Bunbury Coastal Protection

Part A – Koombana Beach Coastal Erosion and Design Report

Photo: 16th May 2003

Seashore Engineering Pty Ltd
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Report SE001-01-Rev0

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Executive Summary

This report considers the potential management of Koombana Beach to address an existing and ongoing threat to coastal infrastructure caused by erosion.

Koombana Beach is located within the Port of Bunbury, between Koombana Yacht Club groyne to the west and Point Busaco groyne to the east. The eastern section of the beach, managed by the Bunbury Port Authority has experienced considerable erosion pressure in the last two decades, which threatens to affect Port infrastructure, as well as the Dolphin Discovery Centre towards the centre of Koombana Beach. The western and central parts of the beach, which are managed by the City of Bunbury, have high recreational value with significant public and tourist use.

Background

Koombana Beach is located to the east of Casuarina Point and was originally part of the narrow coastal barrier seaward of Leschenault Estuary. A discrete beach was formed during the 1970s as part of substantial modifications to the Estuary to reduce the threat of flooding to Bunbury, and later works to construct Bunbury Inner Harbour. Works influencing the beach structure included construction of training walls for Leschenault Inlet entrance and Bunbury Inner Harbour, along with placement of approximately 100,000m^3 of dredged spoil west of the Inner Harbour. The placed material was substantially redistributed, with erosion along the eastern foreshore since the late 1970s and net westerly sediment transport causing significant accretion on the east side of Koombana Yacht Club groyne.

From 2003, the Port has identified that ongoing erosion to the west of the Inner Harbour provides an increasing threat to the port access track adjacent to the Cable Sands site. In badly affected areas undermining has required track relocation. By 2011, the erosion had progressed to a degree where further relocation was considered impractical. Bunbury Port Authority commissioned a preliminary detailed design for a revetment (referred to as the Point Busaco revetment) to provide erosion protection along a 240m length of foreshore, designed to maintain the existing access path width. As part of design investigations, it was identified that the revetment is likely to transfer erosive pressure west, where existing infrastructure towards the centre of Koombana Beach already has limited foreshore setback. Facilities potentially under threat include the Dolphin Discovery Centre, footpaths, roads, and car parks.

This report has been commissioned by the City of Bunbury, with the support of Bunbury Port Authority and the Department of Transport, to investigate erosion occurring at Koombana Beach and determine an appropriate coastal management strategy that achieves optimal outcomes for both the short and long term.

Desktop Review and Knowledge Summary

A review of available coastal data and information relevant to Koombana Beach was undertaken to determine the existing knowledge and refine understanding of the coastal processes at Koombana Beach. Information reviewed included:

- Historical reports;
- Survey information;
- Records of past renourishment exercises;
- Aerial photography and coastline movements;
- Site photographs;
- Meteorological and hydrodynamic data, including winds, water levels and waves.

Understanding of coastal processes

Available survey information was used as the primary means of detecting change. The increased accuracy and spatial resolution of change provided by surveys in comparison to coastline movements previously used by DMH (1989) and Damara WA (2011) allowed for refined estimates of material loss along the eastern foreshore, assessment of accumulation on the western beach and identification of nearshore depth changes.

Vertical difference analysis of surveys indicated net westerly sediment transport regime along Koombana Beach, with storm-induced erosion of the eastern foreshore and nearshore deepening towards the centre of the beach contributing to accumulation on the west side of Koombana Yacht Club groyne. The near balance of erosion and accretion suggested that the beach can be considered largely 'closed', with minimal material loss offshore or bypassing the groynes.

Comparison of beach profile change with coastal data between 1991 and 2012 suggested that Koombana Beach is influenced by waves and water level variations:

- The overall bay shape generally aligns to the pattern of prevailing south-westerly swell waves diffracted around the Outer Harbour breakwater;
- Erosion predominantly occurs during occasional northerly storms, with a severe storm on 16th May 2003 and recent events coincident with high mean sea levels in 2011-2012 contributing significantly to the scarp recession, which has averaged 0.5m/yr from 1991 to 2012;
- Beach recovery following storm events is uneven, with greater accumulation towards the west. This is possibly influenced by locally generated waves due to the northeasterly winds typically occurring during winter post-storm conditions.

Condition inspection of the two groynes which define Koombana Beach identified the Koombana Yacht Club groyne to be in extremely poor condition, indicating its susceptibility to damage during storm events. The potential for reduced capacity to hold material east of the groyne has significant implications for management of Koombana Beach.

Particle size distribution (PSD) of sediment samples taken from the swash zone at the western, centre and eastern sections of the beach showed a general reduction in sediment size to the west. This is evidence supporting the inferred net westerly transport regime.

Coastal Management Options for Koombana Beach

Eight coastal management options were identified to mitigate potential coastal erosion issues at Koombana Beach:

- Managed retreat;
- Renourishment using sand from the Outer Harbour sand traps;
- Renourishment using sand from western Koombana Beach;
- Groynes with renourishment;
- Headland with renourishment;
- Detached headland with renourishment;
- Rock revetment;
- Groynes, renourishment and dune stabilisation without Point Busaco revetment.

Due to the ongoing erosion, narrow buffers and the high value of the Port's infrastructure at risk along the eastern section of the beach, seven of the options consider the construction of the Point Busaco revetment.

Assessment of the existing infrastructure towards the centre of Koombana Beach suggests that 10m of managed retreat may be practical through only minor coastal adaptations, which is therefore only a short-term response. Any further retreat requires substantial and expensive adaptation, suggesting that other forms of erosion management are likely to be cost-effective in the long-term.

Due to the largely enclosed nature of the beach and close proximity to suitable sediment sources, there is good opportunity for erosion hazard management through renourishment. This gives limited disturbance of the existing beach amenity and allows the beach to experience natural cycles of storm erosion and recovery. However, there is potential for ongoing redistribution of placed material, away from the areas experiencing erosive stress. A range of engineered structures have been considered that provide increased sand retention in existing problem areas and therefore reduced ongoing costs. An option to provide complete shoreline retention by constructing a revetment was also identified, although this was not considered in detail as it would cause loss of the beach in front.

Each coastal management option was reviewed in conjunction with the City of Bunbury and Bunbury Port Authority to select two preferred options for a more detailed evaluation. The selection was largely based on engineering performance and financial sustainability, with a sketch for each option presented outlining the key pros and cons, preliminary order of magnitude costs and indicative ongoing requirements. The two selected option were;

- Renourishment using sand from the Outer Harbour sand traps;
- Groynes with renourishment.

Detailed Evaluation of Two Selected Coastal Management Options

Designs of the two selected options were developed to a level where the most appropriate option to mitigate potential coastal erosion issues at Koombana Beach could be determined with a high level of confidence. The evaluation consisted of the following:

- Design of layout and cross-sections, with Plan SE001-2-1 showing the renourishment option and Plan SE001-2-2 showing the groynes with renourishment option;
- Refined cost estimates;
- Indication of ongoing requirements;
- Recommended beach monitoring;
- Identification of potential adaptation pathways.

Renourishment without structures provides lower predicted costs over the next 20 years. However, selection of the most cost-effective option in the long-term is less clear-cut, with uncertainties associated with the rates of sand redistribution and impacts of potential sea level rise. Consequently, it is recommended that the option of renourishment without structures be applied, with suitable performance monitoring and assessment to enable ongoing review of adaptation needs.

The recommended option of renourishment without structures provides low initial cost, a greater degree of flexibility and lower impacts to amenity and access along Koombana Beach. A shift to the alternate erosion management strategy (groynes with renourishment) may be achieved with comparative ease.

Beach monitoring should be undertaken during the first 5 years after renourishment to enable refinement of the beach nourishment program. Should the monitoring identify the rate of loss of renourishment from the feeder beach and renourishment area to a depth of -2m AHD is sufficiently high such that the groyne option becomes more economically viable, construction of the groynes should be considered. It is also noted that due to the largely closed nature of Koombana Beach and the existing capacity of the Koombana Yacht Club groyne to accommodate further accretion, material previously placed on the beach will not be 'lost' and therefore could be reworked to provide renourishment of the beaches updrift (eastern side) of the groynes.

It is recommended the renourishment option proceed to a detailed design and procurement phase, which should incorporate the following:

- Further sediment analysis on the Outer Harbour sand traps to determine the existing properties of the sediment source;
- Refine the design of Point Busaco revetment, to facilitate the feeder beach;
- Design drawings and technical specifications suitable for tender and construction are developed;
- Consideration of approvals required to complete the works. This will require further consultation of the impact of sand nourishment on dolphins in Koombana Bay;
- Identify and source funding for the works.

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1. Introduction

This report considers the potential management of Koombana Beach to address an existing and ongoing threat to coastal infrastructure caused by erosion. The report was commissioned by the City of Bunbury, with project direction from a working group comprised of staff from the City of Bunbury, Bunbury Port Authority and the Department of Transport (Maritime). Report findings were presented to a wider group of stakeholders for discussion and feedback.

Koombana Beach is located within the Port of Bunbury, between Koombana Yacht Club groyne to the west and Point Busaco groyne to the east (Figure 1-1). The eastern section of the beach, managed by the Bunbury Port Authority has experienced considerable erosion pressure in the last two decades, which threatens to affect Port infrastructure, as well as the Dolphin Discovery Centre towards the centre of Koombana Beach. The western and central parts of the beach, which are managed by the City of Bunbury, have high recreational value with significant public and tourist use.

Figure 1-1: Site Location

Koombana Beach is located to the east of Casuarina Point and was originally part of the narrow coastal barrier seaward of Leschenault Estuary. A discrete beach was formed during the 1970s as part of substantial modifications to the Estuary to reduce the threat of flooding to Bunbury, and later works to construct Bunbury Inner Harbour. Works influencing the beach structure included construction of training walls for Leschenault Inlet entrance and Bunbury Inner Harbour, along with placement of approximately 100,000m^3 of dredged spoil west of the Inner Harbour. The placed material was substantially redistributed, with erosion along the eastern foreshore since the late 1970s and net westerly sediment transport causing significant accretion on the east side of Koombana Yacht Club groyne.

From 2003, the Port has identified that ongoing erosion to the west of the Inner Harbour provides an increasing threat to the port access track adjacent to the Cable Sands site. In badly affected areas undermining has required track relocation. By 2011, the erosion had progressed to a degree where further relocation was considered impractical. Bunbury Port Authority commissioned a preliminary detailed design for a revetment (referred to as the Point Busaco revetment) to provide erosion protection along a 240m length of foreshore, designed to maintain the existing access path width (Damara WA 2011). As part of design investigations, it was identified that the revetment is likely to transfer erosive pressure west, where existing infrastructure towards the centre of Koombana Beach already has limited foreshore setback. Facilities potentially under threat include the Dolphin Discovery Centre, footpaths, roads, and car parks.

In February 2012, Seashore Engineering Pty Ltd was commissioned to investigate erosion occurring at Koombana Beach and determine an appropriate coastal management strategy that achieves optimal outcomes for both the short and long term. The agreed scope of the project is summarised by the following points, with details are provided in this report:

- Identify the scope of the erosion problem faced by the City of Bunbury and Bunbury Port Authority;
- Review of the all the relevant available information conducted to establish data available and the current understanding of coastal processes;
- Investigations to further the understanding of coastal processes;
- Development of 8 appropriate coastal management options informed by the detailed understanding of coastal processes;
- Comprehensive evaluation of the two preferred option determined following liaison between Seashore Engineering, Bunbury Port Authority and City of Bunbury staff.

2. Scope of the Erosion Problem

Koombana Beach is approximately 950m long of sandy foreshore, primarily managed by the City of Bunbury, with the Bunbury Port Authority managing the eastern quarter of the beach (Figure 2-1). The beach was artificially formed in the 1970s, through placement of a significant quantity of dredged material and installation of groynes at either end. Construction of foreshore infrastructure commenced shortly after beach formation, with progressive additions to accommodate the popularity of the beach and its visiting dolphins as well as to support industrial facilities at the adjacent Bunbury Inner Harbour.

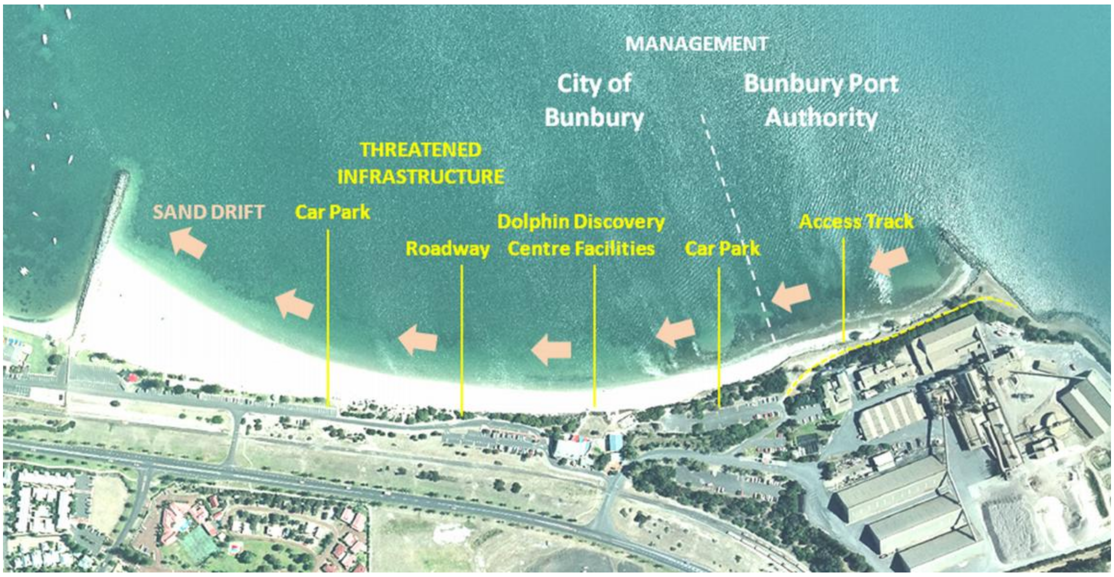

Figure 2-1: Koombana Beach Management and Threatened Infrastructure

Since its initial formation, the beach has experienced evolutionary change, with net sand drift from the east to the west. Change has not been continuous, but has generally occurred in discrete steps, associated with strong northerly storms, generating high waves and storm water levels.

The westward sand drift has caused erosive pressure on the eastern and central parts of the beach, with a limited dune buffer of roughly 10m or less width remaining in front of most of the existing foreshore infrastructure. The threat is more strongly advanced adjacent to the Port Authority access track, where a near-vertical scarp of more than 1m is present. The existing buffers represent minimal protection to the infrastructure, and are barely adequate for erosion impact of a strong storm, without further progressive change. Based upon previous rates of erosion, there is less than 10 years before infrastructure will be impacted.

Bunbury Port Authority has identified the need for improved protection of the port access track and adjacent infrastructure. However, they have also recognised that protection of the eastern part of the beach is likely to transfer erosive stresses towards the west, therefore potentially affecting the City of Bunbury facilities. The need for management of the beach as a whole has been acknowledged by both the Port and the City, prompting a collaborative approach towards this investigation and its interpretation.

3. Desktop Review and Knowledge Summary

A review of available coastal data and information for Koombana Beach was undertaken to determine the existing knowledge and refine understanding of the coastal processes at Koombana Beach. Information sourced from the Department of Transport, Bunbury Port Authority and the City of Bunbury has been summarised in this section.

3.1. REVIEW OF HISTORICAL REPORTS

Previous studies have been obtained to provide context to coastal management in at Koombana Beach and identify the influence modifications made to the region have had on coastal change along Koombana Beach. Development of the Inner Harbour was a key modification, as it incorporated formation of the beach through placement of dredge spoil and installation of groynes.

3.1.1. Site History

The structure of Koombana Bay is highly modified from its original configuration (Figure 3-1; Table 3-1). Modifications commenced in 1897 through the construction of the Outer Harbour breakwater (Le Page 1986) which modified the wave climate within Koombana Bay, increasing shelter and the general tendency for the Bay to capture sediment. The breakwater has since undergone extensions on six occasions to increase its sand trapping capacity (Shore Coastal 2009).

During the late 1920s, strong northern storms caused a strong southward push of beach sediment from the northern part of the Bay, which prompted construction of the Power Station groyne (Silvester & Cooper 1956; PWD 1978). The beach to the north subsequently accreted, with beaches between the Power Station groyne and the previous mouth of the Leschenault, including Koombana Beach, displaying a natural tendency to erode (DMH 1989; DPUD 1993).

In 1950-51, the entrance to the Leschenault Estuary was engineered through installation of a training wall on the northern side and later extended to southern side in the early 1970s. This entrance is now known as the “Cut”. The previous river mouth was subsequently infilled with dredged material, known colloquially as the “Plug”.

Between 1969 and 1974, the construction of the Koombana Yacht Club groyne and the Inner Harbour Project (including Point Busaco groyne) further altered the alignment of Koombana beach and restricted sediment supply from the north. Dredged material including sand, silt and rock fragments was released adjacent to the port entrance, providing major renourishment to the beach in approximately 1974. Finer material rapidly redistributed along the beach resulting in an accretion of about 50m over its entire length (DMH 1989). Accumulation was particularly evident to the east of Koombana Yacht Club groyne, suggesting a net westward sediment transport regime. This accumulated material has previously been used as a source for fill and other uses (DoT 1992).

The Inner Harbour Project also included extensive reclamation which separated the southern section of Leschenault Estuary (now known as the Leschenault Inlet) from the wider water body; redirection of the Preston River; and a new engineered channel cut to the ocean through the "Plug", which included the Bunbury Storm Surge Barrier.

Since 1975, Koombana Beach has progressively eroded. It is understood that due to the relatively fine nature of dredge spoil the erosion rate was initially high, with losses estimated at an average rate of 2,500-3,500m^3/yr, reducing to 1,000m^3/yr as the beach 'stabilised' (Damara WA 2011). Erosion has been particular evident along the eastern section of the beach with the formation of steep scarps, while the coarse remnants of dredged spoil remaining as rock fragments lining the beach. It is noted that erosion may have been accelerated by a previous practice of draining surface waters from the Cable Sands complex to the western side of Point Busaco (DMH 1989).

Table 3-1: Summary of Modifications to the Region (PWD 1978, Shore Coastal 2009)

Year	Capital Works
1864	Original Timber Jetty
1894-99	Outer Breakwater
1906-09	Outer Breakwater Extension 1
1916-18	Outer Breakwater Extension 2
1933-36	Outer Breakwater Extension 3 (northerly orientation) Power Station Groyne
1948-52	Outer Breakwater Extension 4 Eastern and Western Spur Groynes The Cut (Leschenault Estuary)
1952-53	The Plug (Leschenault Estuary)
1961	Outer Breakwater Extension 5 Western Spur Groyne Extension
1969-75	Inner Harbour Southern Training Wall of the Cut Koombana Beach Groyne Bunbury Storm Surge Barrier Training Walls
1980-85	Outer Breakwater Extension 6
1985-91	Eastern Spur Groyne Extension
1991	Inner Harbour Deepening

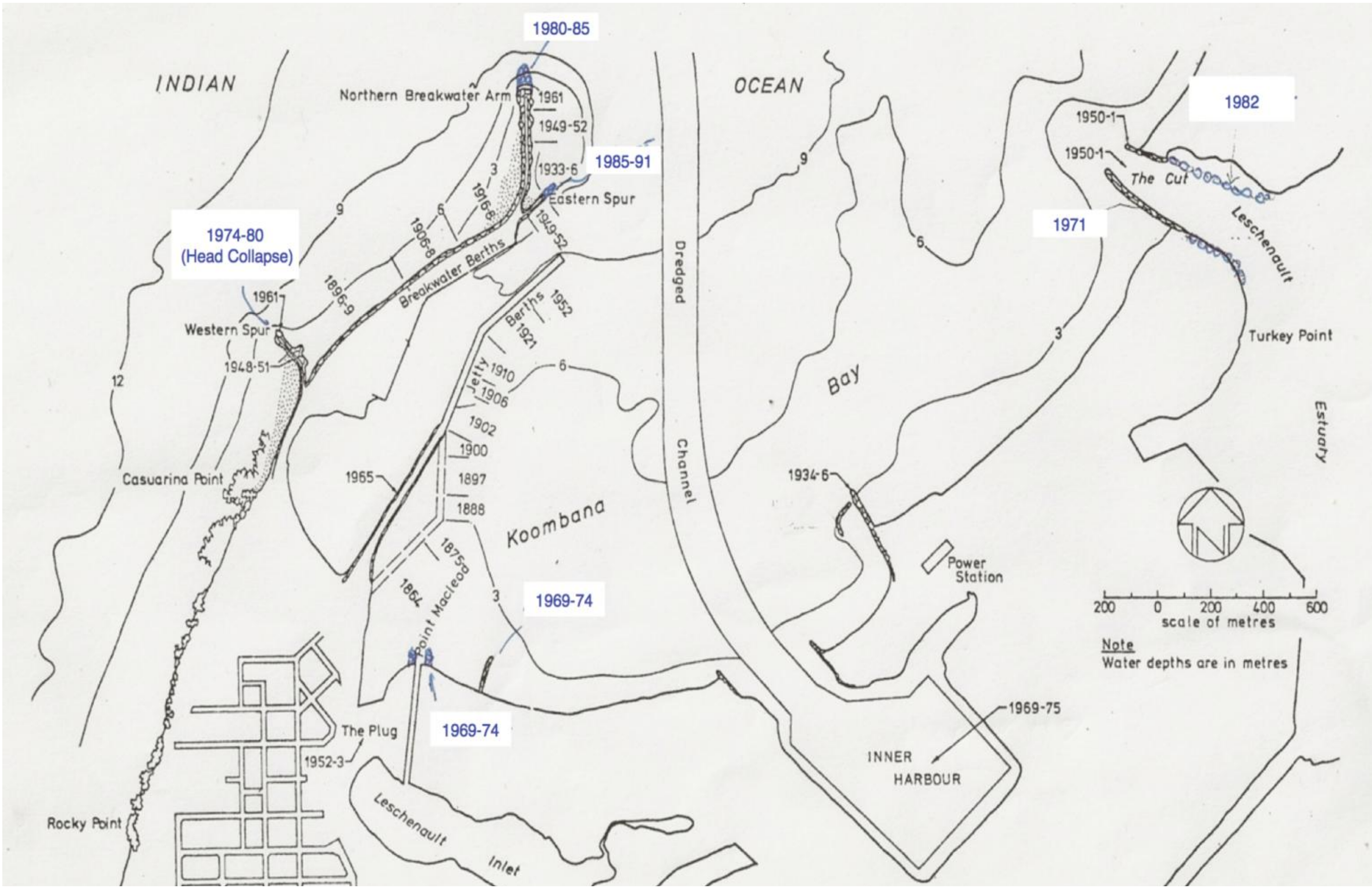

Figure 3-1: Summary of Bunbury Harbour Works
(PWD 1978, Shore Coastal 2009)

3.1.2. Previous Coastal Erosion Investigations

Coastal erosion at Koombana Beach has been previously investigated by a number of agencies, particularly during the late 1980s to early 1990s following ongoing erosion which included a period of accelerated erosion in the mid to late 1980s. Previously recommended management actions have been summarised in Table 3-2.

In 1988, Dr Silvester from UWA was engaged by the Bunbury City Council to investigate the erosion issue along the eastern section of Koombana Beach. Summarised in DMH (1989), he argued the altering of waves by the Inner Harbour shipping channel causes waves to approach the eastern end of Koombana Bay at a greater angle to the shoreline in comparison to the west, resulting in greater westerly transport of sediment. Hence the alignment of the foreshore adjacent to Point Busaco is not compatible with the curvature of the foreshore which otherwise aligns to the direction of wave propagation around the head of the Outer Breakwater.

Dr Silvester's argument was questioned by DMH (1989) on the basis that aerial imagery prior to dredging works for the shipping channel in 1971 shows a similar configuration west of Point Busaco. Instead it was suggested the alignment of the shoreline to the west of Point Busaco is due to local waves diffraction around the head of the groyne which is aligned at an angle across the prevailing direction of wave propagation.

Following recommendations in DMH (1989), the eastern section of the beach was nourished with 5,000m^3 of sand in June 1990 (DMH 1992) and six beach monitoring surveys were conducted between March 1991 and June 1994. Analysis of the first two beach monitoring surveys in March and September 1991 confirmed the westerly transport of sediments and localised erosion along the eastern section of the beach (DoT 1992). Following additional beach monitoring surveys in September 1992, May 1993, November 1993, beach volume analysis between survey periods was conducted (DoT 1994). The analysis was preliminary in nature, likely to be subject to high errors.

Recent undermining of Bunbury Port Authority emergency access track in the vicinity of Point Busaco prompted investigation and preliminary design of a 240m revetment (Damara WA 2011). Recent erosion was identified as coincident with a period of higher than average mean sea levels. It was also noted that the 'scalloped' scarp structure observed is likely to be due to the variable nature of fill causing locally enhanced erosion.

