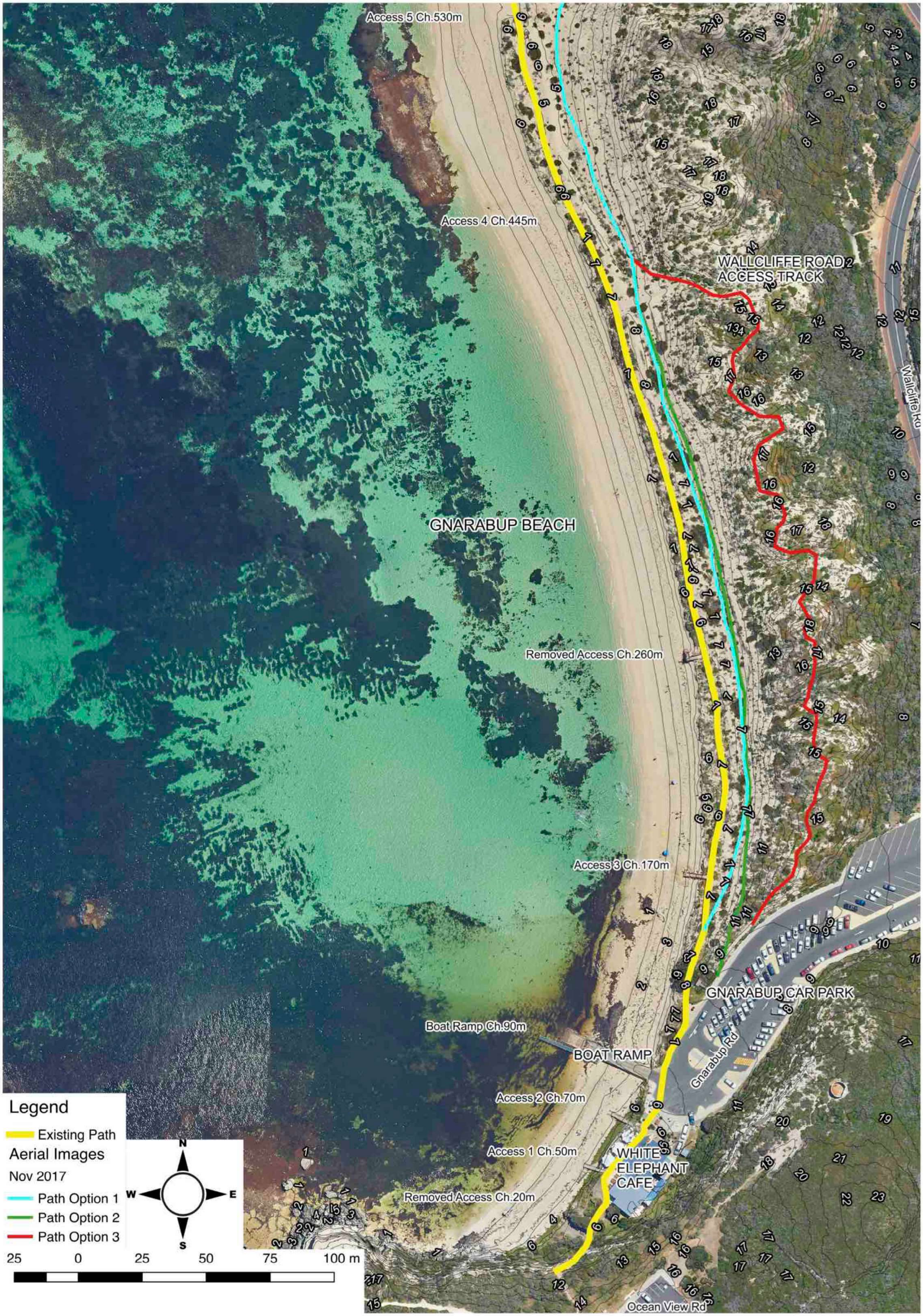
Design concepts have been developed for the coastal walkway, beach access and boat ramp area. The following is recommended:

1. A preferred option is selected for detailed design of the coastal walkway from either Option 1 (limestone) or Option 2 (mixed limestone and boardwalk). This requires consideration of design life for coastal erosion, environmental, social and economic consideration as outlined in this report.
2. The dune boardwalk (Option 3) is not favoured as a replacement for the coastal walkway due to relatively poor accessibility to the beach, steeper grades and high cost.
3. Staged construction of the new coastal walkway should be considered. the relocation of a 320m section of the path along the foredune from Gnarabup to Prevelly (Ch140-460m) should be prioritised, together with a focus on managing the dune buffer at the southern approach to the path (Ch120-140m) and a narrow section at Prevelly (Ch640m).
4. In the future, a cutting or crossing of the dune ridge at the Gnarabup carpark may be required. There are economic advantages in managing the dune buffer at the southern end of the coastal walkway to delay construction of what would be, proportionately, the most expensive section of the path.
5. The trial of a lower cost beach access based on a localised path diversion, retained timber stairs and seasonal beach matts to replace the removed stairs north of the Gnarabup carpark. This is to manage ongoing pedestrian access through the foredune in a popular area of the beach.
6. Ongoing monitoring and adaptation of timber access stairs is required.
7. Reinstatement and management of dune buffers adjacent to the boat ramp and at the southern end of the path with either beach scraping, wrack distribution or sand nourishment. This requires consideration of sand sources that may differ in size and composition to the existing dune material.
8. The placement of sand removed from the coastal walkway back onto the foredune in areas where the foredune is immediately adjacent to the path.
9. Further consideration of ramped access at the southern end of Gnarabup Beach and universal access options.
10. Selection of a scour and erosion protection options for the boat ramp abutment for detailed design.

7. References

1. **University of Western Australia.** *Summary of Gnarabup Beach data collection and preliminary analysis.* Perth : s.n., 2017.
2. **US Army Corps of Engineers.** *Coastal Engineering Manual.* Washington, D.C. : US Army Corps of Engineers, 2002. (in 6 volumes).
3. **Church, J A, et al.** *Sea Level Change: Climate Change 2013: The Physical Science Basis. Contributions of Working Group 1 to the Fifth Assessment Report of teh Intergovernmental Panel on Climate CHange.* s.l. : Cambridge University Press, 2013.
4. **DoT.** *Sea Level Change in Western Australia Application to Coastal Planning.* Perth : Department of Transport Coastal Infrastructure, Coastal Engineering Group, 2010.

Attachment 1 Concept Options for Coastal Walkway


Access 5 Ch.530m
Access 4 Ch.445m
WALLCLIFFE ROAD ACCESS TRACK
Wallcliffe Rd
GNARABUP BEACH
Removed Access Ch.260m
Access 3 Ch.170m
GNARABUP CAR PARK
Boat Ramp Ch.90m
BOAT RAMP
Gnarabup Rd
Access 2 Ch.70m
Access 1 Ch.50m
WHITE ELEPHANT CAFE
Removed Access Ch.20m
Ocean View Rd
Legend
Existing Path
Aerial Images
Nov 2017
Path Option 1
Path Option 2
Path Option 3
N
E
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W
25
0
25
50
75
100 m

RIFLEBUTTS RESERVE BEACH
PREVELLY BEACH
NARDA AVENUE ACCESS
MAINTENANCE ACCESS
GEORGETTE WAY ACCESS
Access 8 Ch.925m
Access 7 Ch.840m
Access 6 Ch.765m
Access 5 Ch.530m
Mitchell Dr
Narda Av
Georgette Wa
Legend
Existing Path
Aerial Images
Nov 2017
Path Option 1
Path Option 2
Path Option 3
N
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W
25
0
25
50
75
100 m

RIFLEBUTTS RESERVE
RIFLEBUTTS RESERVE ACCESS
Access 11 Ch.1470m
RIFLEBUTTS RESERVE BEACH
Access 10 Ch.1295m
MITCHELL DRIVE ACCESS
Access 9 Ch.1195m
Legend
Existing Path
Aerial Images
Nov 2017
Path Option 1
Path Option 2
Path Option 3
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