Coastal erosion hazard lines were developed as part of a Geoscience Australia regional risk assessment (Cowell & Barry 2012) and later interpreted as part of the Peron-Naturaliste Partnership Coastal Adaptation Decision Pathways (PNP-CAPS) project (Damara WA 2012). These lines were developed for regional scale assessment of coastal adaptation options and were deliberately simplified to provide a fit-for-purpose product. For this reason the lines do not provide a suitable indication of future change at the scale of Koombana Beach and therefore have not been considered further in this investigation.

Table 3-2: Previous Recommended Management Actions

Source	Recommended Management Action	Action Taken
Silvester (1988)	A groyne 150m west of Point Busaco and renourishment between the new groyne and Point Busaco.	No
DMH (1989)	5,000m^3 of sand nourishment on the eastern section using more stable sand, identifying coarse sand on the seaward side of the Outer Harbour as a potential source. Should funds permit, a further 2,500m^3 would give a more conservative treatment.	June 1990
DMH (1989)	Annual monitoring surveys of beach cross-sections and grain size analysis be undertaken in order to guide the need for further renourishment and/or low profile groynes.	1991-1994
DMH (1989)	Should a specific section of this beach require immediate and complete stability, then a programme combining renourishment and a low profile groyne will be required and will have to be specifically designed.	No
DMH (1989)	If and when the Koombana Bay Yacht Club removes sand from the western end of the beach, the sand should be deposited on the eastern end of Koombana Beach.	No
DMH (1989) DPUD (1993)	The Cable Sands surface water drainage to be shift to the groyne.	N/A
DMH (1992) DPUD (1993)	The periodic removal of sediment accreting at the KYCG and placement at the eastern end of the foreshore. If additional sand is required for renourishment of the eastern section of the beach, it can be obtained from the ocean side of the Outer Breakwater.	No
DMH (1992) DPUD (1993)	Ceasing of the past practice of removing sand from foreshore system at the western end for fill and other uses.	N/A
DPUD (1993)	Establish annual monitoring surveys, to indicate the nourishment required and whether the low profile groyne will be required in the future to stabilize the beach. If required the groyne will need to be specifically designed.	1991-1994
DPUD (1993)	Rock fragments and associated material from the eastern section of the beach should be relocated off-site[1].	No
Damara WA (2011)	Preliminary detailed design of a 240m revetment extending from Point Busaco to directly address the needs of the BPA.	On hold pending outcomes from this investigation.
Damara WA (2011)	Due to increased erosive pressure likely to occur to the west of the Point Busaco revetment and the existing narrow buffers to CoB infrastructure, liaison is required between the BPA and CoB to further consider erosion mitigation options along Koombana Beach.	Seashore Engineering commissioned by the CoB to undertaken this investigation.

[1] *This action is not anticipated to mitigate coastal erosion, rather it is considered to increase the safety and amenity for beach users*.

3.2. LOCAL BATHYMETRY

Koombana Beach is significantly sheltered from prevailing offshore southwesterly and west wave conditions from the Outer Harbour breakwater (Figure 3-2). The structure of the Bay is exposed to the north, which therefore enables an extended fetch for locally generated waves from the north through to northeast. Wave records adjacent to Bunbury Inner Harbour confirm this pattern, with the most energetic conditions typically occurring during northerly storms. From the bathymetry chart, depths within Koombana Bay are typically 4 to 6m CD, with the design depth of the main shipping channel to the Inner Harbour located east of Koombana Beach at 12.2m CD.

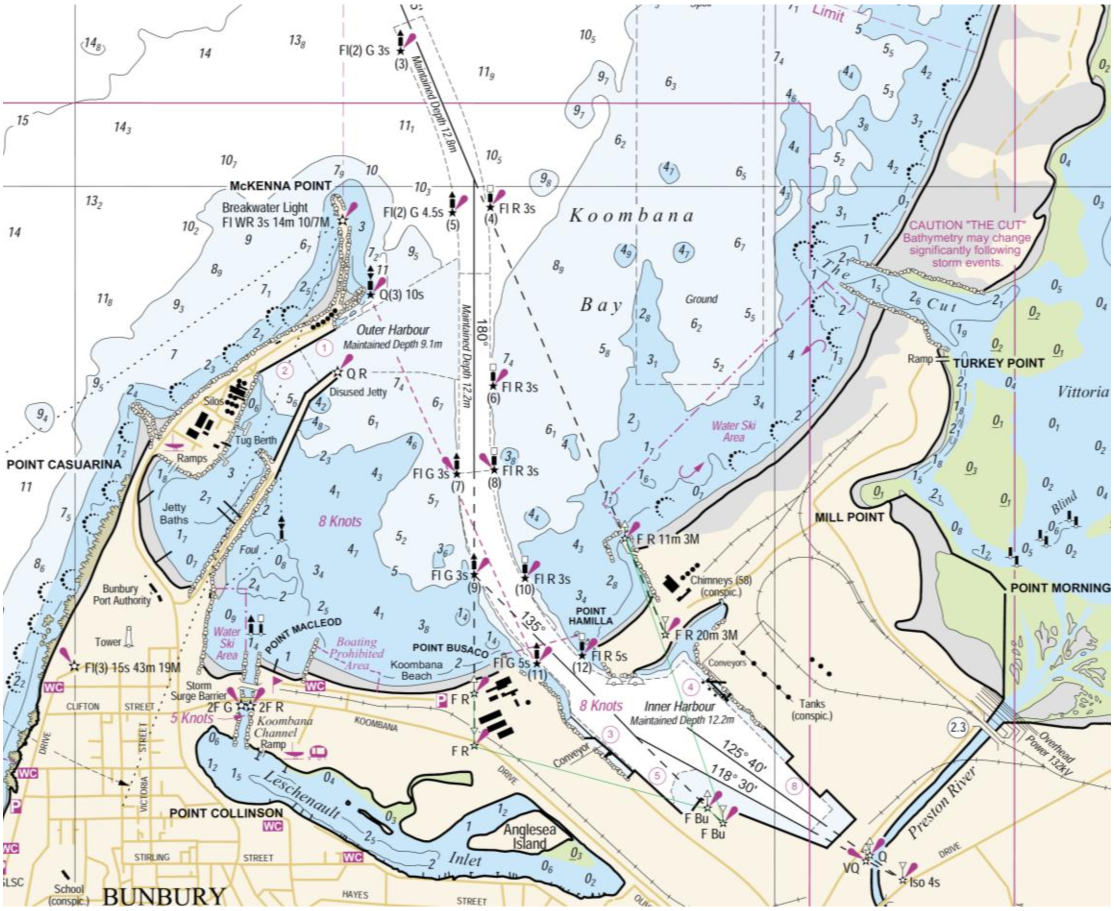

Figure 3-2: Local Bathymetry (Extract from DoT chart 776)

3.3. AVAILABLE SURVEY INFORMATION

Survey information directly relevant to Koombana Beach is collated in Appendix A. Hydrographic survey information covering the wider beach includes 5m gridded LADS data collected in April/May 2009 and six beach monitoring surveys conducted between March 1991 and June 1994. The beach monitoring surveys extend along 14 survey lines from the back of the beach to approximately 300m offshore (DMH 1992, DOT 1994). The remainder of survey information is typically limited to beach levels above 1m CD.

Hydrographic surveys commissioned by the BPA have typically focused on the entrance channel, with partial coverage of Koombana Beach provided by surveys conducted in 1977 and 2010 (Thompsons Surveyors).

3.4. PAST RENOURISHMENT EXERCISES

Koombana Beach has been nourished on two known occasions. It is understood further renourishment exercises may have occurred, however records are not held by either the Department of Transport or the City of Bunbury.

In approximately 1974, a significant volume of dredged material consisting of sand, silt and rock fragments from the Inner Harbour was placed on the beach (Figure 3-3). Assessment of aerial imagery from 1974 suggests volumes were in the order of 100,000m^3. The material was rapidly redistributed resulting in an accretion of about 50m over the entire length of the beach (DMH 1989), with accretion particularly evident adjacent to the Koombana Yacht Club groyne.

Figure 3-3: Dredged Spoil at Koombana Beach in 1974

Following recommendations made in DMH (1989) to manage ongoing erosion, the eastern extent of the beach was nourished with approximately 5,000m^3 of sand in June 1990 (DMH 1992; DPUD 1993) with the proposed works outlined in DoT Plan 539-1-1.

3.5. AERIAL PHOTOGRAPHY AND COASTLINE MOVEMENTS.

Collation of aerial imagery for deriving coastline movements at Koombana Beach has previously been undertaken on two known occasions, with the full list of aerial imagery detailed in Appendix B.

DMH (1989) analysed shoreline position for 21 dates of aerial imagery between 1969 and 1987, determining the following:

- major nourishment of the beach in 1975 was rapidly redistributed along the beach resulting in accretion of approximately 50m over its entire length;
- erosion rates of 5-10m/year along the eastern section of the beach corresponded with minor accretion along the western section of beach between the late 1970s and early 1980s;
- 20m of recession (4m per year) occurred over the whole Koombana Beach from December 1982 to December 1989.

As part of a siltation study for Bunbury Port Authority, Whelans were engaged to derive vegetation and shoreline position around the Bunbury Harbour from 11 dates of imagery between 1957 and 2008 (Shore Coastal 2009). Coastline movements at Koombana Beach were subsequently analysed at points towards the western, eastern and centre of the beach by Damara WA (2011), with the following identified:

- Construction of the Inner Harbour and Koombana Yacht Club groyne in the early 1970s significantly altered the alignment of the beach, with subsequent net westerly sediment transport causing accumulations against the western groyne;
- Additional disposal of dredge spoil from the Inner Harbour in approximately 1974 provided major beach nourishment adjacent to Point Busaco and material subsequently redistributed along the beach;
- Since the late 1970s and early 1980s erosion of the shoreline occurred with material loss from the upper profile of the beach (scarp) estimated average rate of 2,500-3,500m^3/yr, with rates initially high due to the redistribution of nourished material.
- Recession of vegetation lines along the central and eastern parts of Koombana Beach occurred from 1999 to 2008 and corresponded to a period of higher than average mean sea levels. Over this period the recession in the vicinity of Point Busaco was approximately 8m and with volume loss largely restricted to the upper profile (scarp), estimated to be in the order of 1,000m^3/yr.

Shoreline and vegetation lines derived by Whelans at Koombana Beach (1957-2008) and from recent Nearmap Imagery dated 15/09/2012 is presented in the plan SE 001-2-1 provided in Appendix G.

3.6. SITE PHOTOGRAPHS

Photography can provide an important insight to beach changes and can complement more comprehensive datasets such as survey information. Following recent erosion of Koombana Beach, various site photographs with differing field of views have been taken by the CoB, Damara WA, Seashore Engineering and DoT (Table 3-3).

To facilitate the future identification management issues along Koombana Beach, 8 photo-monitoring locations has been set-up to provide a consistent comparison with details for each provided in Appendix E.

Table 3-3: Site Photographs

Date	Source	Coverage
16/05/2003	City of Bunbury	Point Busaco to KYCG
13/07/2011	City of Bunbury	Dolphin Discovery Centre
10/10/2011	Damara WA	Point Busaco to KYCG
14/05/2012	City of Bunbury	Dolphin Discovery Centre
18/02/2013	Seashore Engineering	Point Busaco to KYCG
8/05/2013	Department of Transport	Western Koombana Beach

3.7. AVAILABLE METOCEAN DATA

This section summarises available wind, water level and wave data at Bunbury. In order to understand the processes driving coastal change at Koombana Beach, a relatively brief review of the data has been conducted.

3.7.1. Winds

Bunbury wind data is available from three records with observations, made with variable sampling frequency (Table 3-4), with reported velocity apparently affected by instrument changes. A relatively consistent record is available since 1995 from Bureau of Meteorology station 9965.

Table 3-4: Bunbury Wind Record

Station	BOM Number	Period	Observations
Bunbury Post Office	9514	1/01/1965-11/06/1985	9am, 3pm
Bunbury Power Station	9885	23/11/1985-31/10/1987	9am, 3pm
Bunbury Power Station	9885	1/11/1987-21/11/1995	12am, 6am, 9am, 3pm
Bunbury	9965	22/11/1995-24/02/1999	9am, 3pm
Bunbury	9965	24/02/1999-31/12/1999	3 hourly
Bunbury	9965	22/04/1999-31/08/2011	hourly
Bunbury	9965	31/08/2011-present	half hourly

Speed and direction frequency plots indicate winds at Bunbury are bimodal, with the two dominant directions of south-east and west corresponding to land and sea breezes respectively (Figure 3-4). It is noted that overland sheltering provided the Capes Region results in an increased westerly seabreeze component in comparison to the coast further north which typically has a strong southerly component. Monthly frequency plots indicate the land-seabreeze cycle weakens during winter months and easterly winds become more frequent (Appendix C).

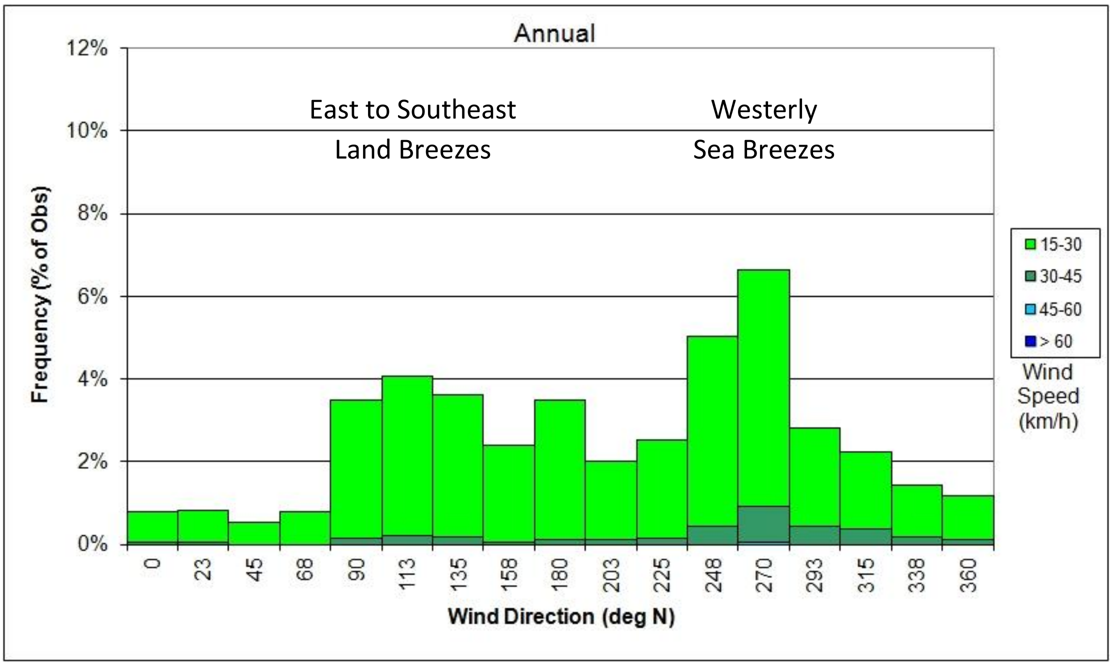

Figure 3-4: Annual Wind Frequency Plot 1995-2013 (Station 9965)

The strongest wind conditions at Bunbury are associated with winter mid-latitude storms, which mostly generate winds from the northwest through to southwest, varying significantly between events (Steedman & Associates 1982). Northerly storms which are significant for Koombana Beach are relatively less frequent (Panizza 1983).

3.7.2. Water Level Records

Bunbury tide gauge is one of the earliest established tide gauges on the Western Australian coast, built within Bunbury Port (Hamon 1963; Easton 1970), now known as the Outer Harbour. Relocation of port facilities and progressive degradation of the Bunbury Timber Jetty required establishment of a tide gauge within the Inner Harbour, installed in 2001. In October 2012, tide gauges were installed on either side of Bunbury Storm Surge Barrier.

Hourly digital data available for the period 1987-2012 has been obtained from the Department of Transport, which maintains the gauge on behalf of Bunbury Port Authority. Tide gauge data from 1930-1987, which was previously analysed by DMH (1990) is archived in paper tape format at the National Tidal Centre. This record includes the highest observed water level of 2.42m CD during passage of TC Alby on the 4th April 1978.

Bunbury is predominantly diurnal, experiencing a single tidal cycle on most days. It has a small tidal range, classified as microtidal, with a lowest to highest astronomic range of 1.20m (Table 3-5). The water level is strongly influenced by non-tidal forcing including surges and mean sea level variation, such that the total water level range from 1987 to 2012 was 2.51m (Figure 3-5), which is approximately twice the astronomic tidal range. Seasonal variation is apparent in the overall water level record, with high water levels mainly occurring during May through to July, and low water levels between October and February. Inter-annual variation of mean sea level is apparent, which is partly echoed in the variation of high water levels. Previous analyses of sea level variation in the region have demonstrated the separate contributions of storm surge, seasonal mean sea level cycle and inter-annual mean sea level variation (Hamon 1966; Pariwono *et al*. 1986; Amin 1993). The relative contributions of mean sea level, surge and tide to Bunbury observed water levels from 1987 to 2012 are suggested by results of time series decomposition (Figure 3-6 to Figure 3-8).

Table 3-5: Bunbury Tidal Planes
(Department of Defence 2010)

Tidal Level		Water Level (m CD)
Highest Astronomical Tide	HAT	1.2
Mean Higher High Water	MHHW	0.8
Mean Sea Level	MSL	0.6
Mean Lower Low Water	MLLW	0.4
Lowest Astronomical Tide	LAT	0.0

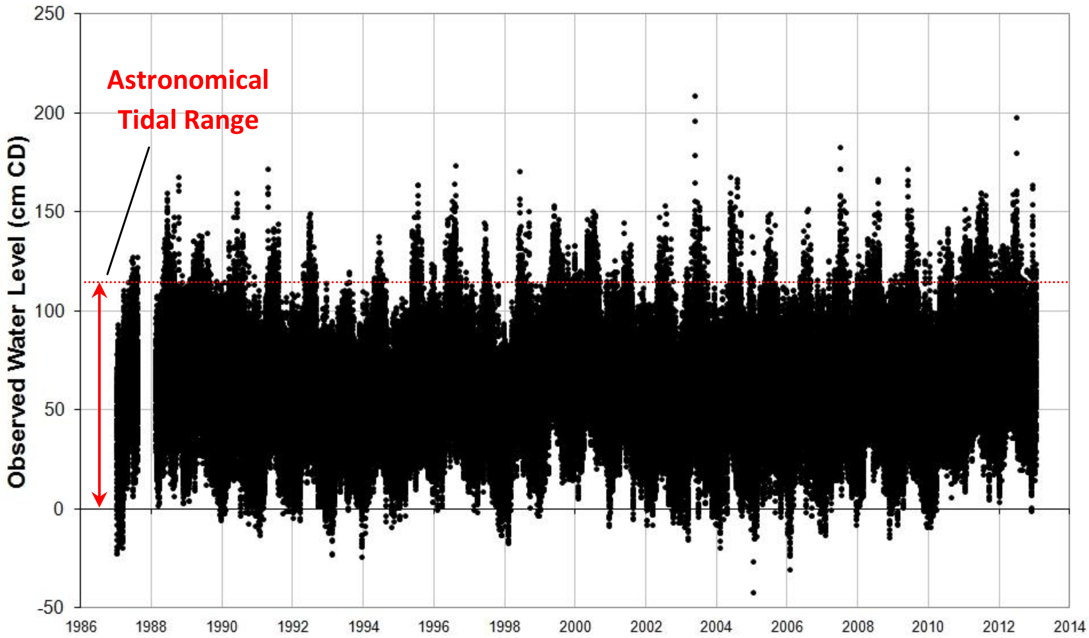

Figure 3-5: Bunbury Observed Water Levels 1987-2012

Mean sea level variation is determined through a combination of seasonal and inter-annual cycles. The seasonal cycle contributes almost 0.3m of water level range, peaking in May-June and lowest in October-November. The range is not constant from year-to-year and has been demonstrated to be largely explained by barotropic variation (i.e. atmospheric pressure and winds), meaning that it is affected by relative annual storminess (Wijeratne *et al.* 2011). Due to its seasonal nature, the signal is represented in tidal predictions through annual and semi-annual constituents, which are constant between years.

Inter-annual variability of mean sea level is strongly linked to the El-Nino / la Nina climate cycle, suggested by a strong correlation to the Southern Oscillation Index (Pariwono *et al* 1986; Haigh *et al*. 2011b). Variation of approximately 0.3m may be attributed to this relationship, with higher water levels occurring during the la Nina phase. The Bunbury record shows recent periods of unusually sustained high mean sea levels occurring during 1999-2000, 2008, 2011-2012, which correspond to extreme la Nina events (Bureau of Meteorology 2012).

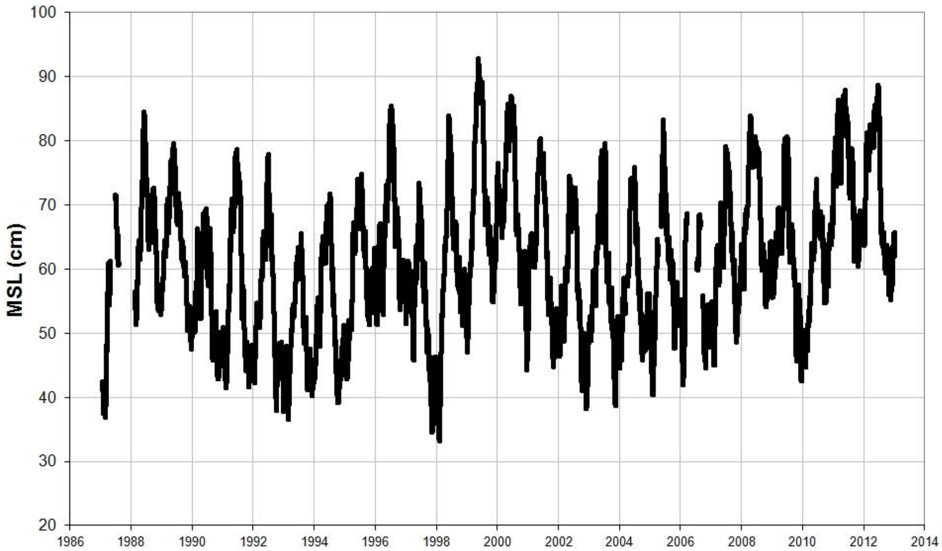

Figure 3-6: Bunbury MSL Component 1987-2012

The surge approximation derived from time series decomposition (Figure 3-7) is influenced by the removal of the seasonal mean sea level signal and filtering out of high frequency surge components. However, despite these effects, the surge approximation displays a highly seasonal pattern with peak surges largely corresponding to intense winter storms. The surge signal also demonstrates inter-annual variability characteristic of storminess, which is independent of ENSO-related climate fluctuations.

Bunbury is dominated by diurnal tides, which provide a single tidal cycle on most days and although experiencing a fortnightly cycle, do not directly correspond to the lunar phase. The diurnal nature also heightens the apparent influence of certain longer-term tidal cycles (Figure 3-8), particularly the bi-annual tidal cycle and the 18.6 year lunar nodal cycle (Haigh *et al*. 2011a). The seasonal tidal peaks coincide with the solstices in June and December. The sub-harmonic of lunar perigee is visible on the seasonal low tides as a 4.4 year cycle, but provides a comparatively small source of variation (Eliot 2011).

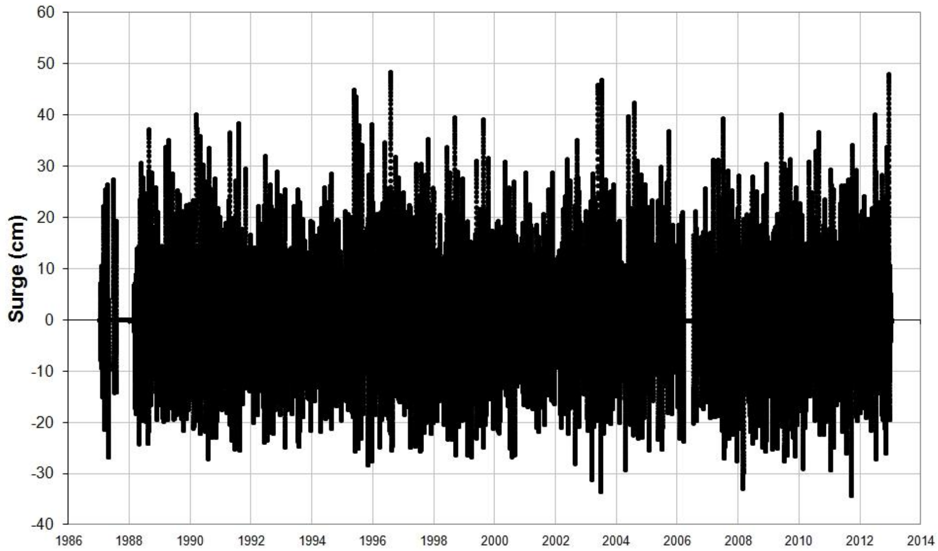

Figure 3-7: Bunbury Surge Component 1987-2012

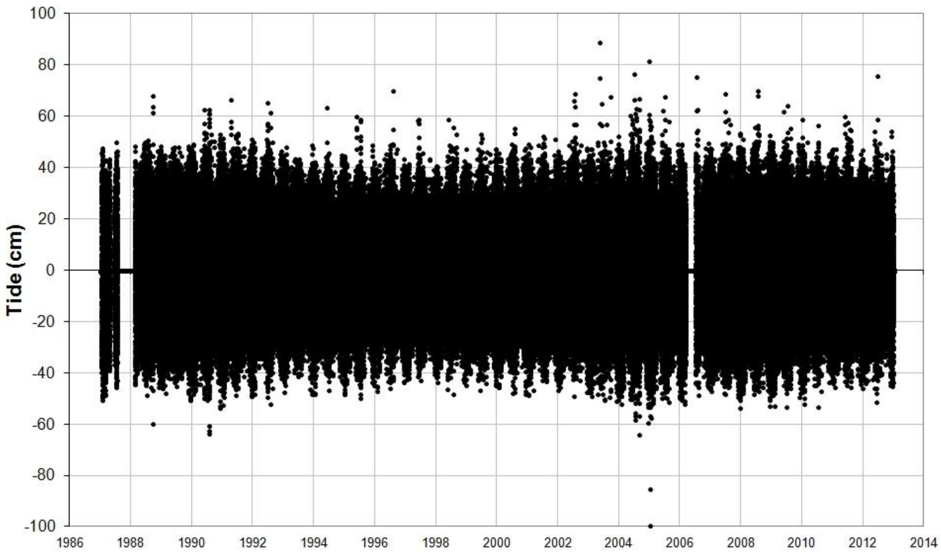

Figure 3-8: Bunbury Tide Component 1987-2012

Tide, surge and mean sea level annual cycles all coincide in the period of May to July, causing a relatively narrow seasonal band in which extreme water level events generally occur (Table 3-6). Although significant storm surge events occur outside this period, their impact is normally reduced, as they are coincident with lower tidal and mean sea level conditions. Over inter-annual timescales, variations in tide (lunar nodical cycle), mean sea level and storminess can cause periods of enhanced and depressed frequency of extreme events.

Table 3-6: Top 20 Water Level Events 1987-2012

Date	Water Level (cm CD)
16/05/2003	209
10/06/2012	198
1/07/2007	183
27/07/1996	174
21/04/1991	172
22/05/2009	172
8/06/1998	171
22/09/1988	168
9/05/2004	168
21/07/2004	167
18/07/2008	167
16/07/1996	165
12/07/1995	164
28/11/2012	164
31/05/1988	160
26/05/1990	160
14/06/2011	160
28/07/2011	159
7/05/2012	159
27/06/1996	156

3.7.3. Waves

Wave conditions are measured by BPA at Beacon 3 and 10 within Koombana Bay (Figure 3-9), and provide real-time data for the Port's Under Keel Clearance system. Beacon 3 replaced a non-directional waverider buoy which was in place from 1996 to 2003, while Beacon 10 was installed in August 2009 (Table 3-7).

Table 3-7: Bunbury Wave Records

Location	Instrument	Data Period	Frequency	Water Depth
Beacon 3	Non-directional waverider buoy	2/09/1996 to 31/12/2003	60 min	12.5m CD
Beacon 3	AWAC	30/04/2004 to 8/03/2013	20 min	12.5m CD
Beacon 10	AWAC	30/08/2009 to 8/03/2013	20 min	5.8m CD

Figure 3-9: Bunbury AWAC Locations

Wave heights recorded at the two locations show the distinctive seasonal wave climate (Figure 3-10) previously reported for the region with energetic conditions typically associated with winter mid-latitude low pressure systems (Reidel & Trajer 1978; Lemm *et al*. 1999; Li *et al*. 2011; Roncevich *et al*. 2011). There is a significant reduction in wave height between Beacon 3 and Beacon 10, with the maximum observed dropping from 3.5m to 1.2m from offshore to inshore. The degree of damping is not apparently constant, with event-by-event wave ratios having significant variation. This implies that sheltering and diffraction play significant roles in inshore wave transformation, along with the commonly applied processes of friction and shoaling. The relative importance of different wave events within Koombana Bay is summarised in Table 3-8.

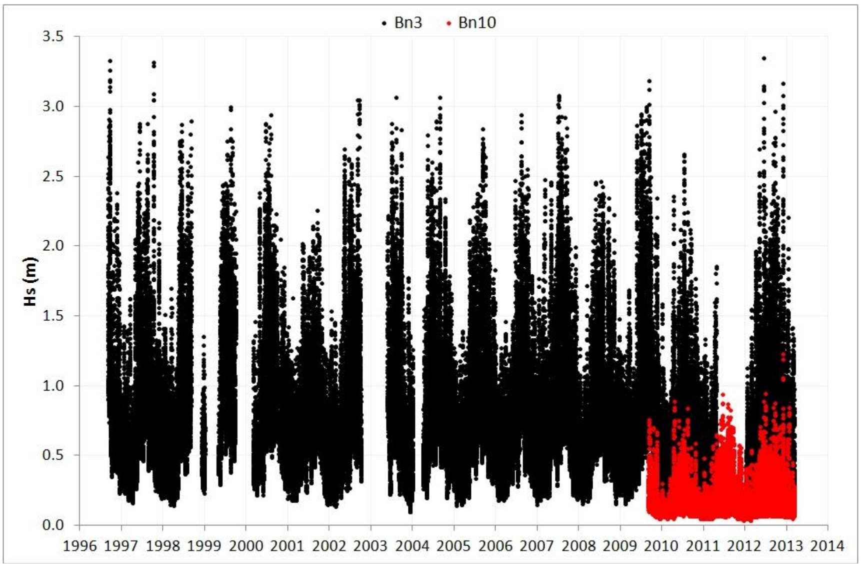

Figure 3-10: Significant Wave Heights Observed at Bunbury AWACs

Table 3-8: Wave Event Types within Koombana Bay

Wave Direction	Event Types	Event Frequency	Comment
Southwest	Prevailing Swell	Common	Significant shelter from the Outer Harbour breakwater.
	Summer seabreeze	Common in summer	
	Southwest Storm	Common	
West	Westerly Storm	Common	Significant shelter from the Outer Harbour breakwater.
Northwest	Northwest Storm/ Tropical Cyclone	Moderate / Very Rare	Minor shelter from the Outer Harbour breakwater.
North	Northerly Storm/ Tropical Cyclone	Rare/ Very Rare	Largely unprotected.
Northeast	High Pressure System	Moderate	Wave climate determined by fetch.

Wave conditions measured at Beacon 10 suggest that significant wave heights above 0.5m are relatively rare within Koombana Bay, although they may exceed 1.0m during northerly storms. This has occurred once when a significant wave height of 1.23m was reached during the late season storm event on the 28th November 2012 which produced strong winds from the north.

The directional range of waves measured at Beacon 10 is significantly wider than the narrower range of swell-dominated waves measured at Beacon 3. This highlights the shelter provided by the breakwater, and the correspondingly greater influence of local wind waves generated across Koombana Bay (Figure 3-11). Despite this restriction, the effect of swell is still evident, with a modal peak of wave conditions approximately 347^{o} at Beacon 10 corresponding to diffracted swell energy around the breakwater.

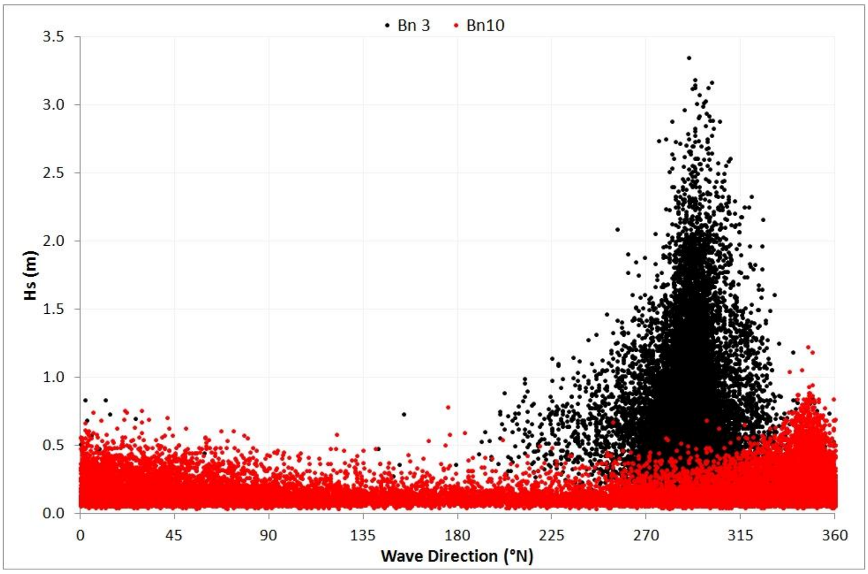

Figure 3-11: Wave Observation Directional Scatterplot (2009-2013)

3.8. TIMELINE SUMMARY

A timeline summary details key modifications made to Koombana Beach since the construction of the Inner Harbour, relevant survey dates, available metocean data and significant events identified from the available metocean record (Figure 3-12).

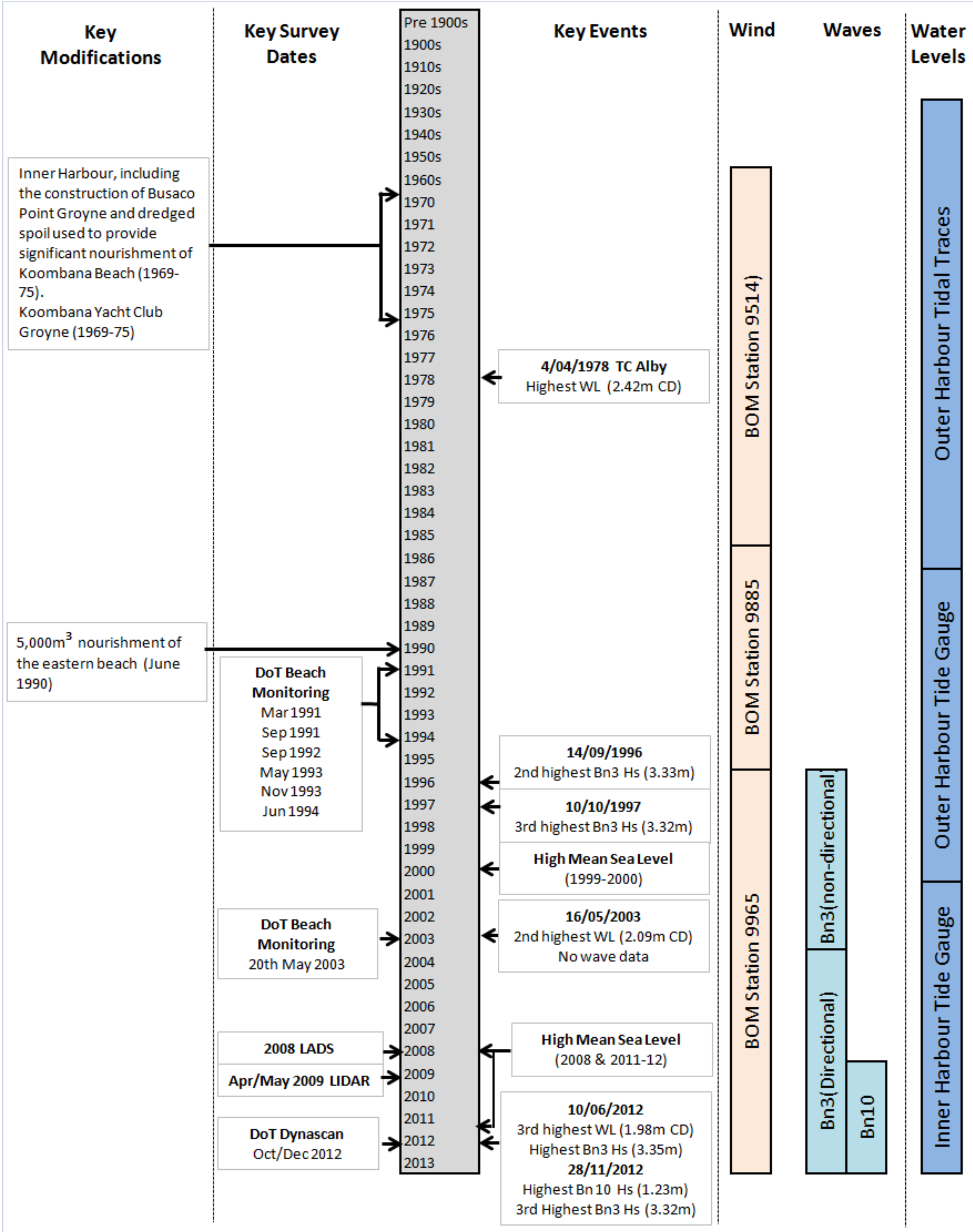

Figure 3-12: Timeline Summary

4. Understanding of Coastal Process

Detailed understanding of coastal processes at Koombana Beach is vital to inform the development of effective coastal management options. In particular, the sediment transport regime determines how a beach will respond to hard structures such as groynes and soft solutions such as renourishment.

Previous reports have investigated coastal processes at Koombana Beach using shoreline analysis from aerial imagery (DMH 1989; Damara WA 2011) which may track water or vegetation lines. Whilst widely applied, these markers do not have sufficient precision to suitably quantify change in the order of 10m. Specifically, tide and seasonal fluctuations cause water line movement of ±15m, whilst the vegetation line on a scarped or fenced beach is likely to give a poor representation of volume change (Camfield & Morang 1996; Boak & Turner 2005). Consequently, this investigation has focused on available survey information as the primary means of detecting change. The increased accuracy and spatial coverage has allowed for refined estimates of volume loss along the eastern foreshore, assessment of accretion on the western beach and identification of offshore changes.

The nature of environmental conditions driving physical change has been explored by evaluating metocean records during periods of heightened observed change between surveys or aerial photography.

4.1. SITE INSPECTION

Koombana Beach was inspected on the 18th February 2013. The inspection included visual observations, site photographs, sediment sampling, condition assessments of the two groynes confining the beach (Koombana Yacht Club and Point Busaco groynes) and informal surveyed beach profiles.

4.1.1. Condition Assessments

Due to their importance in stabilising Koombana Beach, the two groynes which confine Koombana Beach were inspected. The Point Busaco groyne remains in a fair condition and is adequately performing its primary function of training the entrance to the Inner Harbour. The Koombana Yacht Club groyne is in an extremely poor condition, with significant exposure of core material suggesting its susceptibility to damage during storm events[1]. While the groyne has sufficient length to suggest existing capacity to hold additional sand, its capacity would likely be reduced by future damage which would have significant implications for the management of Koombana Beach. It is noted that any future land-based maintenance works is likely to damage a newly constructed path.

[1] Core losses have potentially contributed to the suspension of the seaward section of a newly constructed concrete path on the crest of the groyne

4.1.2. Sediment Size Analysis

Particle size distribution (PSD) of sediment samples taken from the swash zone at the western, centre and eastern sections of the beach show a change in sediment size characteristics along the beach (Figure 4-1). The western beach has the greatest proportion of fine material which can largely be attributed to the westerly transport of the finer fraction of beach sediments, including the originally placed dredge spoil, and the increased shelter provided by the breakwater. Sediments on the eastern beach are bimodal in nature with coarser material largely attributed to the less mobile fraction of dredge spoil and hydraulic fill, while the finer fraction indicates the potential for occasional easterly transport of material.

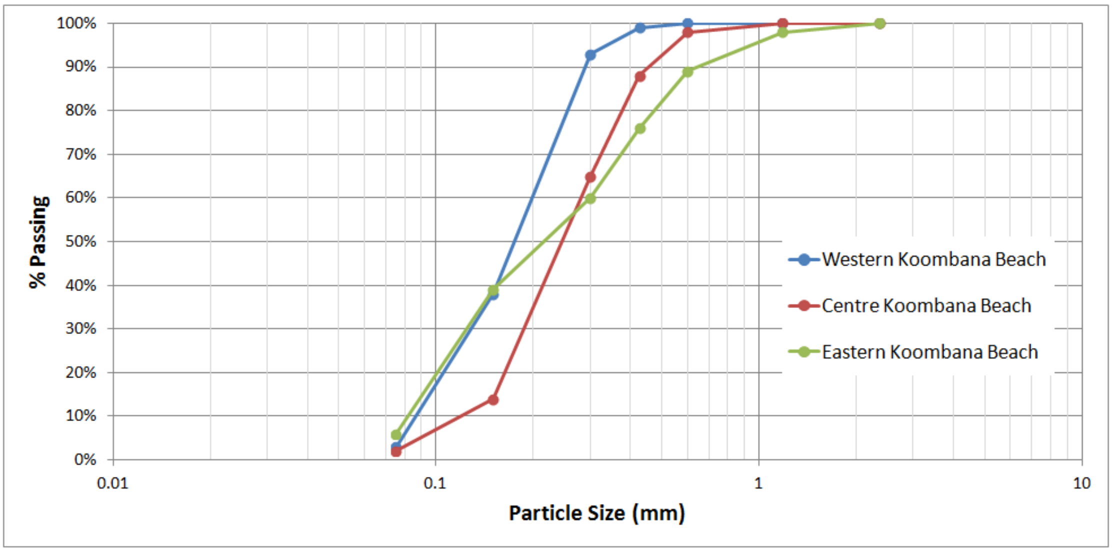

Figure 4-1: Koombana Beach Sediment Sizes

4.2. SURVEY ANALYSIS

Survey analysis has been used as the primary means of describing change at Koombana Beach. It is noted the coverage of each survey is variable, which partly limits the ability to interpret change.

4.2.1. Depth Difference Analysis

A colour coded depth difference plot between the first beach monitoring survey and LADs data shows the net changes at Koombana Beach over the period from March 1991 to April/May 2009 (Figure 4-2, plan SS-24841-1A in Appendix G). It is noted that due to the relatively coarse spatial coverage provided by the 14 beach monitoring survey profiles and the subsequent need for extrapolation, the along-beach dimensions are effectively inferred, giving derived quantities a high level of uncertainty. The difference plot suggests four distinct zones of change within the surveyed region (Table 4-1) and implies the following sediment transport pathways at Koombana Beach:

- Sediment is mobilised from the erosion scarp along eastern beach during elevated wave and water level conditions is subsequently transported to the west contributing to accumulations on the western beach;

- Deepening offshore towards the centre of the beach and subsequent westerly transport of sediments. This is common evolutionary behaviour for a bay, supported by refraction and groyne-deflected currents, until it reaches a deeper, more stable, embayment curvature;
- Accumulation occurring offshore from Point Busaco is considered to be caused by vessel-bank interaction along the navigation channel rather than part of the processes of beach change.

It is noted that, with exception adjacent to the navigation channel, minimal change along the offshore survey limit suggests that cross-shore transport beyond the survey boundary is small. Further, the containing groynes extend well beyond the toe of the beach, indicating capacity to retain additional sediment, which suggests the quantity of material bypassing either groyne is likely to be relatively low. For this reason, Koombana Beach can be considered a largely ‘closed’ system.

Table 4-1: Koombana Beach Volume Changes

Area	Profiles	Est. Volume Changes		Est. Transport Rates	
		1991-2009	2009-2012	1991-2009	2009-2012
Accretion along the western beach	1-7	+30,000m^3	-6,000m^3	+1,650m^3/yr	-1,500m^3/yr
Deepening offshore the centre of the beach	4-9	-16,000m^3	N/A	-900m^3/yr	N/A
Erosion along the eastern foreshore	9-14	-7,500m^3	-4,000m^3	-400m^3/yr	-1,000m^3/yr
Accretion offshore the Point Busaco Groyne	12-14	+5,000m^3	N/A	+300m^3/yr	N/A

Notes: (1) Volume estimates are coarse, based on changes along 14 beach monitoring profiles.
(2) The December 2012 survey only covered beach elevations above approximately 1m CD, so part of the volume change may be caused cross-shore movement from 28/11/2012 storm.

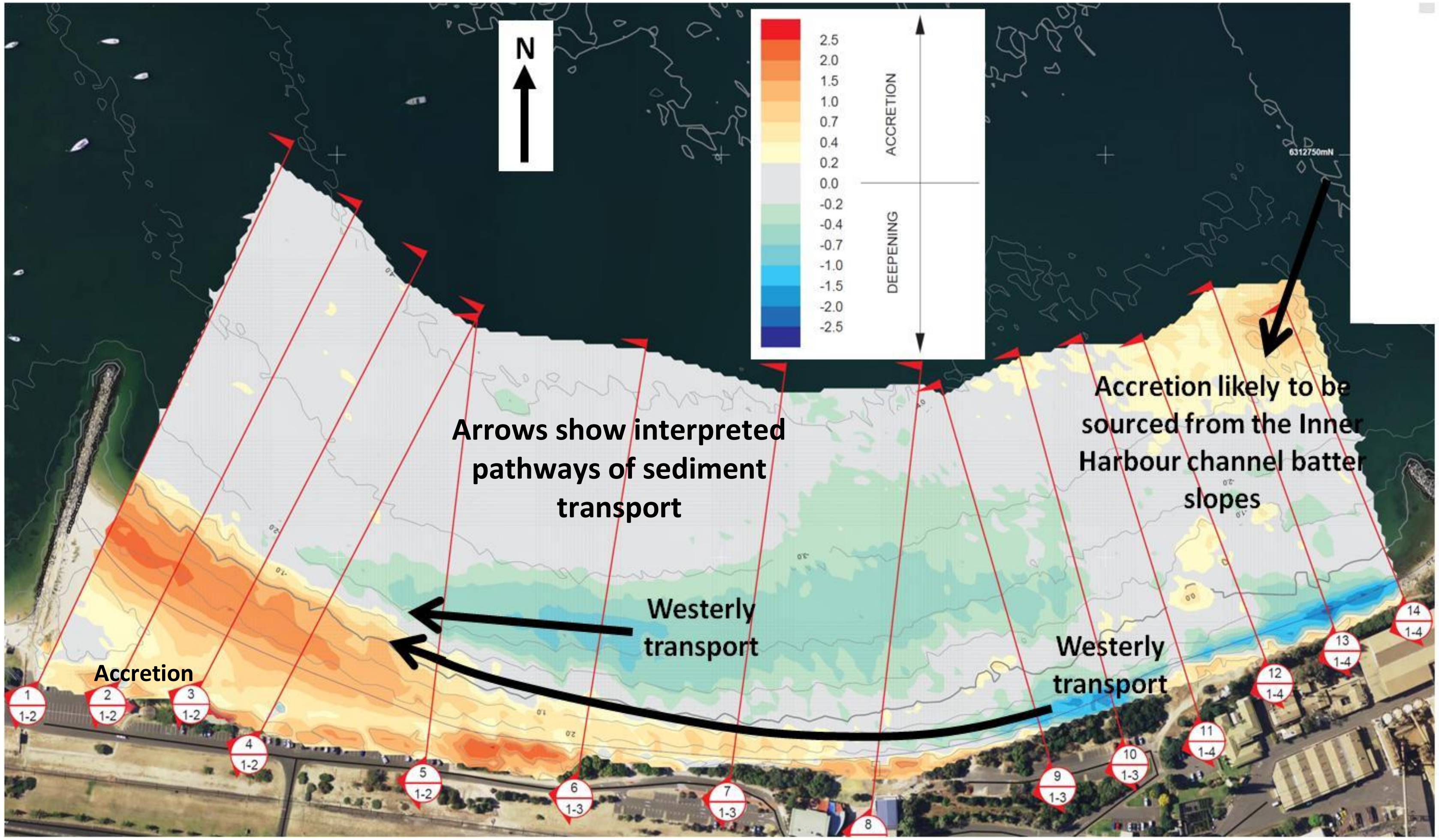

Figure 4-2: Depth Difference Plot and Sediment Transport Pathways (March 1991 to April/May 2009)

4.2.2. Profile Analysis

Fourteen beach survey profiles were established in March 1991 and used for monitoring up between 1991 and 1994. These profiles provide a baseline against which to compare more recent points-based surveys in 2009 and 2012. Differences in behaviour are apparent along the beach. These have been illustrated using selected beach profiles on the western (profile 2), central (profile 7) and eastern (profile 14) parts of the beach (Figure 4-2); along with changes contours approximating the beach or scarp crest (+1m or +2m CD) for all profiles.

<u>Western Beach (Profile 2)</u>: Profile change between two beach monitoring surveys, LADS data and a recent onshore survey (Figure 4-3) show:

- Significant accretion above -2m CD between March 1991 and April/May 2009;
- Minor accretion below -2m CD between March 1991 and June 1994;
- Beach erosion between April/May 2009 and December 2012.

Profile changes over all relevant survey periods for profile 2 are provided in Appendix D.

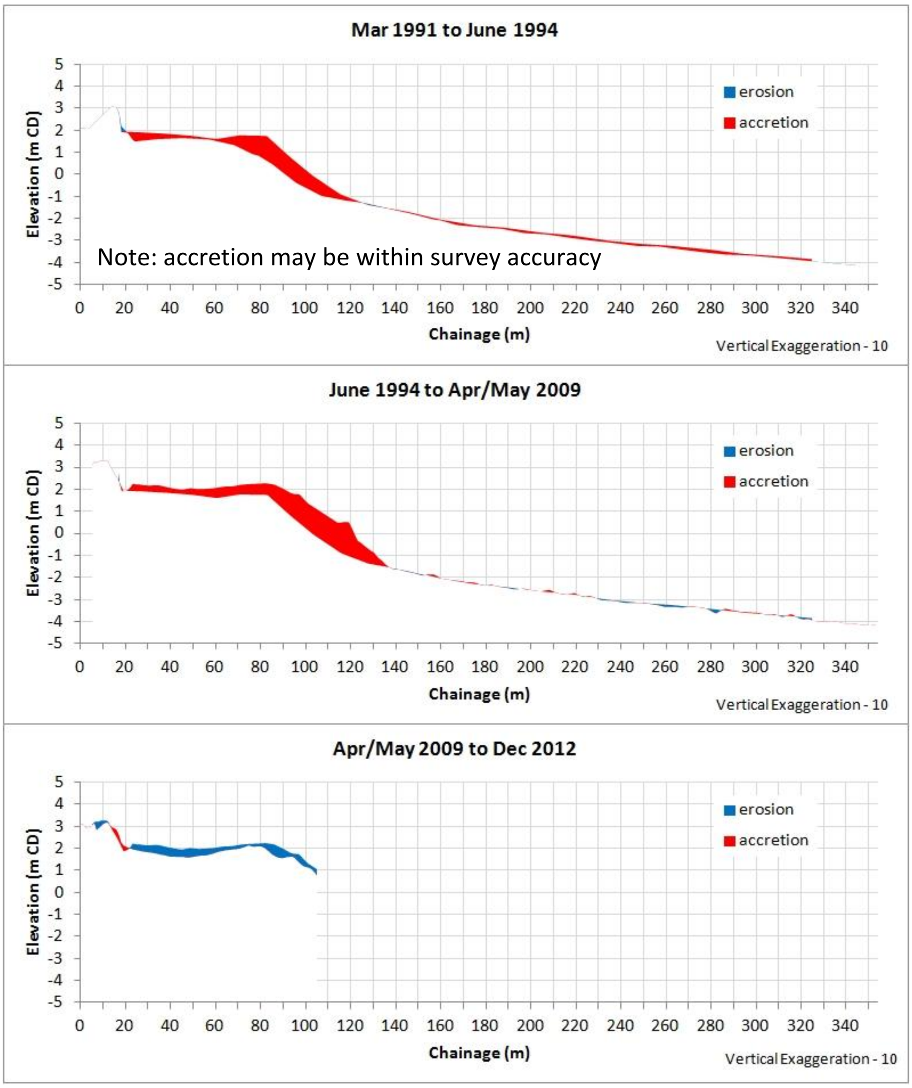

Figure 4-3: Western Beach Change from 1991-2012 (Profile 2)

Accretion at the western Koombana Beach (Profiles 1-5) has been illustrated by the position of the +1m CD contour, located on the beachface, relative to March 1991 (Figure 4-4). Accretion of the western beach is greatest adjacent to the Koombana Yacht Club groyne (profile 1), with an increase in beach width of 28m at profiles 1 and 2 from 1991 to 2012, reducing to 10m at profile 5. Assessments of the rates of change between periods of surveys suggest:

- An initial short term burst of accretion between March 1991 and September 1992. This can largely be attributed to the westerly transport of material used to nourish the eastern beach in June 1990;
- Minor accretion between June 1994 and May 2003;
- Further accretion between May 2003 and April/May 2009;
- Erosion between April/May 2009 and December 2012;
- The shoreline adjacent to Koombana Yacht Club groyne is subject to the greatest variability.

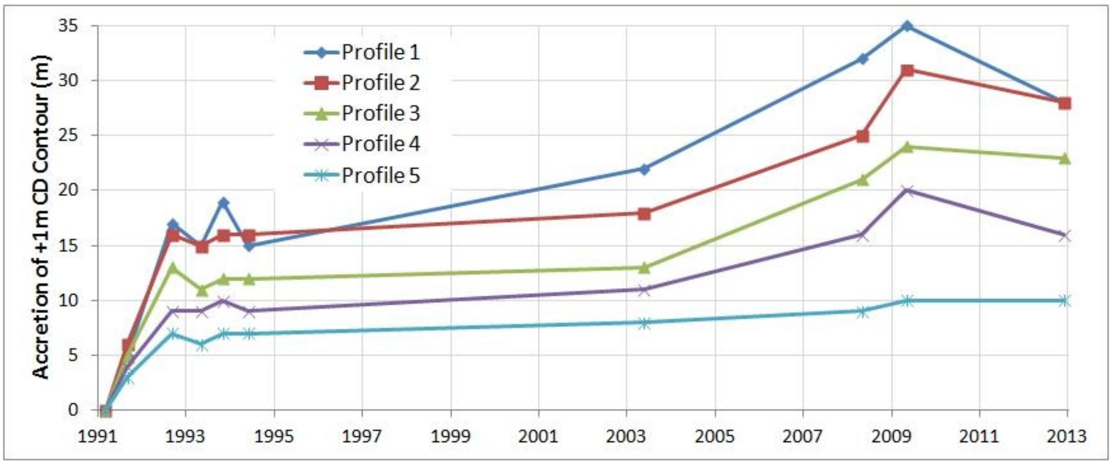

Figure 4-4: Accretion of the Western Beach Relative to March 1991

<u>**Central Koombana Beach (Profile 7)**</u>: Profile changes between two beach monitoring surveys, LADS data and a recent onshore survey (Figure 4-5) show:

- Accretion of the beach above -1m CD between March 1991 and Apr/May 2009;
- Deepening below 0m CD between June 1994 and Apr/May 2009;
- Beach erosion between Apr/May 2009 and October 2012.

Profile changes over all relevant survey periods for profile 7 are provided in Appendix D.

Beach change towards the centre of Koombana Beach (Profiles 6-8) has been represented by the position of the +1m CD contour, located on the beachface (Figure 4-6). Despite deepening offshore, the beach position has remained relatively stable since March 1991, with overall accretion, the majority occurring after nourishment of the eastern beach in June 1990.

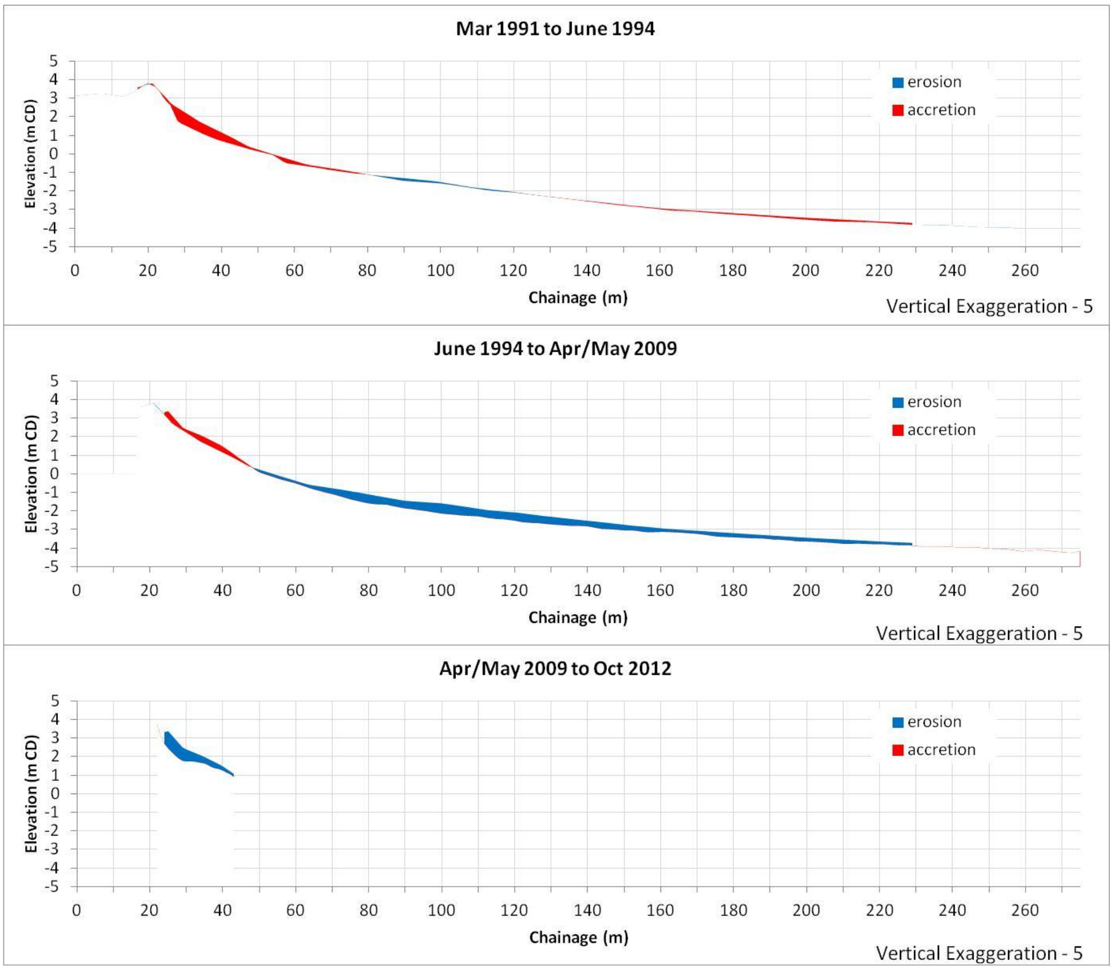

Figure 4-5: Central Beach Change from 1991-2012 (Profile 7)

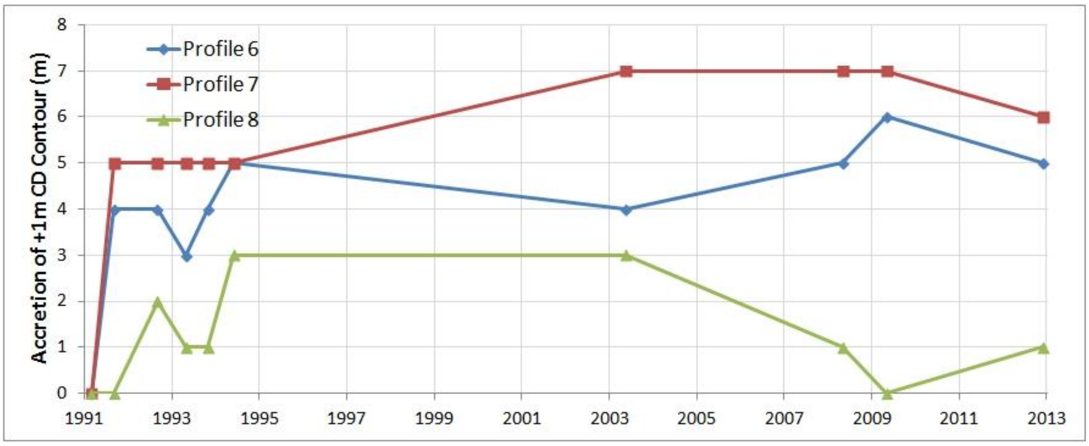

Figure 4-6: Accretion of the Central Beach Relative to March 1991

Eastern Koombana Beach (Profile 14): Profile changes between two beach monitoring surveys, LADS data and a recent onshore survey (Figure 4-7) show:

- Progressive scarp erosion (above 1m CD) since March 1991;
- A zone of accretion below -3m CD between June 1994 and Apr/May 2009;
- Limited change at beach levels around 0m CD, which may be attributed to the presence of rocky material along the beach;

Profile changes over all relevant survey periods for profile 14 are provided in Appendix D.

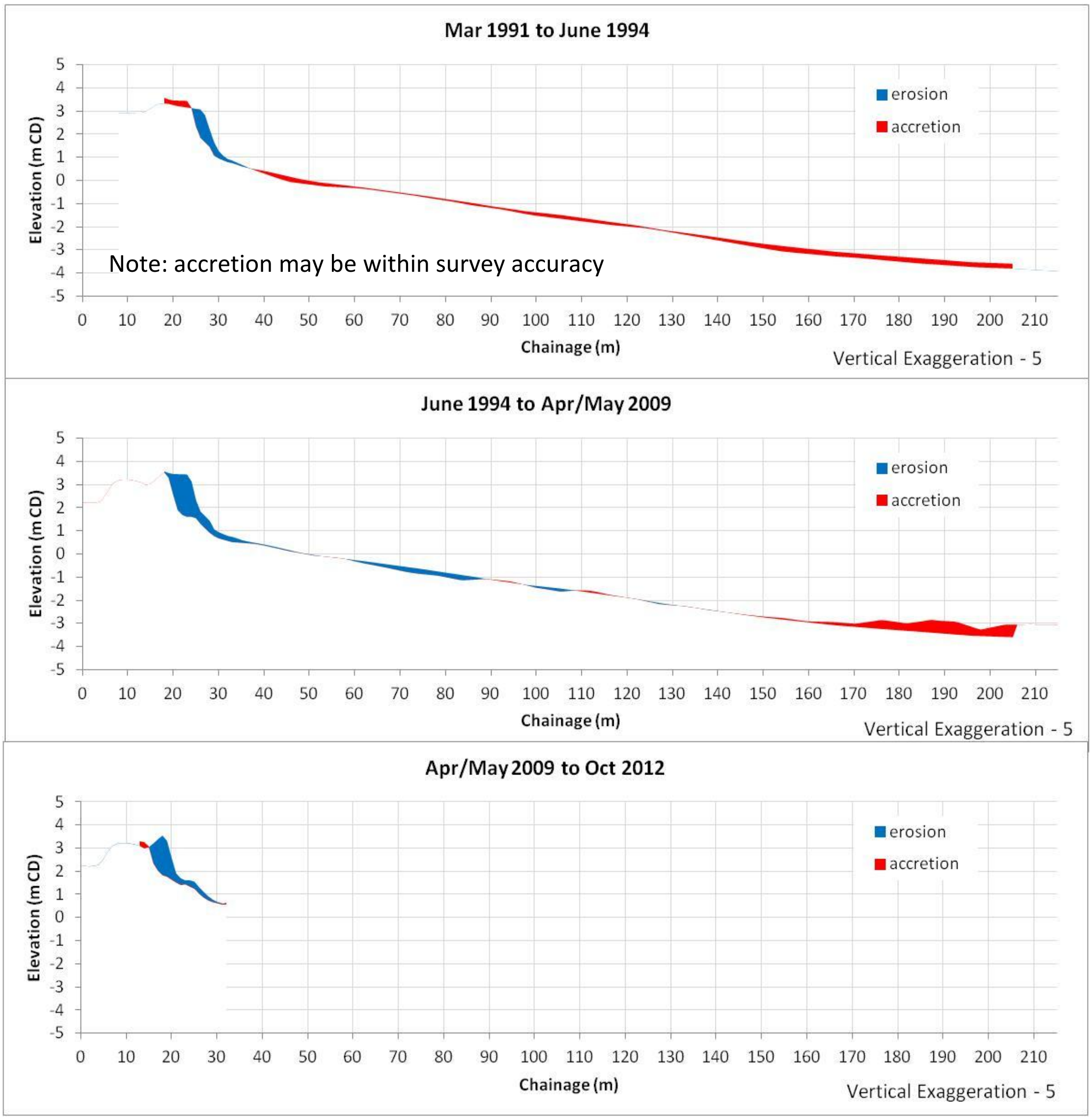

Figure 4-7: Eastern Beach Change from 1991-2012 (Profile 14)

Erosion of the scarp along the eastern extent of Koombana Beach (profiles 9-14) has been represented by the position of the +2m CD contour (Figure 4-8). The overall scarp recession is relatively consistent, with minor variations generally considered to reflect the variable nature of placed fill at the back of the beach (Damara WA 2011). Reduced erosion at profile 11 (6m) is apparently due to the increased presence of rocky material on the fronting beach which provides additional protection and alongshore control.

Rates of scarp recession suggests an average of 0.5m/year over the 22 year period. An initial period of erosion during 1991 to 1994 was largely associated with the westerly transport of nourished material (DMH, 1992), while periods of active erosion occurred between June 1994 to May 2003 and since 2008.

Comparison to rates defined prior to 1991 based on coastline movements (refer to Section 3.5) suggest that rates of recession significantly reduced as the available material from the placement of dredged spoil in 1974 reached a more stable configuration.

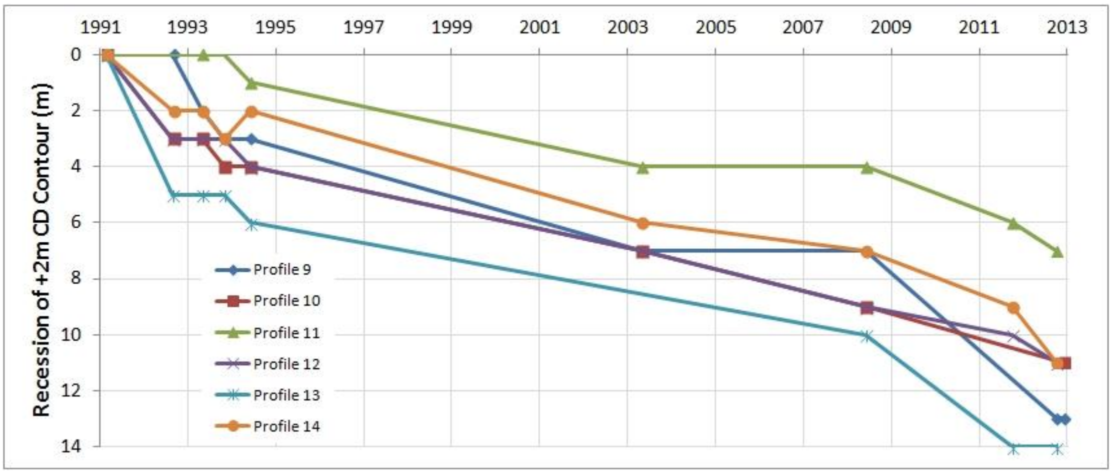

Figure 4-8: Scarp Erosion on the Eastern Beach Relative to March 1991

4.3. COASTAL RESPONSE TO METOCEAN FORCING

The state of Koombana Beach is apparently influenced by the following three dominant modes of metocean forcing (Figure 4-9):

- Prevailing swell and wave energy diffracted/refracted around the Outer Harbour breakwater;
- Locally generated north-easterly waves;
- Occasional northerly storms.

Recommended beach monitoring programs outlined in Section 6.1.3 and Section 6.2.5 combined with analysis of future metocean data is considered sufficient to establish the relative influence of each mode on the observed net westerly transport of sediments experienced at Koombana Beach.

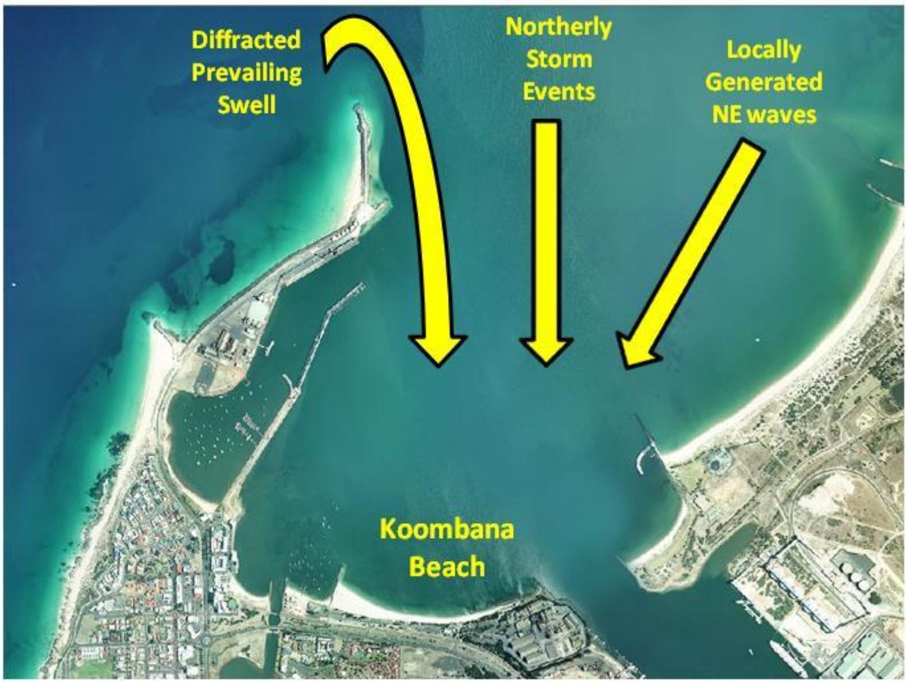

Figure 4-9: Dominant Modes of Metocean Forcing at Koombana Beach

The prevailing condition at the beach is associated with the diffraction/refraction of swell energy around the Outer Harbour breakwater. As the beach is structurally controlled by groynes at either end of the beach, the beach forms a bay shape generally aligned to the prevailing swell direction.

The influence of locally generated north-easterly wave is evident adjacent to Koombana Yacht Club groyne by the change in beach alignment relative to the rest of the beach. This can be attributed to a combination of increased exposure (available fetch) to north-easterly winds and increased shelter from swell energy. Analysis of the Bunbury wind record suggests that north-easterly winds were particularly prevalent during 2007 and 2008 which may have contributed to accumulation adjacent to Koombana Yacht Club groyne between the May 2003 and April/May 2009 surveys.

The most significant forcing within Koombana Bay is experienced during the combination of elevated water levels and wave conditions within Koombana Bay, predominantly during northerly storms. Resulting occasional bursts of alongshore and cross-shore sediment transport from waves impact on the upper profile, cause disturbances to the beach configuration. These are particularly evident adjacent to Koombana Yacht Club groyne (profile 1). Shoreline accretion on the western beach was greatest between the May 2003 and April/May 2009 surveys, during which there was a relative absence of significant northerly events.

Storm induced change is particular evident by an erosion scarp along the eastern section of the beach. Storms deemed most likely to have contributed to the observed erosion of the scarp have been extracted from the Bunbury metocean record (Table 4-2). In particular, a storm event on the 16th May 2003 produced the highest water level on record excluding tropical cyclone Alby (April 1978); with a recent set of events during a period of sustained period of high mean sea level from 2011-2012 are likely to have contributed significantly to recession.

Table 4-2: Significant Northerly Events

Period	Scarp Recession	Storm[1]	Water Level	Bn 10 Hs	Northerly Wind Speed
Mar 1991-Sep 1992	1-5m[2]	21/04/1991	1.72m CD	-	55km/hr
Sep 1992-June 1994	0-1m	-			
Jun 1994-May 2003	2-4m	16/07/1996	1.65m CD	-	55km/hr
		7/06/1998	1.71m CD	-	46km/hr
		16/05/2003	2.09m CD	-	42km/hr
May 2003-2008	0-2m	21/07/2004	1.67m CD	-	46km/hr
2008-Oct-2012	3-6m	22/05/2009	1.72m CD	-	39km/hr
		14/06/2011	1.60m CD	0.95m	30km/hr
		28/07/2011	1.59m CD	0.94m	42km/hr
		10/06/2012	1.98m CD	0.72m	33km/hr
		28/11/2012	1.64m CD	1.23m	48km/hr

[1]*Storm events recorded elevated water levels (>1.50m CD) combined with either sustained strong westerly winds (1991-2012) or elevated wave conditions at Beacon 10 (2009-2012).*
[2]*Likely to reflect initial redistribution of the sand renourishment placed in June 1990*

4.4. IMPLICATIONS OF CLIMATE CHANGE

The timeframe of projected climate induced sea level rise is defined by a recent Department of Transport (2010) discussion paper (Figure 4-10) which is based on the upper limit of Intergovernmental Panel on Climate Change (IPCC) predictions (IPCC 2007).

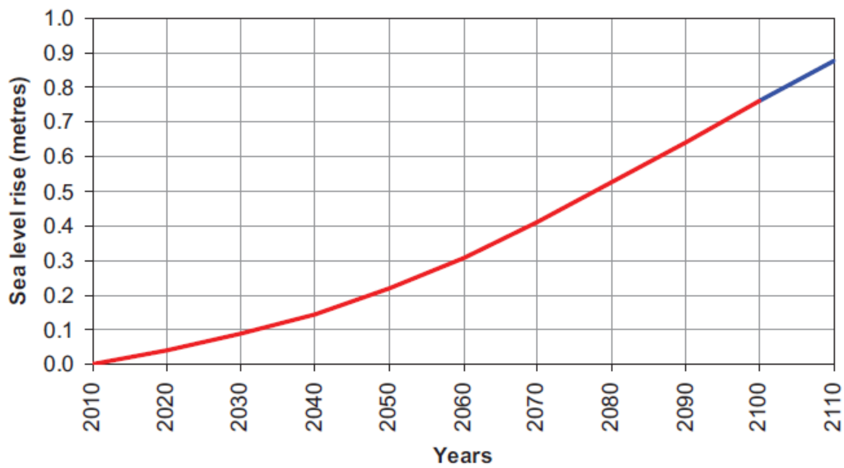

Figure 4-10: Sea Level Rise Allowance Time Series
Source: DoT (2010)

Sea level rise is anticipated to result in adjustment of the beach profile, with a tendency for transfer of sand from the beach to offshore. The response to sea level rise cannot directly be estimated through observations, as full-profile response occurs over decades. However, the rapid mean sea level rise from 1994 to 2012 caused by the ENSO cycle gives an indication of coastal sensitivity at Koombana Beach. Between the 1994 and 2012 surveys, approximately 8,000m^3 of material was lost from the eastern scarp, coincident with .2-0.3m mean sea level rise. This gives a coarse estimate of 2,500-4,000m^3/per 0.1m of sea level rise.

4.5. KNOWLEDGE GAPS

Existing knowledge gaps that limit the ability to understand coastal processes at Koombana Beach have been identified and discussed in this section. Where appropriate, future data collection or monitoring to reduce uncertainties have been noted.

4.5.1. Metocean Data

Inshore wave data is the most limited metocean dataset at Bunbury, with wave conditions within Koombana Bay only measured since August 2009. As the number of extreme events observed is strongly related to the length of the data set, the 3.5 years of data represents a short observation period, and introduces considerable uncertainty to the estimated recurrence intervals of extreme wave heights at Beacon 10 (Table 4-3).

When reviewing a proposed jetty design for Koombana Bay Sailing Club on behalf of the Department of Transport, Damara WA previously used combined a derived relationship between Beacon 10 and Beacon 3 measurements with analysis of historic storm directions to translate the longer term history of measurement at Beacon 3 into an extreme distribution for the inner (Beacon 10) location (Table 4-3). This analysis suggested that the effects of sheltering, friction, refraction and diffraction reduced the equivalent wave height from Beacon 3 to Beacon 10 by 45%.

Table 4-3: Derived ARI Wave Heights for the Bunbury AWACs

	1yr	**2yr**	**5yr**	**10yr**	**20yr**	**50yr**	**100yr**
Beacon 3 (1996-2009)[1]	2.72m	3.03m	3.14m	3.20m	3.26m	*3.33m*	*3.37m*
Beacon 10 inferred from Beacon 3[1]	1.22m	1.36m	1.41m	1.44m	1.47m	*1.50m*	*1.52m*
Beacon 10 (log-linear)[2]	0.89m	1.05m	1.19m	1.28m	1.37m	*1.50m*	*1.59m*

[1] *Wave heights extrapolated beyond 30 years average recurrence interval (ARI) should be considered approximate, given limitations provided by a 14 year wave data set.*

[2] *Wave heights extrapolated beyond 10 years average recurrence interval (ARI) should be considered approximate, given limitations provided by a 3.5 year wave data set.*

4.5.2. Survey Information

The spatial and temporal coverage of available survey information is generally limited in nature which restricts the ability to confidently determine:

- Accurate volume changes using volumetric analysis from surveyed depth differences. Surveyed profiles should generally be conducted at approximately 25m intervals and include the 14 existing beach monitoring profile lines if accurate volume changes between survey periods is required.
- Conditions contributing to the observed net westerly transport of sediments at the beach, the extent and periods of reversals, and periods of change offshore. This can be determined using recommended beach monitoring programs outlined in Section 6.1.3 and Section 6.2.5 combined with analysis of future metocean data.

4.5.3. Sediments

Grain size information from the in situ beach material can indicate active coastal processes, particularly the direction of net alongshore transport (Gao & Collins 1992; USACE 2006). Sediment size information at Koombana Beach is limited to basic particle size distribution (PSD) from samples collected from the swash zone on western, central and eastern beaches. It is noted that further assessment of sediments along Koombana Beach is likely to be deemed of low value, with greater value being obtained from understanding of potential sites of source material, particularly the Outer Harbour sand traps.

4.5.4. Photo-monitoring

Site photos identified of Koombana Beach identified in the desktop review are limited to recent inspections conducted by Seashore Engineering staff or the City of Bunbury, with few containing similar fields of view. As photo-monitoring is a simple and cost-effective tool for identifying beach change and potential management issues, 8 photo-monitoring sites along Koombana Beach have been established according to the recommended approach by DoT (2012) to provide a consistent visual comparison (Appendix E).

An alternative to photo-monitoring are fixed beach cameras (i.e. 'go pro' cameras) which can provide a consistent snapshot of conditions. These cameras may potentially be vulnerable to vandalism or theft.

4.5.5. Previous Renourishment Exercises

Details of the dredged spoil placement which initially formed Koombana Beach around 1974 are limited. In particular, the volume and relative composition of the dredged material have only been inferred. A volume has been coarsely estimated from the area of deposition shown in the 1974 aerial imagery, with the remnant material apparently displaying that there was a mixture of sand, silt and rock fragments.

It is noted that additional renourishment exercises may have occurred with records not held by either the Department of Transport or the City of Bunbury.

5. Coastal Management Options for Koombana Beach

Coastal management options have been developed to mitigate the potential coastal erosion issues at Koombana Beach (Table 5-1). To facilitate selection of two preferred options for a more comprehensive evaluation, infromation regarding each option has been developed for discussion and review. This information incorporates a concept design sketch, a list of key pros and cons, potential ongoing requirements and order of magnitude cost estimate. Further consideration has been given to potential environmental, social, economic, aesthetics and engineering impacts; constructability and adaptive capacity (Appendix F).

Assessment of the existing infrastructure towards the centre of Koombana Beach suggests that 10m of managed retreat may be practical through only minor coastal adaptations, which is therefore only a short-term response. Any further retreat requires substantial and expensive adaptation, suggesting that other forms of erosion management are likely to be cost-effective in the long-term.

Due to the largely enclosed nature of the beach and close proximity to suitable sediment sources, there is good opportunity for erosion hazard management through renourishment. This gives limited disturbance of the existing beach amenity and allows the beach to experience natural cycles of storm erosion and recovery. However, there is potential for ongoing redistribution of placed material, away from the areas experiencing erosive stress. A range of engineered structures have been considered that provide increased sand retention in existing problem areas and therefore reduced ongoing costs. An option to provide complete shoreline retention by constructing a revetment was also identified, although this was not considered in detail as it would cause loss of the beach in front.

Influence of Point Busaco Revetment

Due to the ongoing erosion, narrow buffers and the high value of the infrastructure at risk along the eastern section of the Beach, seven of the options consider the construction of the Point Busaco revetment. Option 8 considers an alternative that involves more extensive renourishment to provide a buffer that gives equivalent erosion protection for the access track from a severe storm.

Installation of the revetment will transfer at least a portion of existing erosive pressure towards the west, increasing the threat City of Bunbury infrastructure, which includes the Dolphin Discovery Centre, footpaths, roads, and car parks. Renourishment quantities have been estimated assuming that all erosion from the eastern part of the beach is transferred to the central part, with an overall potential rate of loss in the order of 550 m^3/year estimated from survey analysis between 1991 and 2012.

Local erosion is also likely to occur adjacent to the Busaco Point revetment due to the difference in alongshore transport rates between the revetment and beach, termed flanking erosion (Sumer & Fredsoe 2002). It is recommended that this is limited through provision of a ‘feeder’ beach, which has the additional benefit of mitigating scour.

Table 5-1: Coastal Management Options

No.	Option	Coastal Structures	Preliminary Renourishment Volumes	Capital Cost (Order of Magnitude)	Assumed Ongoing Requirements
1	Managed Retreat	- Point Busaco revetment	-	\$400,000	- Maintenance of the revetment at a cost in the order \$4,000- \$8,000 p.a. - Relocation of instructure is antipicated to be a realtively costly execise.Where possible relocation should target the end of working life or when major maintenance is required.
2	Renourishment using Outer Harbour Sand Traps	- Point Busaco revetment	12,000m^3	\$580,000	- Beach monitoring. - Future renourishment exercises estimated to be required every 3- 5 years, with volumes of in the order of 5,000m^3 at a cost of \$90,000. - Maintenance of the revetment at a cost in the order \$4,000- \$8,000 p.a.
3	Renourishment using Western Koombana Beach	- Point Busaco revetment	12,000m^3	\$530,000	- Beach monitoring. - Annual renourishment exercises, with volumes and costs in the order of 5,000m^3 and \$70,000 respectively. - Maintenance of the revetment at a cost in the order of \$4,000- \$8,000 p.a.
4	Groynes and Renourishment	- Point Busaco revetment - Two groynes	12,000m^3	\$1,000,000	- Monitoring of groynes performance. - Maintenance of the groynes and revetment at a cost in the order of \$8,000- \$16,000 p.a. - Future renourishment exercises are likely to be relatively small and infrequent exercises.
5	Headland and Renourishment	- Point Busaco revetment - Headland	12,000m^3	\$950,000	- Monitoring of groynes performance. - Maintenance of the headland at a cost in the order of \$8,000- \$16,000 p.a. Maintenance will typically be more expensive that option 4 as you need to build access to repair. - Future renourishment exercises are likely to be relatively small and infrequent exercises, albeit greater than option 4.
6	Detached Headland and Renourishment	- Point Busaco revetment - Headland	12,000m^3	\$1,300,000	- Monitoring of headland performance - Maintenance is very hard and expensive, need to design and construct accordingly. - Future renourishment exercises are likely to be relatively small and infrequent exercises, albeit greater than option 4 and 5.
7	Rock Revetment	- Point Busaco revetment	12,000m^3	\$1,200,000	- Beach monitoring - Maintenance of the groynes at a cost in the order of \$5,000- \$10,000 p.a construction;
8	Groynes, Renourishment and Dune Stabilisation	- Two groynes	65,000m^3	\$1,600,000	- Beach monitoring - Maintenance of the groynes at a cost in the order of \$12,000- \$24,000 p.a - Future renourishment exercises are likely to be relatively small and infrequent exercises. Potential for cross- shore losses suggest exercises will be greater than option 4.

Notes

1. *Maintenance costs of rock armoured structures depend on the design and construction. For the purpose of predicting costs, ongoing maintenance requirements are based on typical maintenance costs of rock armoured structures in the south-west of Western Australia (1-2% p.a. of capital costs)*
2. *Where applicable, costs include the construction of the Point Busaco revetment which has been inferred from cost estimates detailed in Damara WA (2011).*

5.1. OPTION 1: MANAGED RETREAT

This option assumes Koombana Beach west of the Point Busaco revetment is allowed to recede and infrastructure is removed or relocation landward is feasible. Considering a loss rate of approximately 500-600m^3/yr based on observed loss rates over the unprotected 460m of beach, it is estimated a setback greater than approximately 50m from the existing dune line would be required to accommodate continued erosion over a 100 year planning timeframe, with an additional setbacks likely to be required to meet the State Coastal Planning Policy SPP 2.6 (WAPC 2003). Infrastructure that may need to be relocated along the three distinct beach sections for this option is outlined in Table 5-2 and Figure 5-1.

Table 5-2: Koombana Beach – Coastal Infrastructure

Location	Infrastructure within 10m setback from vegetation line	Additional Infrastructure within 50m setback from vegetation line	Notes
Western Section	Surfclub & kiosk building Paths, public recreation areas, car parks.	Public car parks, services and access roads.	- Highly valued public infrastructure.
Central Section	Carparks, Dolphin Discovery Lease Area, viewing platform and stairs.	Dolphin Discovery buildings, car parks, services & access roads.	- Highly valued regional tourism infrastructure.
Eastern Section	BPA Industrial Lease Area and Buildings (Cable Sands), Major Telecommunications Tower, car parks.	Major industrial complex (Cable Sands), access roads and services.	- High value industrial & commercial infrastructure - Point Busaco revetment to provide protection.

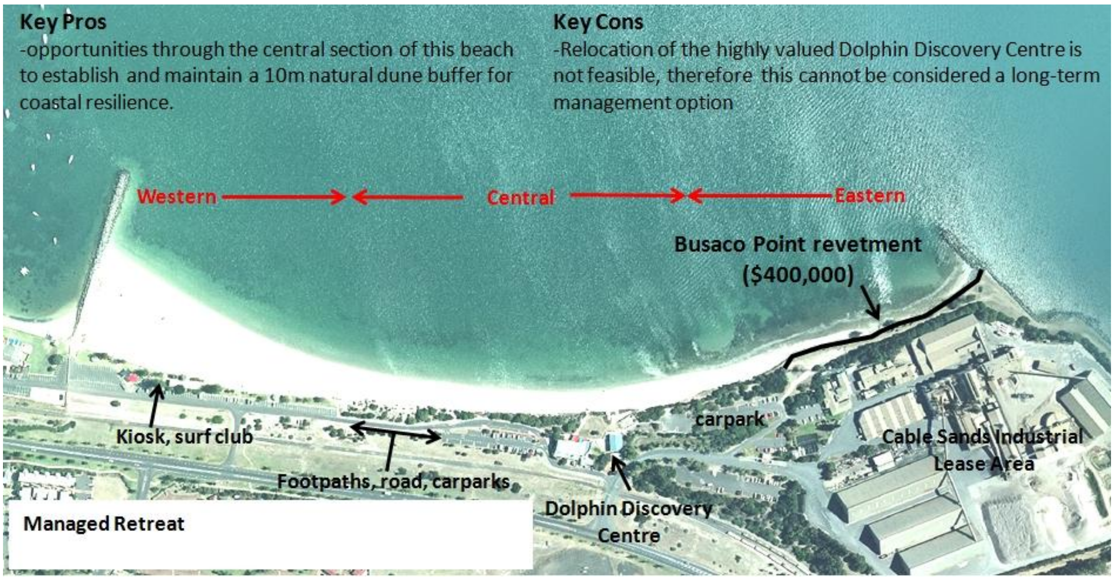

Figure 5-1: Managed Retreat Sketch

Western Section

This is an area of mainly public infrastructure (Table 5-2, Figure 5-2). Structures including a toilet block, kiosk, surf club, paths, barbecues and car parks are generally located immediately behind a small revetment at the back of the beach, typical of public beaches in Western Australia. Relocation of these assets is potentially feasible, due to the presence of undeveloped unallocated Crown land behind the beach; however this would be a major foreshore redevelopment project, with cost-benefit issues beyond the scope of this study. The width of the beach at this location presently provides reasonable protection to existing assets.

Figure 5-2: Western Section – Coastal Infrastructure

Central Section

This is an area of significant regional tourism infrastructure (Table 5-2; Figure 5-3). The Dolphin Discovery Centre is a not-for-profit organisation that undertakes Research, Education and Conservation Programs. These programs are funded through tourism experiences associated with interaction with wild dolphins in Koombana Bay. Infrastructure includes a discovery pool, aquariums, 3D 360 degree digital dolphinarium, 3D & 2D movies, cafe, souvenir shop, lawn area, beach access & playground.

Concept plans have been developed and previously presented to the City of Bunbury for upgrade of the Dolphin Discovery Centre, with estimated costs in the order $10,000,000 excluding coastal mitigation works. The presentation to the City estimated the Centre has a contribution of $7,200,000 million to the local economy.

The Dolphin Discovery Centre requires a beachfront location and relocation of assets to the long term target of 50m is not practical. Major infrastructure is set back more than 20m from the existing vegetation line, with smaller infrastructure presently exposed. However, there are opportunities through this central section of this beach to establish and maintain a 10m natural dune buffer to provide greater coastal resilience. In particular, this could involve removing some bays or redesigning the car park immediately east of the Centre, and ensuring future infrastructure within the Centre is appropriately set back from the coast. Beach access would still be required through the dunes.

Figure 5-3: Central Section – Coastal Infrastructure

Eastern Section

This is an area of industrial infrastructure (Table 5-2; Figure 5-4). The Cable Sands industrial lease area is a major industrial site located less that 10m from the vegetation line at the eastern end of the beach and immediately adjacent to the Bunbury Inner Harbour. Additionally, there is a major telecommunications tower within 20m of the vegetation line along the eroding western section of the beach.

Relocation of these assets is unlikely to be either practical or cost effective. Due to ongoing erosion, narrow buffers and the high value of the infrastructure at risk, the BPA are planning construction of a revetment along this section of the beach.

Figure 5-4: Eastern Section – Coastal Infrastructure

5.2. OPTION 2 & 3: RENOURISHMENT

This option considers ongoing renourishment of Koombana Beach with beach quality sand to increase the capacity to 'resist' erosion. This is a 'soft' engineering option that would have minimal impact on beach amenity.

It is anticipated that a relatively large initial renourishment exercise should be considered, with estimated losses along the eastern foreshore of 12,000m^3, matching those experienced since 1991, likely to provide a suitable volume. Ongoing renourishment exercises are likely to vary with the relative stability of placed sand and variability in future coastal processes. Future renourishment should be subject to ongoing adaptation, with monitoring of the beach required (surveyed beach levels, photo-monitoring, and beach widths measurements) to determine suitable timing, volumes and placement of future exercises. Two suitable sediment sources have been identified, distinguished as Options 2 and 3. Dredged material from the adjacent Bunbury Harbour entrance channel is likely to be unsuitable due to a high proportion of silt and organic material.

<u>Option 2: Source from the Outer Harbour western sand traps</u>

Sand traps on the western side of the Outer Harbour breakwater provide a nearby source of high quality clean beach sand, which may be trucked to Koombana Beach (Figure 5-5). Preliminary costs in the order of $180,000 are based on a volume of 12,000m^3 with a trucking rate of $15/m^3. The trapped material is coarse, with previously analyses giving median diameters of 0.55mm (Taylor *et al*. 2001) or 0.85mm (PWD 1978). The size relative to existing sediments at Koombana Beach will give a higher threshold for sediment transport and hence be more stable. Combining historic loss rates along the eastern foreshore and offshore towards the centre of the beach, future exercises associated with the redistribution of material in the active transport zone are estimated to be in the order of 5,000m^3, every 3 to 5 years at a cost in the order of $90,000.

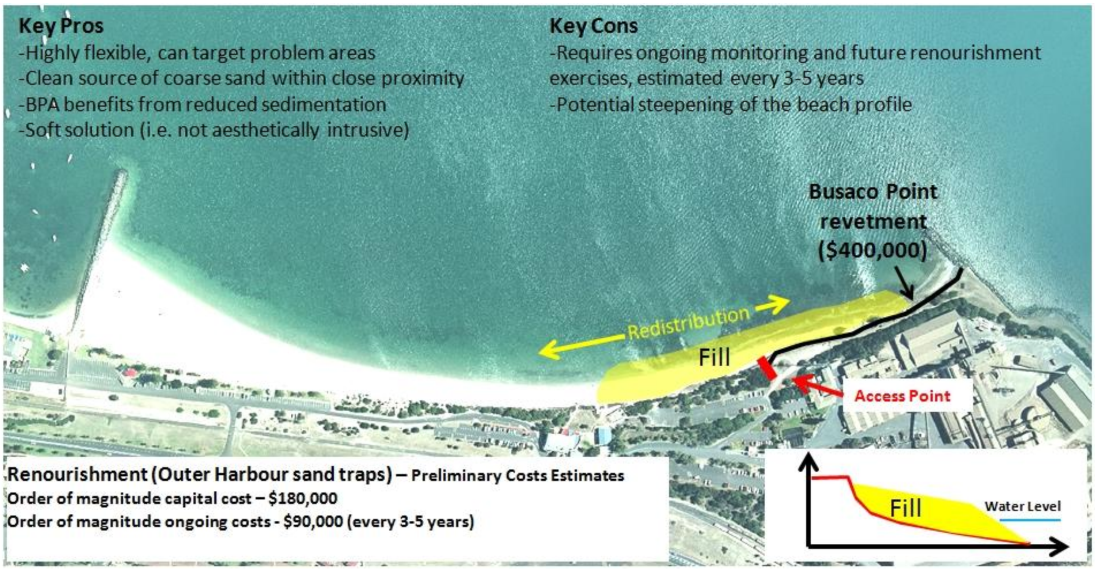

Figure 5-5: Ongoing Renourishment Sourced from the Outer Harbour Sand Traps Sketch

Option 3: Source from Western Koombana Beach

The approach of mechanically reversing the direction of sediment transport within Koombana Beach (backpassing) gives a means of providing renourishment without significant addition to the beach volume. Material would be excavated from western Koombana Beach and transported to the central and eastern part of the beach using trucks (Figure 5-6). Preliminary costs are lower than importing sand due to the shorter distance, in the order of $130,000 based on a volume of 12,000m^3 and a transport rate of $11/m^3.

The approach of backpassing is normally reserved for situations where there are limited suitable sources of fill, and existing shore protection works are close to their capacity for retention, such that any additional material will be lost to the system.

It is recognised that the removal of a significant volume of material adjacent to the Koombana Beach Yacht Club groyne will substantially reduce beach widths at the highly popular western beach. This will create a significant sink for material as the beach adjusts to back to a more stable configuration and together with the relatively fine nature of sediments adjacent to Koombana Yacht Club groyne is predicted to result in high westerly transport rates of nourished material. Consequently, annual renourishment been assumed, preferably conducted prior to the onset of winter storms, with volumes in the order of 5,000m^3 at a cost of $70,000.

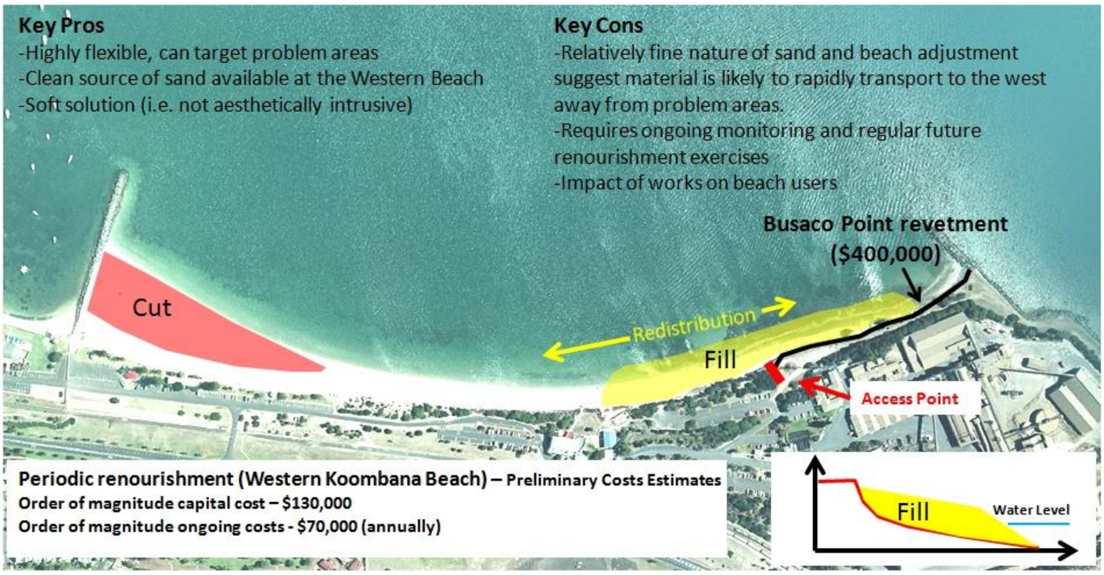

Figure 5-6: Sketch of Ongoing Renourishment Sourced from Western Koombana Beach

5.3. OPTION 4: GROYNES WITH RENOURISHMENT

This option considers a combination of renourishment with two groynes to stabilise the beach to the west of the proposed Point Busaco revetment (Figure 5-7). The groynes target the area of renourishment to threatened infrastructure and restrict the westward transport of material, resulting in accumulation updrift (eastern side) of the groynes. A consequence of installing the groynes is enhanced shoreline variability on their downdrift (western) sides, as post-storm recovery is preferentially trapped on their eastern side.

The eastern groyne is located to the west of the highly valued Dolphin Discovery Centre increasing the beach's capacity to accommodate erosion to the east. A second groyne to the west will stabilise the beach to the west where downdrift erosion (reduced sediment supply) is likely to threaten existing infrastructure (footpath, road, carpark) located on narrow buffers[2]. The groyne has been placed such that potential downdrift impact from the groyne has limited effect on infrastructure. The short distance to Koombana Yacht Club groyne and limited capacity for bypassing is anticipated to restrict downdrift erosion impacts.

If one groyne is preferred, it would either require a longer groyne at the western site to provide sufficient buffer for the Dolphin Discovery Centre, or located at the eastern site with a revetment to defend the infrastructure further west from downdrift erosion. Structural requirements may be reduced by relocating infrastructure, but as discussed in Section 5.1, the design life is limited without major relocation of footpaths, roads and car parks.

This option is anticipated to have a relatively high capital costs with preliminary estimates in the order of $600,000, with relatively low ongoing costs mainly related to maintenance of the groynes.

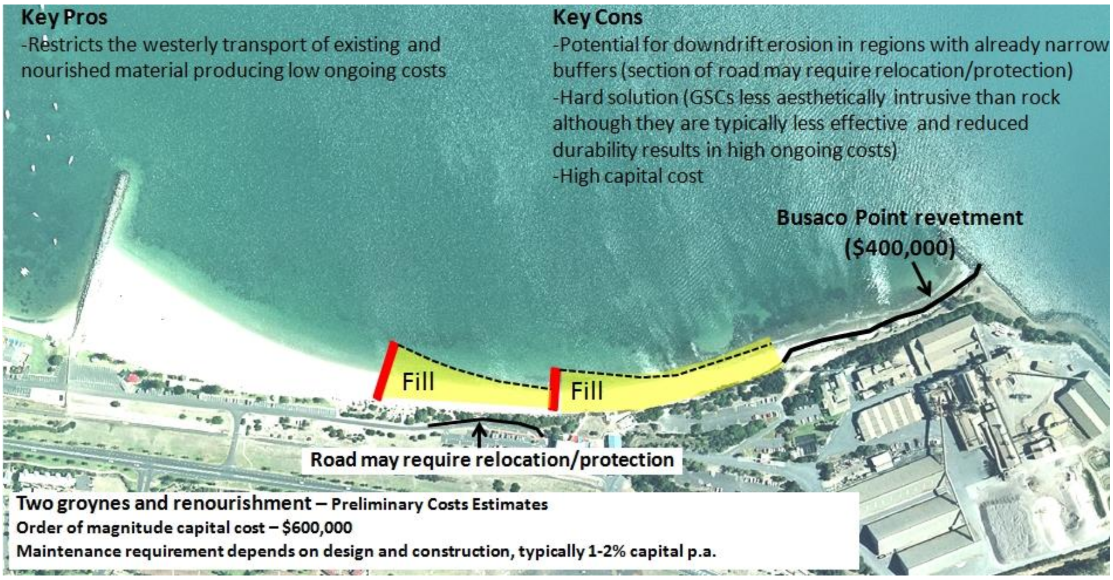

Figure 5-7: Groynes and Renourishment Sketch

[2] If a downdrift threat is identified additional renourishment, relocation of infrastructure or construction of a revetment are potential mitigation options.

5.4. OPTION 5: HEADLAND WITH RENOURISHMENT

This option considers the combination of renourishment with a headland constructed parallel to the shoreline to stabilise the beach to the west of the proposed Point Busaco revetment (Figure 5-8). The headland will result in a zone of deposition in its lee by altering wave heights and direction. Under the majority of conditions the shoreline is expected to join to the structure forming a tombolo which effectively acts as a barrier to the alongshore sediment transport; however during elevated wave and water levels the tombolo is likely to become inundated and erode, allowing sediments to bypass. For this reason ongoing renourishment costs are likely to be greater than required for the groyne option (option 4).

This option has a preliminary capital cost estimated to be in the order of $550,000, with potentially low ongoing costs mainly due to maintenance of the headland, with future renourishment exercises potentially required to offset any bypassing of the headland.

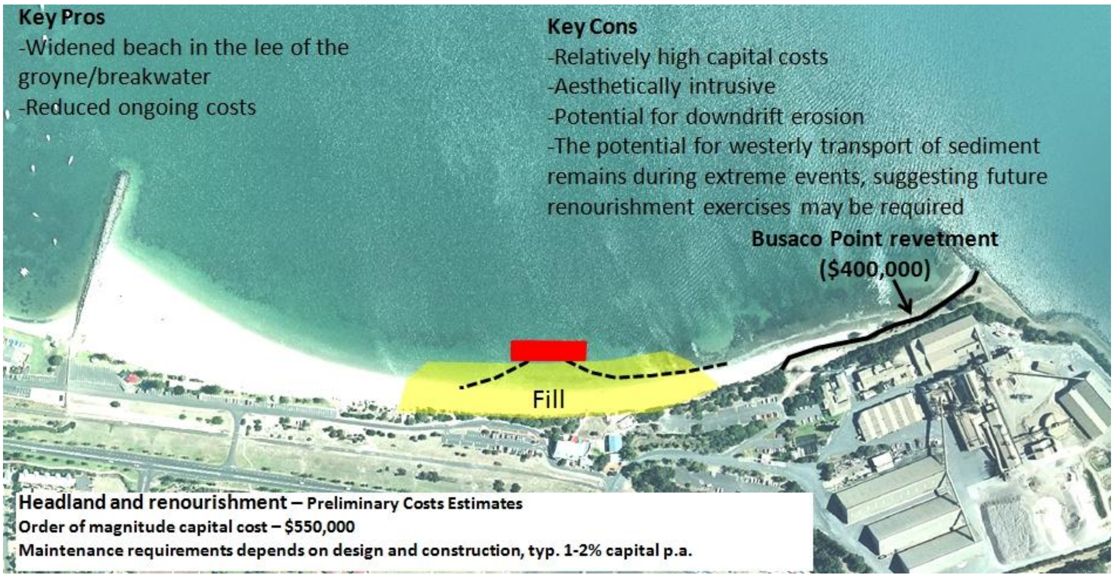

Figure 5-8: Headland and Renourishment Sketch

5.5. OPTION 6: DETACHED HEADLAND WITH RENOURISHMENT

This option considers the combination of renourishment with a detached headland (i.e. not connected to shore) constructed parallel to the shoreline to stabilise the beach to the west of the proposed Point Busaco revetment (Figure 5-9). The detached headland acts similarly to the headland, however accumulation in the lee of the structure form a convex feature (termed a salient) where the shoreline remains disconnected from the structure. This configuration will result in comparative ease for sediments to bypass the headland and hence greater ongoing renourishment needs.

This option has a very high capital cost estimated to be in the order of $900,000, largely due to increased cost attributed to its marine based construction. It is noted that any form of maintenance to an offshore structure is an extremely difficult and costly exercise, which determines the need for the structure to be designed to minimise the need for future maintenance.

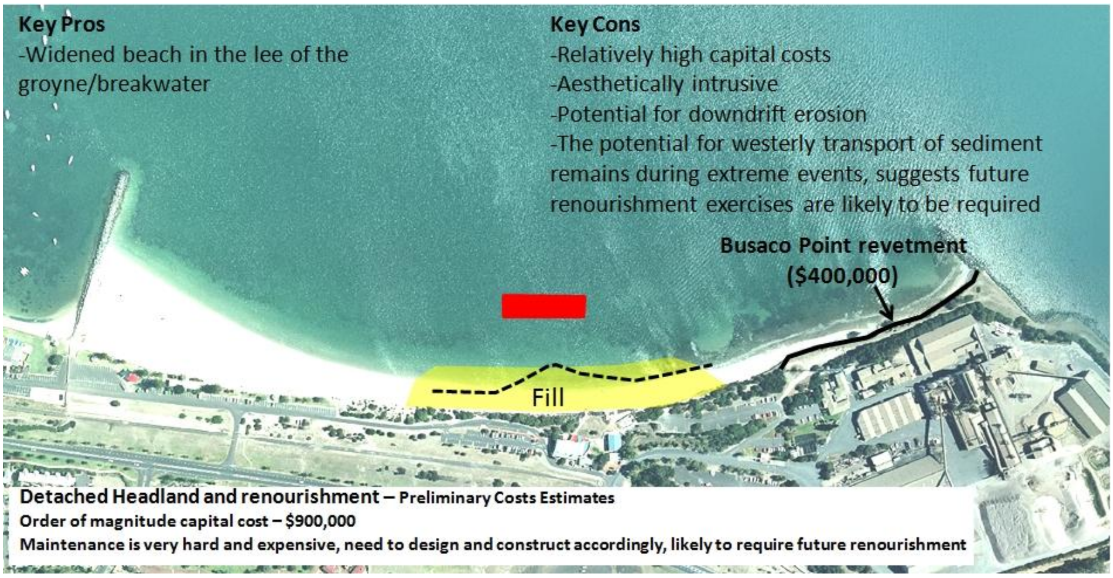

Figure 5-9: Detached Headland and Renourishment Sketch

5.6. OPTION 7: ROCK REVETMENT

This option considers extending the proposed Point Busaco revetment 450m to the existing rock wall that backs the western beach (Figure 5-10). The revetment provides erosion protection to infrastructure by preventing the landward loss of sediments; however will encourage greater erosion immediately in front due to enhanced wave reflection, effectively transferring erosive pressures downward rather than alongshore.

Construction of a revetment is likely to result in a significant challenge to beach amenity. Whilst it is possible to build a sandy beach in front of the revetment, any exposure during a storm event will result in rapid lowering and narrowing of the beach and accelerated alongshore transport. An active renourishment program would be required to reduce the threat of undermining of the revetment, with structural alternatives to construct an extensive toe or future deepening of the revetment.

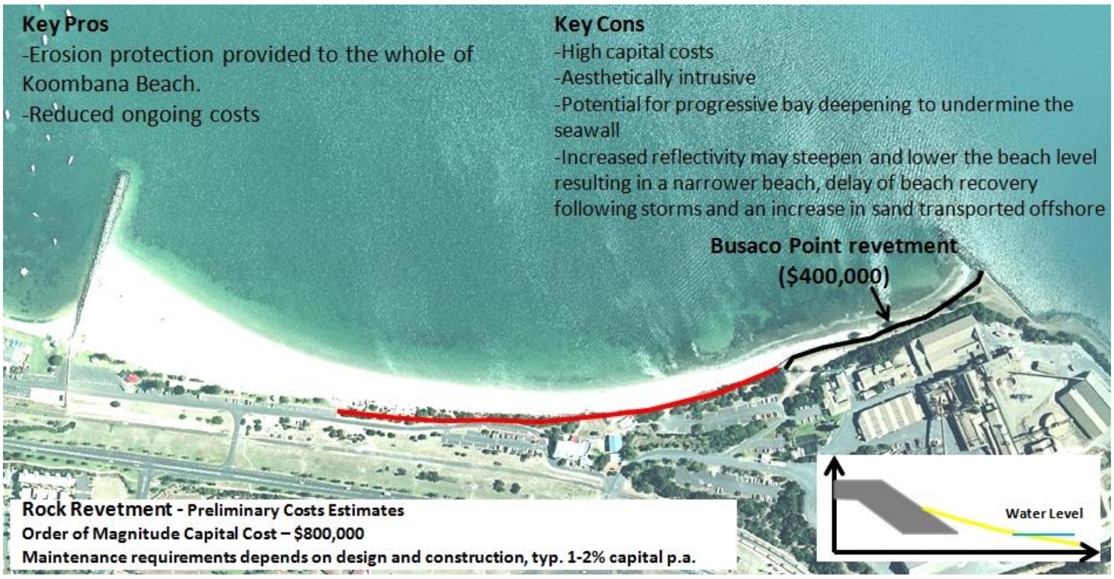

Figure 5-10: Rock Revetment

5.7. OPTION 8: GROYNES, RENOURISHMENT & DUNE STABILISATION

This option considers an alternative option to the proposed Point Busaco revetment (Figure 5-11). In order to provide an adequate 5m setback buffer to the access track and Port infrastructure and to achieve a stable dune that prevents sand drift issues impacting of the Port, a minimum dune width of at least 20m is required. This requires significant renourishment in the order of 65,000m^3, an intensive dune stabilisation programme (fencing and vegetation) and the construction of a 100m long groyne to restrict westwards sand transport and ensure the dune buffer is maintained. A second groyne of 60m length will be required to the west to limit downdrift threat to existing infrastructure located on narrow buffers[3], including footpath, road, car park.

The use of renourishment to protect infrastructure is strongly limited by the capacity for managing agencies to respond to erosion triggers. Where there is limited capacity for response, whether financial, resource constrained or physical (e.g. seasonal placement) then the volume of renourished buffer must be consequently increased. For example, it may be necessary to increase the recommended buffer width to 30 or 40m with a trigger for renourishment of 20m if works can only be achieved on an annual basis.

As noted for Option 4, a consequence of installing the groynes is enhanced shoreline variability on their downdrift (western) sides, as post-storm recovery is preferentially trapped on their eastern side. The western groyne has been placed such that potential downdrift impact from the groyne has limited effect on infrastructure. The short distance to Koombana Yacht Club groyne and limited capacity for bypassing is anticipated to restrict downdrift erosion impacts.

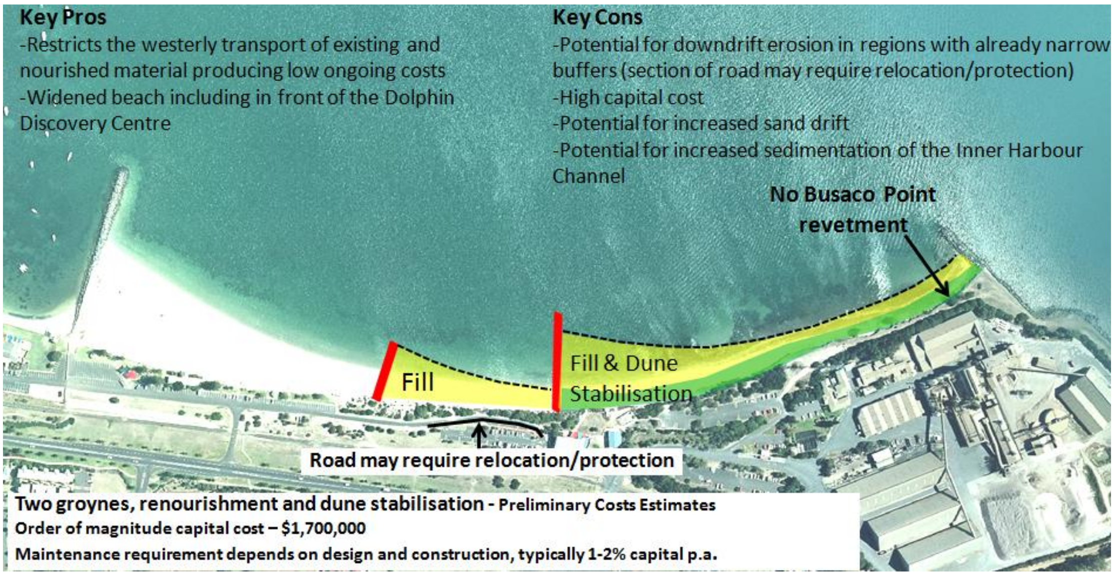

Figure 5-11: Two Groynes, Renourishment and Dune Stabilisation Sketch

3 If a threat is identified additional renourishment, relocation of infrastructure or construction of a revetment are potential mitigation options.

5.8. SELECTION OF OPTIONS FOR DETAILED EVALUATION

A review of the eight coastal management options was undertaken in conjunction with the City of Bunbury and Bunbury Port Authority to select two preferred options for more comprehensive evaluation, described in Section 6.

The selection was largely based on engineering performance and financial sustainability, with a sketch for each option presented outlining the key pros and cons, preliminary order of magnitude costs and indicative ongoing requirements. Following discussions, three options were identified as potentially cost-effective:

1. Renourishment using the Outer Harbour sand traps;
2. Groynes with renourishment;
3. Groyne, renourishment and dune stabilisation, without Point Busaco revetment.

These options were subsequently narrowed down to two preferred options following further evaluation of the groyne, renourishment and dune stabilisation option. More refined cost estimates suggested the cost would be approximately 40% greater than the groynes with renourishment option (including Busaco Point revetment); hence it was subsequently excluded from the comprehensive evaluation[4].

[4] It was determined preliminary costs presented to the City of Bunbury and Bunbury Port Authority significantly underestimated the volume of rock required to achieve depths at the seaward extent of the eastern groyne and the renourishment required to achieve a stable 20m dune.

6. Detailed Evaluation of Two Selected Coastal Management Options

The purpose of the detailed evaluation was to develop design of the two selected options to a level where the most appropriate option to mitigate the potential coastal erosion issues at Koombana Beach could be determined with a high level of confidence. The two options are:

1. Renourishment using the Outer Harbour sand traps;
2. Groynes with renourishment ;

Both assume that Point Busaco revetment is constructed.

The evaluation consisted of the following:

- Design of layout and cross-sections, with Plan SE001-2-1 showing the renourishment option and Plan SE001-2-2 showing the groynes with renourishment option;
- Refined cost estimates;
- Indication of ongoing requirements;
- Recommended beach monitoring;
- Identification of potential adaptation pathways.

6.1. RENOURISHMENT USING OUTER HARBOUR SAND TRAPS

The renourishment option makes use of the available high quality sand source located within close proximity at sand traps on the western side of the Outer Harbour breakwater and assumes construction of the Point Busaco Revetment. The option involves widening of the beach and dune to increase the buffer and subsequent dissipation of storm wave energy. Figure 6-1 shows an example of renourishment, at Wonnerup Beach on the eastern side of the Port Geographe following works in 2011.

Figure 6-1: Renourishment at Wonnerup, Port Geographe

6.1.1. Sediment Source

The sediment source for the renourishment is located at two sand traps along the Outer Harbour breakwater (Figure 6-2). Volumetric analysis using rectified aerial imagery from 2008 suggests available volumes are in the order of 65,000m^3 and 35,000m^3 at the Western spur groyne and in the Outer Harbour sand trap respectively (Shore Coastal 2009). It is noted that rapid infill following previous excavation exercises of the sand traps indicates that any reductions in sediment bypassing the breakwater into the harbour benefiting Bunbury Port Authority will be relatively short-lived (pers. comm. Dave Lantry).

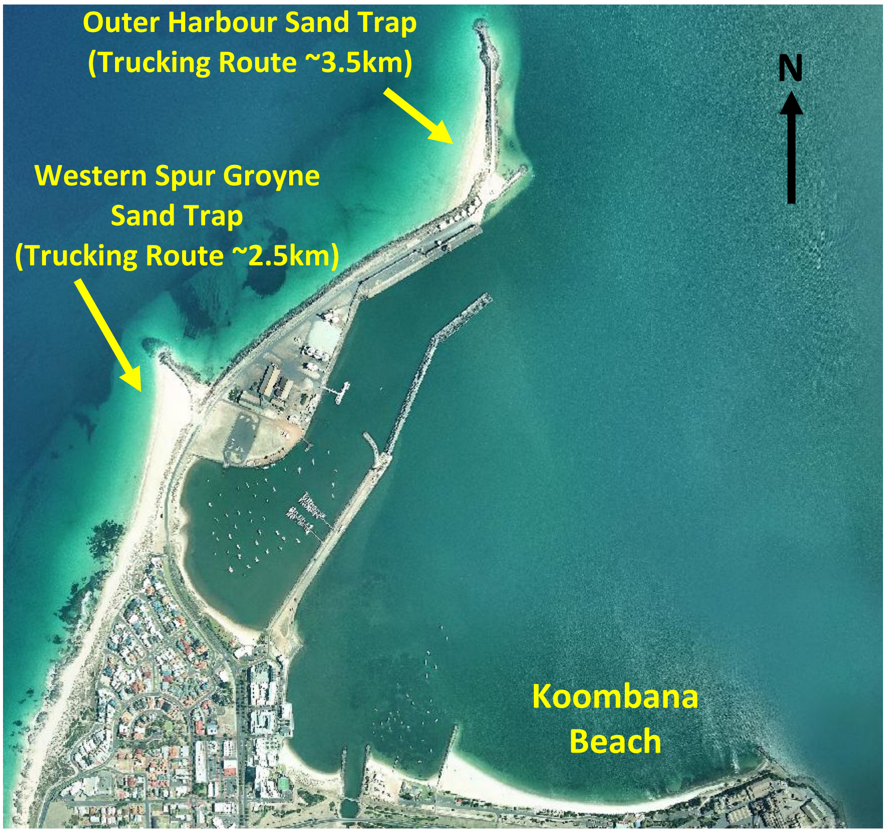

Figure 6-2: Sediment Sources
Imagery - February 2009 (GSWA)

Sediment size is the most critical design parameter as it affects the cross-shore shape of the beach, the rate at which material is transported from the beach and how the beach responds to storms. Previous sediment size analysis has indicated the sand source is significantly coarser than existing sediments along Koombana Beach, with previous estimates of the median diameter of 0.85mm (PWD 1978) and 0.55mm (Taylor *et al*. 2001). The coarser material will produce a higher threshold for sediment transport and will consequently be more stable. Further sediment analysis should be undertaken during the detailed design phase.

It is noted that the sand trap on the eastern side of the breakwater contains a significantly higher proportion of fine sands, with a median diameter (d50) of 0.24mm and therefore has not been further considered as a source.

6.1.2. Design Layout

Plan SE001-2-1 (Appendix G) details the proposed design layout and cross-sections of the renourishment option. It is noted the datum used for the design is Australian Height Datum (AHD) which is 0.57m above Chart Datum (CD) at Bunbury.

6.1.2.1. Location

The area of renourishment includes direct placement along the 470m long unprotected beach extending from the proposed Point Busaco revetment to the eastern extent of the rock wall along western Koombana Beach. Additional placement will occur in front of the Point Busaco revetment to act as a 'feeder' beach, which offsets a portion of potential alongshore transport losses by ongoing sediment supply to the renourished area.

6.1.2.2. Renourishment Volumes

Cross-shore Erosion Component

Severe storm impacts have been modelled at beach monitoring profiles located within the renourishment area (profiles 6-8) using the SBEACH numerical beach profile model. The design storm chosen was the northerly event occurring on the 14th June 2011 due to the sustained nature of elevated wave and water levels recordings. Modelled scenarios include the design storm wave heights and water levels factored to 100 year ARI levels. Profile change for model scenarios show the existing dune is highly susceptible to breaching during 100 year conditions (Figure 6-3), with an estimated renourishment volume required to offset cross-shore losses along the upper profile in the order of 10,800m^3 (Table 6-1).

Table 6-1: Required Renourishment Volumes for Modelled Scenarios

Design Event	Peak WL (m AHD)	Peak Hs (m)	Erosion volume (m^3)
14th June 2011 Storm	1.1	1.0	6,100
Factored (100yr ARI WL)	1.5	1.0	9,700
Factored (100yr ARI Hs)	1.1	1.5	9,700
Factored (100yr ARI Hs, WL)	1.5	1.5	10,800

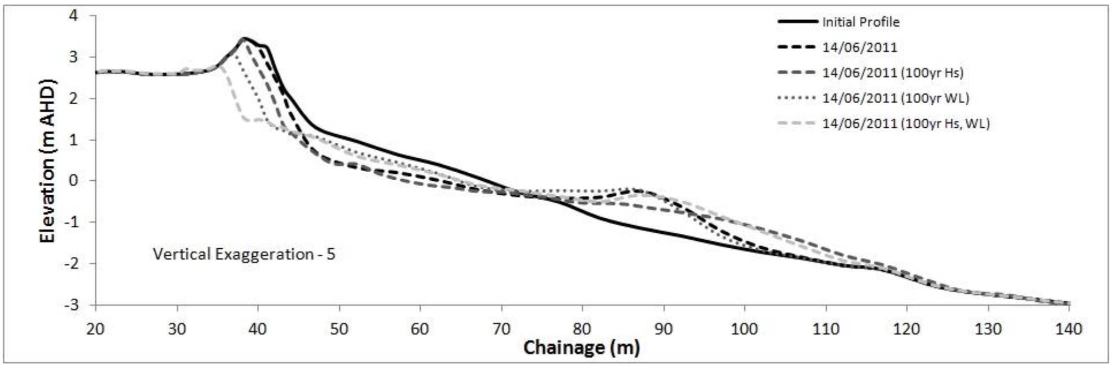

Figure 6-3: SBEACH Storm Induced Change (Profile 8)

Alongshore Transport Component

Alongshore transport rates of placed material will be highly influenced by the stability of nourished material, realignment as the shoreline equilibrates to the wave regime and position of renourishment on the beach profile. The rate will also vary on a year to year basis due to variability in coastal processes, with periods of high easterly wave energy component likely to result in increased net westerly transport of sediment.

Estimated alongshore transport rate of 1,500m^3/year has been assumed based on observed rates of loss along the eastern foreshore and offshore near the centre of the beach for the period 1991-2012, noting the lower rates may be achieved due to the increased stability provided by the coarser material. In order to reduce alongshore transport rates, the design includes transition zones at the ends of the renourishment area and dune placement to restrict sediment exchange between the backshore and foreshore (Jackson *et al*. 2010). The gradients (alongshore and cross-shore) and the balance of material placed in the active beach zone and the dune may be varied to adjust the speed of transport.

Consideration of Climate Change

Estimated rates of potential erosion due to profile adjustment in response to sea level rise are described in Section 4.4. Based on the upper limit of these estimates (4,000m^3/per 0.1m of sea level rise) and a projected upper limit time series of climate induced sea level rise (DoT 2010), the required renourishment volumes required to counter sea level rise has been estimated (Table 6-2). Due to the large uncertainties associated with response to sea level rise and the relatively small volumes compared to predicted alongshore losses, particularly prior to 2070, the volumes represent only a small variation to the present-day requirements, and have not been directly included in the detailed assessment.

Table 6-2: Sea Level Rise Induced Renourishment Volumes

Year	2030	2070	2100
Sea level rise (m)	0.1	0.4	0.9
Cumulative Nourishment Volume (m^3)	4,000	16,000	36,000

It is noted that the relatively small scale of Koombana Beach and its enclosed nature potentially make this a location where renourishment can be used to ‘keep pace’ with sea level rise impacts. However, this interpretation is conjectural, and a more detailed assessment would require further assessment.

Initial Renourishment Volumes

The volume of material for initial renourishment is 18,500m^3, with 3,500m^3 placed in front of the Point Busaco revetment to act as a 'feeder' beach (Table 6-3). This is based on potential alongshore losses of material over a 5 year period plus modelled cross-shore erosion during severe storms. Volumes use a beach overfill ratio of 1 suggested for renourishment projects with coarse material (Dean 1974; Bodge 2006), while it is noted that the calculated overfill ratio of 3 implies the volume will provide improved protection against storm attack[5].

Table 6-3: Renourishment Volumes

Renourishment Component	Required Volume (m^3)
Cross-shore erosion (Renourishment Area)	11,000
Alongshore transport (Renourishment Area)	4,000
Alongshore transport (Feeder Beach)	3,500
Total	18,5000

Potential Ongoing Renourishment Requirements

To ensure that infrastructure remains adequately protected from severe storm erosion, ongoing renourishment exercises should generally occur following alongshore loss of 4,000m^3 from the renourishment area to a depth of -2m AHD. While the timeframes between required renourishment exercises are likely to vary and are to be determined by monitoring, this is anticipated to be required every 5 years based on estimated rates.

6.1.2.3. Nourished Profile

The dune and beach berm are primary features of the design. For ease of construction using land based plant, the design employs a uniform cross-section.

Dune Berm: The dune berm involves increasing the width of the existing dune by 5m with a batter slope of 1V:3H based on typical dune slopes. The planting of suitable vegetation and dune fencing is essential to stabilise the nourished dune.

Beach Berm: In order to maximise the nourishment volume per metre of beach berm width, while restricting scarp formation along the beach, the design beach berm elevation corresponds approximately to the natural level along Koombana Beach (1.3m AHD). A gentle berm slope of 1V:100H is incorporated into the design to help prevent ponding at the back of the beach following overtopping.

[5] The overfill ratio describes the volume of nourished material that, in theory, will ultimately yield a residual unit volume of sediment on the beach after grain sorting and losses. That is, the overfill factor attempts to account for the natural loss of some fraction of the nourished material that is finer than the existing beach sediment. For example, an overfill factor of 3 suggests that 300m3 of borrow sediment must be placed to yield 100 m3 of residual fill on the beach.

The initial batter slope of the beach berm should be the angle of repose of the material, assumed to be 1V:1H, to allow for easy verification of volumes. Following verification the batter slope should be levelled as close to the predicted beach slope of 1V:10H as practically possible. This is likely to be significantly constrained by working limitations of land based plant and therefore natural wave and tide processes will be required to redistribute material below mean water level.

<u>Cross-shore Erosion of the Nourished Profile</u>: SBEACH numerical modelling of cross-shore beach change for the nourished profile under combined 100 year ARI wave and water level conditions demonstrates how the beach berm is designed to limit dune erosion (Figure 6-4). The cross-sectional volume of the berm has been sized such that flattening of the beach does not create an erosion scarp at the face of the dune. A large portion of the beach material moved offshore will move back on shore under post-storm conditions to rebuild the berm.

As the berm progressively erodes through alongshore transport, the potential for scarp formation in the dune progressively increases. The dune volume been sized such that the protective capacity is sufficient to handle a 100 year ARI storm event, even if the berm has been previously eroded.

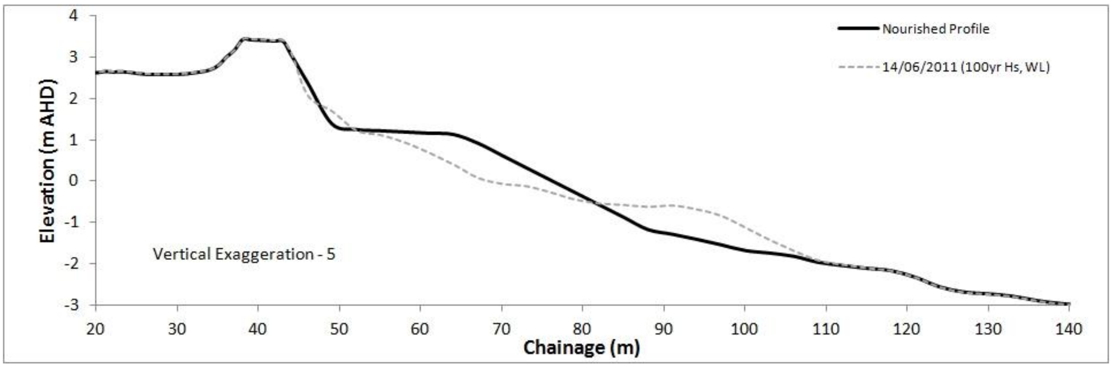

Figure 6-4: SBEACH Storm Induced Change (Renourished Profile 8)

6.1.3. Beach Monitoring

The functional performance of renourishment is largely dependent on the design cross-shore transport component (11,000m^3) of renourished material remaining within the renourishment area. The primary objective of monitoring is therefore to identify volume changes occurring within the renourishment area and feeder beach to allow for evaluation of the projects performance and determine appropriate future nourishment exercises.

The beach monitoring program utilises three techniques (Table 6-4). Beach monitoring surveys provide the means of quantifying profile change and volume losses occurring along Koombana Beach. Photo-monitoring and GPS beach widths are simple inexpensive techniques easily undertaken by non-technical personnel. They are particularly useful in identifying relatively high frequency beach changes and can be used to complement more comprehensive beach monitoring surveys.

Table 6-4: Recommended Beach Monitoring Program

Monitoring tool	**Initial Phase Frequency (Approx. <5 years)**	**Ongoing Phase Frequency (Approx. >5 years)**	**Coverage**
GPS Beach widths	Monthly for 1st year then 3-monthly and post significant erosion event	6-monthly and post significant erosion event	Measured width from the base of the dune to the beach berm along the existing 14 beach monitoring surveys.
Photo-monitoring	Monthly for 1st year then 3-monthly and post significant erosion event	6-monthly and post significant erosion event	8 photo-monitoring locations detailed in Appendix E.
Beach monitoring surveys	Seasonal (post summer & winter)	Annually[1]	Minimum coverage is along the existing 14 beach monitoring surveys which provide a consistent record. If significant volume change above low tide level is identified since the previous survey, surveys should extend to a minimum depth of -2m AHD.

[1] *The Environmental Protection Agency (EPA) recommends a process of defining simplified proxies to trigger appropriate times to undertake monitoring. For this reason relationships between GPS beach width measurements and beach volume change should be determined during the initial phase to define when beach monitoring surveys in the ongoing phase should be conducted. The relationship should take into account storm induced and post event recovery beach change.*

6.1.4. Potential Adaptation Pathways

There is considerable uncertainty associated with estimation of observed coastal change and consequent forecast performance of beach nourishment along Koombana Beach. Within such an uncertain situation, it is appropriate to use an adaptive management framework that integrates monitoring, defined triggers and review into a management plan.

Potential adaptation pathways and triggers have been identified to minimise the future threat to infrastructure that may result if the uncertainties associated with the proposed management are realised (Table 6-5). In particular, identified pathways take into account uncertainties associated with the predicted rates of losses from the renourishment and feeder beach areas.

Table 6-5: Adaptation Pathways and Triggers

Adaptation Pathway	Trigger
Flatten gradient of the placed renourishment	Preceding renourishment exercise shows rapid adjustment, leading to shoreline retreat up to 20% faster than expected.
Use dune as temporary storage for berm material, to be pushed down	Berm supports effective storm-recovery cycle, but experiences progressive loss.
Lowering the nourished beach berm of the feeder beach or Increase volume of material for dune placement in the renourishment area	Rate of volume loss in the renourishment area significantly exceeds losses in the feeder beach area.
Increase renourishment volumes.	A combined loss of 7,500m^3 from the renourishment and feeder beach areas to a depth of -2m AHD in less than 5 year timeframe.
Construct stub groyne at the western end of Point Busaco revetment	Feeder beach erodes rapidly without corresponding loss of renourishment area.
Extension of Koombana Yacht Club groyne or source future renourishment from the beach adjacent to the groyne	Significant increases of sediment bypassing into the Koombana Yacht Club associated with the 'saturation' of the groyne.[1]
Construction of the groyne option	Volume losses in the feeder beach and renourishment area to a depth of -2m AHD are significantly large making the groyne option the more economically viable option.

[1] *Assessment of the Koombana Yacht Club groyne's existing capacity suggests it can accommodate approximately 25,000m^3 of additional material. It is recognised that due to the poor condition of the groyne, maintenance has been deemed required in the short-term to ensure the existing capacity to trap sediments to the west is not reduced by future damage (refer Section 4.1.1).*

6.1.5. Indicative Costs

Cost estimates for initial and ongoing phases of the renourishment option are outlined in Table 6-6. The accuracy of costs is deemed suitable for comparison the two selected options to determine the preferred option.

Table 6-6: Indicative Costs – Renourishment

Item No.	Description	Quantity	Unit	Rate ($ Ex GST)	Amount ($ Ex GST)
1	*Initial Costs*				
1.1	Mobilisation/Demobilisation	1	Item	$ 20,000.00	$ 20,000.00
1.2	Surveys (pre and post)	2	Item	$ 15,000.00	$ 30,000.00
1.3	Traffic Management	18	days	$ 1,200.00	$ 21,600.00
1.4	Renourishment	18,500	m3	$ 12.00	$ 222,000.00
1.5	Dune Vegetation	4,700	m2	$ 5.00	$ 23,500.00
1.6	Dune Fencing	470	m	$ 15.00	$ 7,050.00
1.7	Site Supervision	1	%	5%	$ 14,680.00
1.8	Busaco Point Seawall	1	Item	$ 400,000.00	$ 400,000.00
				Total	**$ 740,000.00**
2	*Ongoing Costs (initial phase <5 years)*				
2.1	Mobilisation/Demobilisation	1	Item	$ 20,000.00	$ 20,000.00
2.2	Renourishment	7,500	m3	$ 12.00	$ 90,000.00
2.3	Traffic Management	8	days	$ 1,200.00	$ 9,600.00
2.4	GPS beach width measurements	-	In Kind	-	In Kind
2.5	Photo-monitoring	-	In Kind	-	In Kind
2.6	Beach monitoring surveys	10	Item	$ 7,500.00	$ 75,000.00
2.7	Busaco Point Seawall Maintenance	5	% p.a	2%	$ 74,000.00
				Total	**$ 270,000.00**
3	*Ongoing Costs (every 5 years during ongoing phase >5 years)*				
3.1	Mobilisation/Demobilisation	1	Item	$ 20,000.00	$ 20,000.00
3.2	Renourishment	7,500	m3	$ 12.00	$ 90,000.00
3.3	Traffic Management	8	days	$ 1,200.00	$ 9,600.00
3.4	GPS beach width measurements	-	In Kind	-	In Kind
3.5	Photo-monitoring	-	In Kind	-	In Kind
3.6	Beach monitoring surveys	5	Item	$ 7,500.00	$ 37,500.00
3.7	Busaco Point Seawall Maintenance	5	% p.a	1%	$ 37,000.00
				Total	**$ 190,000.00**

Notes:

1) *The renourishment rate of $12/m^3$ includes trucking and placement of material is based on recent experience in the south west of Western Australia.*
2) *The cost of the Point Busaco revetment is likely to vary based on available rock supplies and therefore has been inferred from cost estimates detailed in Damara WA (2011). Potential maintenance requirements of the Point Busaco revetment are based on typical maintenance costs of rock-armoured structures in the south-west of Western Australia.*
3) *Costs do not include allowances for maintenance of the Koombana Yacht Club groyne, detailed design, approvals or project management.*
4) *Costs for GPS beach width measurements and photo-monitoring are 'in-kind' for the City of Bunbury.*
5) *Costs are based on 2013 prices.*

6.2. ROCK GROYNES WITH RENOURISHMENT

A major constraint of renourishment projects is the general reluctance of agencies to accept a solution that implies relatively high ongoing costs. The major objective of the rock groynes with renourishment option is to significantly reduce ongoing costs. This is achieved by incorporation of two groynes to restrict the net alongshore loss of renourished material, recognising that rock armoured structures have relatively low maintenance requirements and have high longevity when appropriately designed, constructed and maintained. The eastern groyne is located to ensure a wide beach is maintained in front of the Dolphin Discovery Centre and the western groyne is located to retain the beach buffer in front of car park and road infrastructure. It is noted that the groynes will impact on beach access and can pose a hazard to beach users such as trips and falls.

6.2.1. Materials

Consideration of Geotextile Sand Containers (GSCs): Consideration has been given to low profile GSC groynes due to the advantages they provide over rock armoured groynes along a recreational beach, including their low visual impact and ease of access along the beach.

A major constraint which limits their suitability at Koombana Beach is that placement of GSCs using land-based plant is limited to shallow water, with achievable depths in the order of -0.5 to 1m AHD during favourable spring conditions with dewatering[6]. This constrains groyne length, which significantly limits their functional performance as the groynes are likely to be 'saturated with sand' under the majority of conditions allowing material to actively bypass. A further major constraint is their reduced durability. GSCs are vulnerable to tearing, UV exposure, vandalism[7] and settlement and are have an uncertain design life.

As the combined effect of these constraints is anticipated to result in much higher ongoing costs than rock armoured groynes, they have not been deemed to provide a cost-effective solution. If further consideration is given to GSCs groynes, then:

- Based on predicted shoreline alignments, readily achievable depths and required renourishment for protection against cross-shore losses during severe wave attack, approximately four groynes (constructed following renourishment) will be required to restrict the alongshore transport of nourished material;
- Large 2.5m^3 GSCs[8] will be required to withstand to the wave climate at the seaward extent of the groynes, while there is potential for the smaller 0.75m^3 GSCs to be used towards the landward end. It is noted that GSCs may be used at the landward end of rock armoured groynes to reduce their impact on beach access.

[6] Construction costs increase substantially beyond this depth due to the need for either the crest of the groynes to be wide and high enough for the excavator to drive on, or a barge mounted excavator.

[7] Significant research has been undertaken with regard to 'vandal proofing' the bags and GSCs are available in more robust vandal deterrent fabrics at an increased cost.

[8] For the larger 2.5m^3 GSCs, the filling and placing process is slightly more involved than the dry filled 0.75m^3 GSCs. They require a hydraulic lifting cradle, which doubles as the excavator head and the GSCs are then filled with a sand/water slurry using a hydraulic pumping system. The cradle and pump are available for hire through Geofabrics in Malaga, Perth.

Rock Armour: Rock groyne design is heavily dependent on the type of rock used, with lower density rock requiring larger units and hence a larger volume of rock. Further, rock supply costs are highly variable based on the available quarry yield and transport distances. For the purpose of this investigation, the design of the groyne assumes the use of granite (2.6 t/m^3) which has historically been used widely in coastal works at Bunbury. As commercial quarries near Bunbury only supply Basalt rock, granite may need to be supplied from the Darling Scarp or Byford. It is noted that previous investigation of available quarry yields for the Point Busaco revetment preliminary design suggests that Ironstone (2.3 t/m^3) or Basalt (3.0 t/m^3) are alternative, potentially cost-effective options (Damara WA 2011).

6.2.2. Design Criteria and Armour Stability

Australian Standards AS4997-2005 *Guidelines for the Design of Maritime Structures* recommends design criteria of 50-200 yr ARI for 'structures presenting a low degree of hazard to life or property' (Standards Australia 2005). For the purpose of this design, a 100 year wave height (1.52m) has been selected which implies a working design life between 25-50 years according to AS4997[9]. Using Hudson's formula (USACE 1984), with a 'zero damage' (0-5%) criteria applied to reduce maintenance costs, the required armour sizing to provide the basic protection against wave action has been derived (armour class I; Table 6-7). Due to the increased wave exposure and difficulty of performing maintenance at the seaward extent of the structure, larger rock sizes have been used at the at the head of the groynes with a median mass of 1.5 times the stable armour size (armour class II).

Table 6-7: Required Rock Sizes

Armour Class	Mass Range	Median Mass	Inferred D50
1	0.5-1.2t	0.9t	0.9m
11	0.8-1.6t	1.3t	1.0m

It is noted that if the groyne option is selected to be evaluated to a detailed design level, design criteria should be optimised to ensure the most cost effective groyne design (Figure 6-5), with potential maintenance requirements using methods outlined in the *Shore Protection Manual* (USACE 1984).

[9] It is recognised that this does not represent the length of time structures will last, as minor maintenance of rock armoured coastal protection structures can significantly extend the design life. Furthermore, rock armour structures have a high residual capacity, such that they maintain a high level of functionality following minor damage.

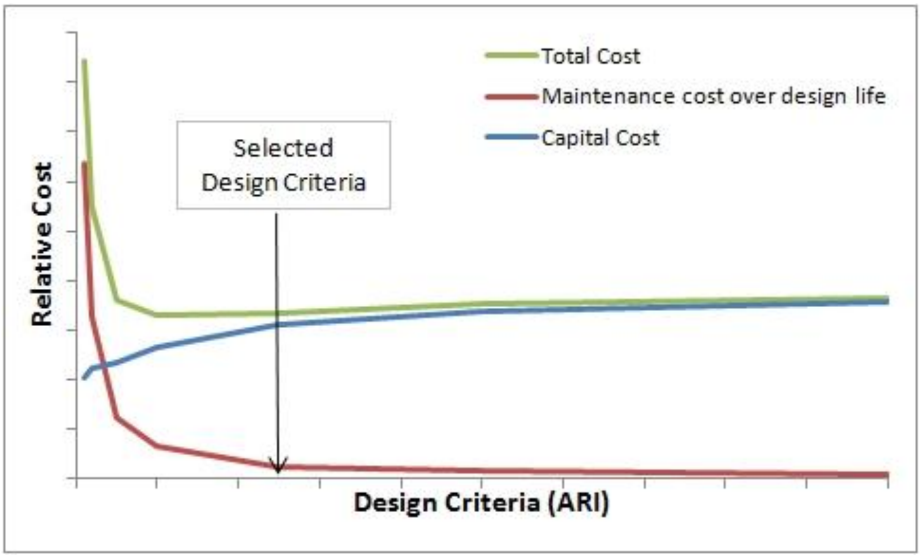

Figure 6-5: Relative Cost Versus Design Criteria

6.2.3. Predicted Shoreline Orientation

A critical parameter for the optimal layout of groynes and renourishment is the predicted shoreline orientation updrift of the groynes. This has been estimated based upon the existing shape of Koombana Beach, which apparently responds to incoming prevailing swell. Comparison of shore normal lines suggests a point of convergence offshore from Koombana Beach (Figure 6-6), which is consistent with diffraction around the Outer Harbour breakwater. Using this point of convergence to predict the beach configuration, the shore normal orientation at the western and eastern groynes is 13.5˚N and 0.5˚N respectively.

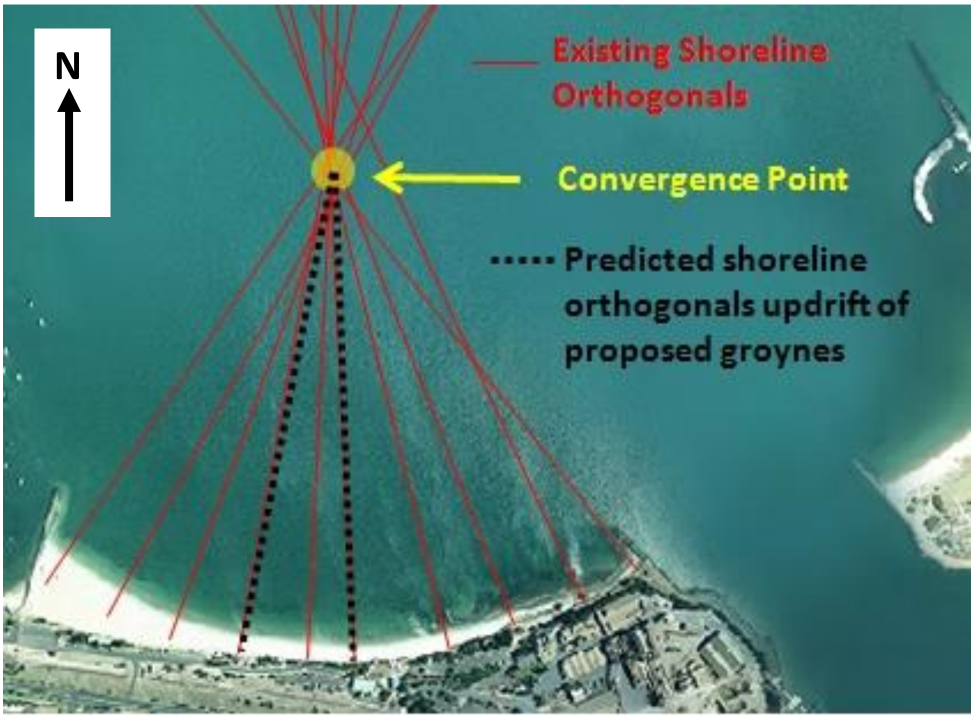

Figure 6-6: Predicted Shoreline Orientation Updrift of Groynes

6.2.4. Design Layout

Plan SE001-2-2 (Appendix G) details the proposed design layout and cross-sections of the groynes with renourishment option. The groyne layout and renourishment volumes have been designed to achieve the following primary outcomes:

- Renourishment is targeted to areas where there are narrow existing erosion buffers for infrastructure;
- The groynes are to remain "wholly effective" in trapping renourishment volumes, maintaining wide beaches updrift and limiting ongoing renourishment needs;
- The threat of downdrift erosion immediately to the west of the groynes is restricted to areas where there is little infrastructure, or it may be readily relocated;
- The threat of flanking erosion adjacent to the Point Busaco revetment outlined in Damara WA (2011) is limited.

Groyne Layout: The optimal groyne layout is considered to be two 60m groynes extending from the existing dune, with the eastern groyne located to ensure a wide beach is maintained in front of the Dolphin Discovery Centre and the western groyne is intended to transfer the threat of downdrift erosion to an area of wider erosion buffer and reduced infrastructure. A third short (20m) low profile groyne has been incorporated into the possible layout at the western extent of the Point Busaco revetment. This stub groyne has been considered following discussions with Bunbury Port Authority and will reduce the threat of toe undermining from the ongoing net westerly transport of sediments. However, it may have an important role to control the rate of westward alongshore feed.

The two 60m design groynes consist of 3 distinct sections summarised in Table 6-8. Where possible the rock required for the works has been minimised, including using a 1V:1.5H design armour slope, only 1 layer of rock armour on the updrift side of the inner trunk and restricting the crest height and width.

Table 6-8: Design Groyne Sections

Section	Inner Trunk	Outer Trunk	Head
Chainage	0-20m	20-45m	45-60m
Crest Height	+2.0m AHD	+2.5m AHD	+2.5m AHD
Toe Level	-0.5m AHD	-0.5m AHD or existing bed depth	existing bed depth
Amour Class	I	I	II
No. of Armour Layers on updrift side	1	2	2

Renourishment Volumes: The renourishment volume required to achieve the desired shoreline configuration has been established based on the predicted shoreline orientation and existing and expected beach profiles (Table 6-9). The volumes assume sediment is sourced from coarse sands located in sand traps on the ocean side of the Outer Harbour breakwater.

Table 6-9: Renourishment Volumes

Groyne	Renourishment Volume (m^3)
Western Groyne	10,000
Eastern Groyne	9,000

The renourishment volumes are predicted to achieve an expected depth of -1.0m AHD at the head of the groyne (Figure 6-7). As the majority of alongshore sediment transport is expected to take place between the outermost breaking waves and the beach face, which are both landward of the -1.0m AHD contour, the groyne design is predicted to significantly reduce the westerly transport of nourished material.

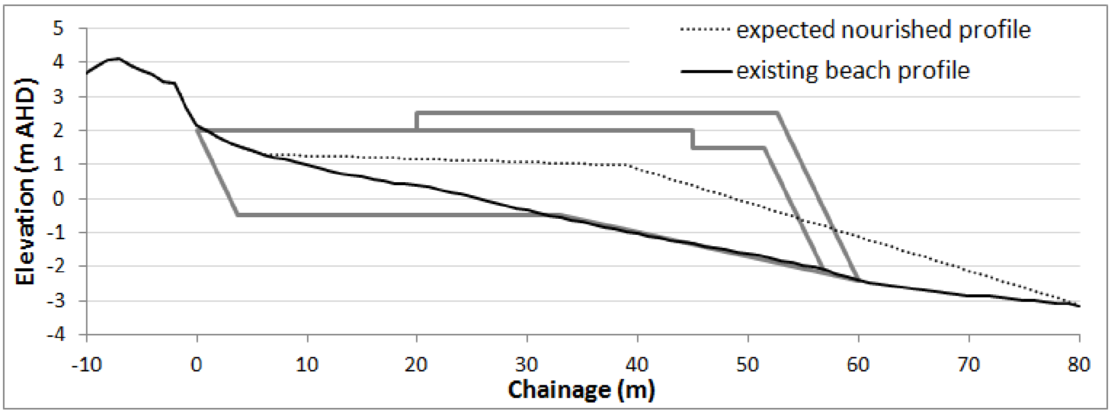

Figure 6-7: Expected Renourished Profile Updrift Side of Western Groyne

Cross-shore Erosion of Nourished Profile: The renourishment exceeds the volume required (11,000m^3) to offset modelled cross-shore losses during severe storms at Koombana Beach (refer Section 6.1.2.2). As shown in Figure 6-4, this is anticipated to limit dune erosion during severe storm events, particularly on the updrift side of the groynes.

6.2.5. Beach Monitoring

Evaluating the performance of the groynes is considered an essential component of the project. The primary objective of the monitoring is to identify volume changes occurring updrift of the groynes and to rapidly identify adverse downdrift impacts.

The beach monitoring program utilises three techniques (Table 6-10). Beach monitoring surveys provide the means of quantifying profile change and volume losses occurring updrift of the groynes. Photo-monitoring and GPS beach widths are simple cost-effective techniques easily undertaken by non-technical personnel. Both these techniques are considered particularly useful in monitoring the performance of the groynes and rapidly identifying downdrift erosion issues. It is noted that GPS beach width information will be particularly useful in determining the prevailing shoreline orientation.

Table 6-10: Recommended Beach Monitoring Program

Monitoring tool	Initial Phase Frequency (Approx. <5 years)	Ongoing Phase Frequency (Approx. >5 years)	Coverage
GPS Beach widths	Monthly for the 1st year then 3-monthly and post significant erosion event	6-monthly l and post significant erosion event	Measured width from the base of the dune to the beach berm along the existing 14 beach monitoring surveys.
Photo-monitoring	Monthly for the 1st year then 3-monthly and post significant erosion event	6-monthly and post significant erosion event	8 photo-monitoring locations detailed in Appendix E. Additional locations to be established on the crest of the groyne.
Beach monitoring surveys	Seasonal (post winter/summer)	N/A[1]	The minimum required coverage is along the existing 14 beach monitoring surveys which provide a consistent record. If significant volume change above low tide level is identified since the previous survey, surveys should extend to a minimum depth of -2m AHD.

[1] *The Environmental Protection Agency (EPA) recommends a process of defining simplified proxies to trigger appropriate times to undertake monitoring. For this reason relationships between GPS beach width measurements and beach volume change should be determined during the initial phase to define when beach monitoring surveys in the ongoing phase should be conducted. The relationship should take into account storm induced and post event recovery beach change.*

6.2.6. Potential Adaptation Pathways

As noted in Section 6.1.4, there is considerable uncertainty associated with estimation of observed coastal change and consequent forecast performance of beach nourishment along Koombana Beach. Within such an uncertain situation, it is appropriate to use an adaptive management framework that integrates monitoring, defined triggers and review into a management plan.

Potential adaptation pathways and triggers have been identified to minimise the future threat to infrastructure that may result if the uncertainties associated with the proposed management are realised (Table 6-11). In particular the pathways consider uncertainties associated with predicted shoreline orientation updrift of the groynes, potential loss of material within the groyne field and potential downdrift erosion. In general, these sources of uncertainty are smaller than those for renourishment without structures; however, installation of groynes represents a significant capital outlay, with less capacity for cost-effective adaptation.

Table 6-11: Adaptation Pathways and Triggers

Adaptation Pathway	Trigger
Provide additional renourishment	Insufficient initial renourishment of the groynes resulting in too small a buffer without the groynes being saturated by sand.
Extend the Point Busaco revetment along the affected area	Downdrift erosion or flanking erosion west of the Point Busaco poses a significant threat to infrastructure.
Ongoing renourishment	The volume of material lost from the groyne field above -2m AHD is sufficiently large for erosion to pose a threat to infrastructure
Extension of the groynes	The rate of volume loss within the groyne field above -2m AHD is sufficiently large that extending the groynes is more economically viable than ongoing renourishment. It is noted that due to the largely closed nature of Koombana Beach (detailed in Section 4.2) and the existing capacity of Koombana Yacht Club groyne to accommodate further accretion, any renourishment provided to the beach will not be 'lost' and can be reworked to provide renourishment of the beaches updrift of the groynes.

6.2.7. Structural Monitoring and Maintenance

Although well-design and constructed rock-armoured structures generally have the capacity to withstand highly varied environmental conditions, there is always some probability that extreme conditions will cause structural displacement. In order to ensure the groynes perform adequately over their structure life, an ongoing program of maintenance is required, with maintenance requirements strongly linked to the structural life-cycle, which follows the general sequence described by Table 6-12.

Table 6-12: Groyne Structural Life Cycle

Initial phase	Initially, structural stability is determined by a combination of interlocking between rock units and the self-weight of the armour units and compaction of core material;
Early phase	During early storm events, areas of low-stability rock may be mobilised in the 'shakedown' period, reducing the degree of interlocking and causing an early phase of settlement;
Main phase	Subsequently, the groyne typically changes slowly, with energetic wave conditions occasionally mobilising armour units, gradually reducing the effect of interlocking and contributing to core losses;
Episodic over life	Bed erosion may provide accelerated settlement of the groyne, particularly at the head of the groyne.
Late phase	Tertiary failure mechanisms, such as rock fracture, settlement, intertidal voids and piping usually develop exponentially, such that they do not require maintenance until the latter phases of the structure life-cycle.

In order to determine future maintenance requirements of the groynes, periodic engineering inspections are required. Inspections should evaluate the groynes condition utilising the US Army Corps of Engineers Repair, Evaluate, Maintain and Rehabilitate (USACE-REMR) technique (Oliver *et al*. 1998; USACE 2006). It is recommended that an engineering inspection should be scheduled following the first severe storm to evaluate the degree of structural deformation, if any.

6.2.8. Indicative Costs

Cost estimates have been prepared for initial and ongoing phases of the groynes with renourishment option (Table 6-13). The accuracy of costs is deemed suitable for comparison the two selected options to determine the preferred option.

Table 6-13: Indicative Costs – Groynes with Renourishment

Item No.	Description	Quantity	Unit	Rate ($ Ex GST)	Amount ($ Ex GST)
1	*Initial Costs*				
1.1	Mobilisation/Demobilisation	1	Item	$ 50,000.00	$ 50,000.00
1.2	Surveys (pre and post)	2	Item	$ 15,000.00	$ 30,000.00
1.3	Renourishment	19,000	m3	$ 12.00	$ 228,000.00
1.4	Traffic Management	60	days	$ 1,200.00	$ 72,000.00
1.5	Western groyne - Supply & Placement of Granite Rock	1,450	t	$ 57.00	$ 82,650.00
1.6	Western groyne - Supply & Placement of Core Material	2,300	t	$ 57.00	$ 131,100.00
1.7	Eastern groyne - Supply & Placement of Core Material	1,550	t	$ 57.00	$ 88,350.00
1.8	Eastern groyne - Supply & Placement of Granite Rock	2,500	t	$ 57.00	$ 142,500.00
1.9	Site Supervision	1	%	5%	$ 41,230.00
1.10	Busaco Point Seawall	1	Item	$ 400,000.00	$ 400,000.00
1.11	Busaco Point Seawall (small groyne)	1	Item	$ 50,000.00	$ 50,000.00
				Total	**$ 1,320,000.00**
2	*Ongoing Costs (initial phase <5 years)*				
2.1	Maintenance	5	% p.a	2%	$ 63,783.00
2.3	GPS beach width measurements	-	In Kind	-	In Kind
2.4	Photo-monitoring	-	In Kind	-	In Kind
2.5	Beach monitoring surveys	5	Item	$ 7,500.00	$ 37,500.00
2.6	Busaco Point Seawall Maintenance	5	% p.a	2%	$ 45,000.00
				Total	**$ 150,000.00**
3	*Ongoing Costs (every 5 years during ongoing phase >5 years)*				
3.1	Maintenance	5	% p.a	1%	$ 31,891.50
3.2	GPS beach width measurements	-	In Kind	-	In Kind
3.3	Photo-monitoring	-	In Kind	-	In Kind
3.4	Beach monitoring surveys	1	Item	$ 7,500.00	$ 7,500.00
3.5	Busaco Point Seawall Maintenance	5	% p.a	1%	$ 22,500.00
				Total	**$ 60,000.00**

Notes:

1) *The renourishment rate of $12/m^3 includes trucking and placement of material is based on recent experience in the south west of Western Australia.*
2) *The cost of the Point Busaco revetment and groynes are likely to vary according to availability of rock supplies. Costs for the Point Busaco revetment has been inferred from cost estimates detailed in Damara WA (2011), while costs for the groynes have been based on calculated rock quantities and the supply, transport and placement of rock sourced from a currently viable source of granite rock.*
3) *Potential maintenance requirements of the Point Busaco revetment and groynes are based on typical maintenance costs of rock-armoured structures in the south-west of Western Australia.*
4) *Costs do not include allowances for maintenance of the Koombana Yacht Club groyne, detailed design, approvals or project management.*
5) *Costs for GPS beach width measurements and photo-monitoring are 'in-kind' for the City of Bunbury.*
6) *Costs are based on 2013 prices.*

6.3. SELECTION OF THE PREFERRED OPTION

In order to aid the selection of the preferred option, indicative costs for the two options outlined in Table 6-6 and Table 6-13 have been used to estimate costs accrued over time (Figure 6-8). Due to the potential for lower net westerly transport rates due to the increased stability of the nourished material, additional costs for the renourishment option are presented based on 1/2 and 1/3 of the observed rate.

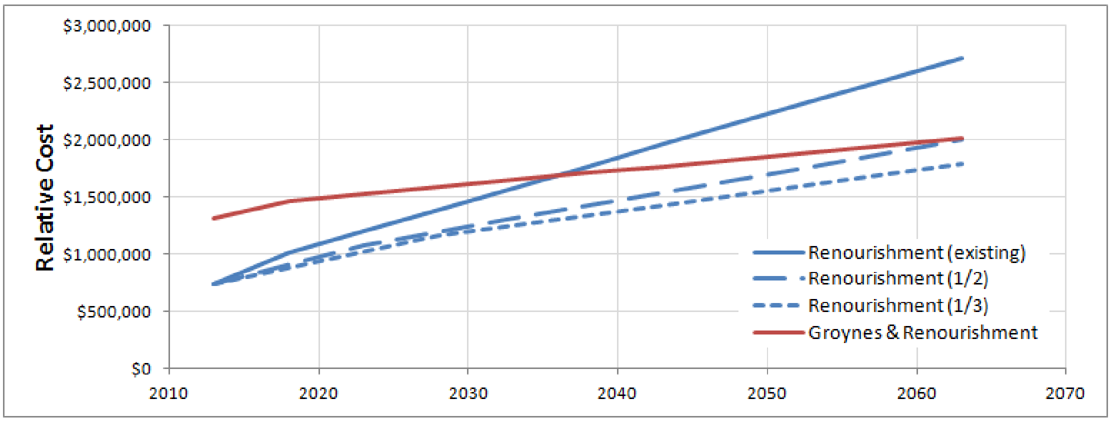

Figure 6-8: Incurred Costs for the Two Options

Renourishment without structures provides lower predicted costs over the next 20 years. However, selection of the most cost-effective option in the long-term is less clear-cut, with uncertainties associated with the rates of sand redistribution and impacts of potential sea level rise. Consequently, it is recommended that the option of renourishment without structures be applied, with suitable performance monitoring and assessment to enable ongoing review of adaptation needs.

The recommended option of renourishment without structures provides low initial cost, a greater degree of flexibility and lower impacts to amenity and access along Koombana Beach. A shift to the alternate erosion management strategy (groynes with renourishment) may be achieved with comparative ease.

Beach monitoring should be undertaken during the first 5 years after renourishment to enable refinement of the beach nourishment program. Should the monitoring identify the rate of loss of renourishment from the feeder beach and renourishment area to a depth of -2m AHD is sufficiently high such that the groyne option becomes more economically viable, construction of the groynes should be considered. It is also noted that due to the largely closed nature of Koombana Beach and the existing capacity of the Koombana Yacht Club groyne to accommodate further accretion, material previously placed on the beach will not be 'lost' and therefore could be reworked to provide renourishment of the beaches updrift (eastern side) of the groynes.

7. Conclusions

Koombana Beach is a highly modified beach, with a history of intervention and subsequent redistribution of placed material. Available records indicate net westerly sediment transport, with erosion of the eastern foreshore and nearshore deepening towards the centre of the beach roughly balanced by ongoing accumulation on the east side of Koombana Yacht Club groyne. This balance suggests that Koombana Beach can be considered a largely 'closed' system, thereby indicating that available information and survey analysis conducted as part of this investigation provides a sound basis for describing the active coastal processes.

Analysis of the historic record suggests that, on average, approximately 1,500m^3 of sand has been transported westward per year. The rate of erosion is not constant, with accelerated erosion occurring during periods of strong northerly conditions or elevated mean sea levels. Occurrence of both these phenomena over 2011-2012 has caused rapid shoreline retreat. This is presently threatening Bunbury Port Authority infrastructure at the eastern end of Koombana Beach, with only a limited erosion buffer protecting City of Bunbury infrastructure and the Dolphin Discovery Centre facilities, towards the centre of the beach.

An analysis of existing erosion buffers has suggested that they are insufficient to protect existing infrastructure from impact of a severe erosion sequence. With continuation of the erosive trend, the threat to coastal infrastructure will progressively increase. In the short-term, minor adaptation of the existing facilities may enable the buffers to be increased to approximately 10m. This is likely to provide protection against minor to moderate erosion events for a maximum of 10 years. Provision of a larger erosion buffer through relocation of facilities is not practical at Koombana Beach due to the scale of infrastructure and its proximity to the coast. Long-term management of Koombana Beach therefore requires consideration of coastal protection measures.

Evaluation of the relative threat posed to infrastructure along the eastern section of Koombana Beach indicates that a practical solution is provision of a revetment constructed along the Bunbury Port Authority foreshore. Construction of this structure is anticipated to increase erosive stresses upon the central part of Koombana Beach, thereby affecting land managed by the City of Bunbury. This potential transfer of erosion hazard requires a co-ordinated approach to management of Koombana Beach.

Investigation of a range of coastal management options has identified that Koombana Beach may be most effectively managed through a combination of a revetment along the eastern foreshore and renourishment along the east and central parts of the shore. Readily available source of sand with low transport distances located at sand traps on the western side of the Outer Harbour makes renourishment a viable option. The effectiveness of the proposed approach is subject to the range of weather conditions, the stability of placed material and potential impacts of sea level rise. These uncertainties may be managed through an adaptive management framework, including beach monitoring, with an option to install groynes in the central beach section if performance of the renourishment works is inadequate.

8. Recommendations

The recommended coastal management strategy for Koombana Beach is to construct Point Busaco revetment and undertake renourishment works for the central and eastern parts of the beach, using material supplied from the Outer Harbour sand traps. It is recognised that the procurement and implementation phases will take some time to be established, with need for significant ongoing collaboration between stakeholders.

Immediate recommendations include those to establish the proposed management strategy and those to manage the threat of erosion prior to the strategy's implementation within a period of no more than three years:

1. Establish 10m erosion buffer through the central section of Koombana Beach. Review minor coastal infrastructure, to assess whether it should be relocated, or is considered sacrificial;
2. Identify ownership and responsibility for Koombana Yacht Club groyne. The groyne is in extremely poor condition and susceptible to further damage. In order to maintain the groyne's retentive capacity, repair works should be undertaken;
3. Identify likely responsibilities and funding arrangements for ongoing management of Koombana Beach;
4. Confirm capacity to undertake emergency nourishment works to protect existing infrastructure;
5. Complete detailed design and procurement for Point Busaco Revetment;
6. Commence detailed design and procurement for the renourishment works. This should should incorporate the following:
   - Further sediment analysis on the Outer Harbour sand traps to determine the existing properties of the sediment source;
   - Refine the design of Point Busaco revetment to facilitate the feeder beach, including provision of stub groyne option;
   - Design drawings and technical specifications suitable for tender and construction are developed;
   - Consideration of approvals required to complete the works. This will require further consultation of the impact of sand nourishment on dolphins in Koombana Bay;
   - Identify and source funding for the works.

Short-term recommendations cover implementation of the proposed management strategy and initial performance assessment. These include:

1. Beach Monitoring Program for the initial phase as outlined in Table 6-4 should be implemented within 1 year;
2. Simultaneously install Point Busaco Revetment and undertake initial renourishment works within 3 years;
3. Manage Koombana Beach through an adaptive management framework, including variation of renourishment quantities and placement;
4. Review performance of the management system after 5 years of operation. If beach monitoring identifies renourishment loss from the feeder beach and renourishment area (to a depth of -2m AHD) during the first 5 years is sufficiently high such that the groyne options becomes more economically viable, construction of the groynes should be evaluated. Evaluate need for stub groyne to control loss from feeder beach.

In the long-term, it is recommended that Koombana Beach be managed through an adaptive management framework, built around the proposed management strategy of ongoing renourishment. This should include:

1. Manage Koombana Beach through variation of renourishment quantities and placement. Assess the retentive capacity of Koombana Yacht Club groyne, to determine whether backpassing may be practical;
2. Establish periodic management arrangements for renourishment works, such as 5-year environmental approvals, to achieve improved economies of scale;
3. Beach Monitoring Program should be maintained according to the "ongoing" practices, following Table 6-4: Beach Monitoring Program;
4. Review performance of the management system approximately every 5-10 years. Should beach monitoring identify the rate of loss of renourishment from the feeder beach and renourishment area since the last review is sufficiently high such that the groyne option is likely to be more economically viable, construction of the groynes should be evaluated.

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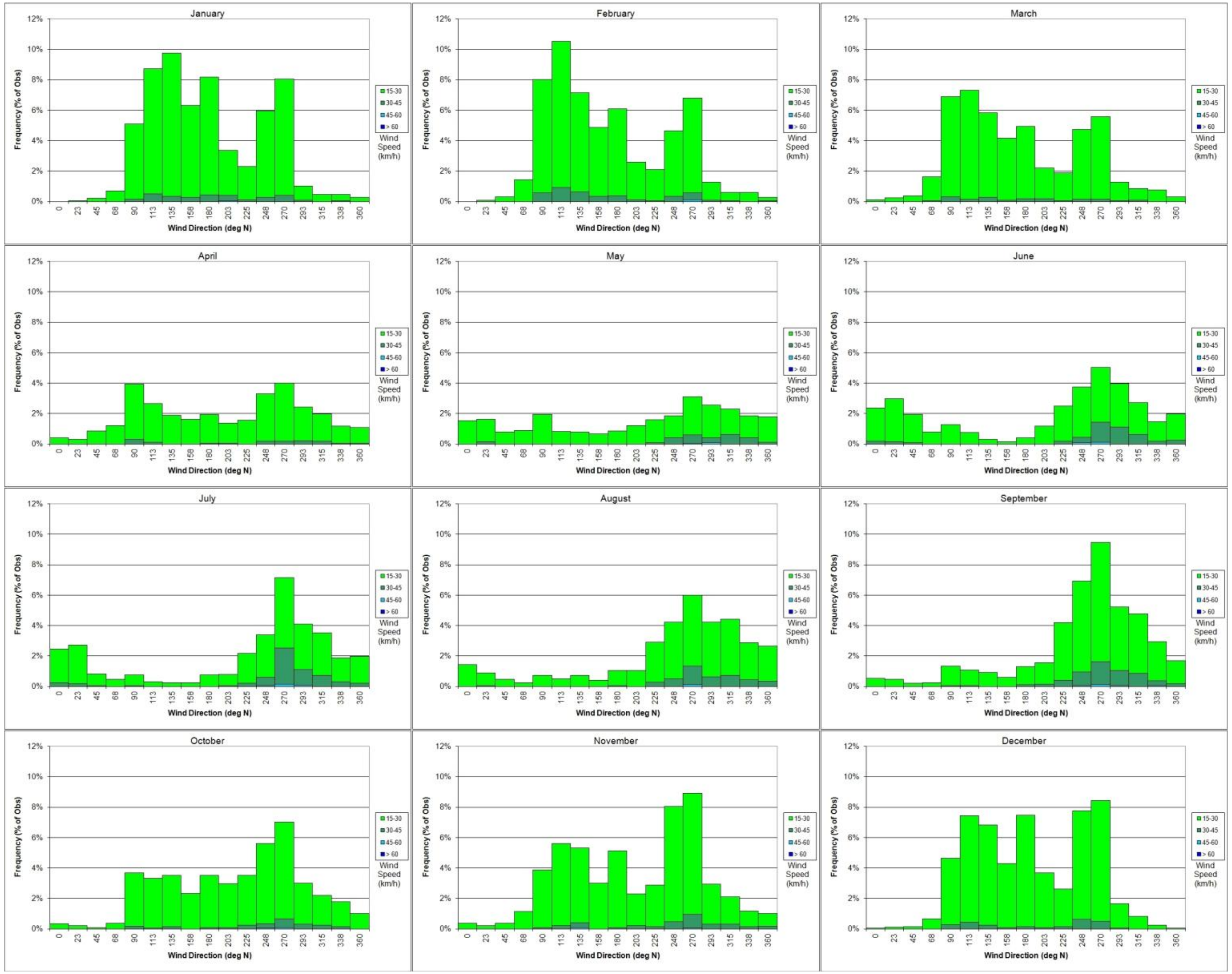
Appendix A Available Survey Information

Koombana Beach		
Date	**Description/Title**	**Plan Number**
Bunbury Port Authority		
1977	-Hydrographic survey which extends to approximately 60-90m from the Koombana Beach shoreline	BPA 1033-3-1
Approx 2007	-Foreshore survey conducted by Thompsons Surveying Consultants along the eastern extent of Koombana Beach	-
2010	-Hydrographic Survey conducted by Thompsons Surveying Consultants of Koombana Beach	-
20/10/2011	-Foreshore survey conducted by Thompsons Surveying Consultants along the eastern extent of Koombana Beach for the purpose of preliminary detailed revetment design	-
Department of Water		
2008	Nearshore high resolution LADS data.	-
Department of Planning		
April/May 2009	LiDAR and LADS for the Swan Coastal Plain. Laser bathymetric survey tool that has applicability in clear coastal (Case II) waters down to -70 m depth	-
Department of Transport/Public Works Department		
12-06-1971	Bunbury Harbour - Erosion of the Koombana Shoreline Levels & Soundings	PWD 46904-2-2
Mar-1990	Koombana Bay (Cable Sands) North Shore Layout Plan & X-sections (Beach Profiles)	539-3-1
Mar 1991	Koombana Bay Levels & Soundings	285-2-1
Sep 1991	Koombana Bay	285-3-1
Sep 1992	Koombana Bay Levels and Soundings (Beach Monitor)	285-5-1
May 1993	Koombana Bay Levels and Soundings (Beach Monitor)	285-5-1
Nov 1993	Koombana Bay Levels and Soundings (Beach Monitor)	285-8-1
Jun 1994	Koombana Bay Levels and Soundings (Beach Monitor)	285-10-1
20-05-2003	Koombana Bay Levels and Soundings (Beach Monitor)	285-12-1
Oct 2012	Bunbury Port Area - Dynascan Survey	1638-6-1
9 Dec 2012	Koombana Beach - Dynascan Hydrographic Survey Levels	1638-6-1

Appendix B Available Aerial Imagery and Derived Shoreline Movements

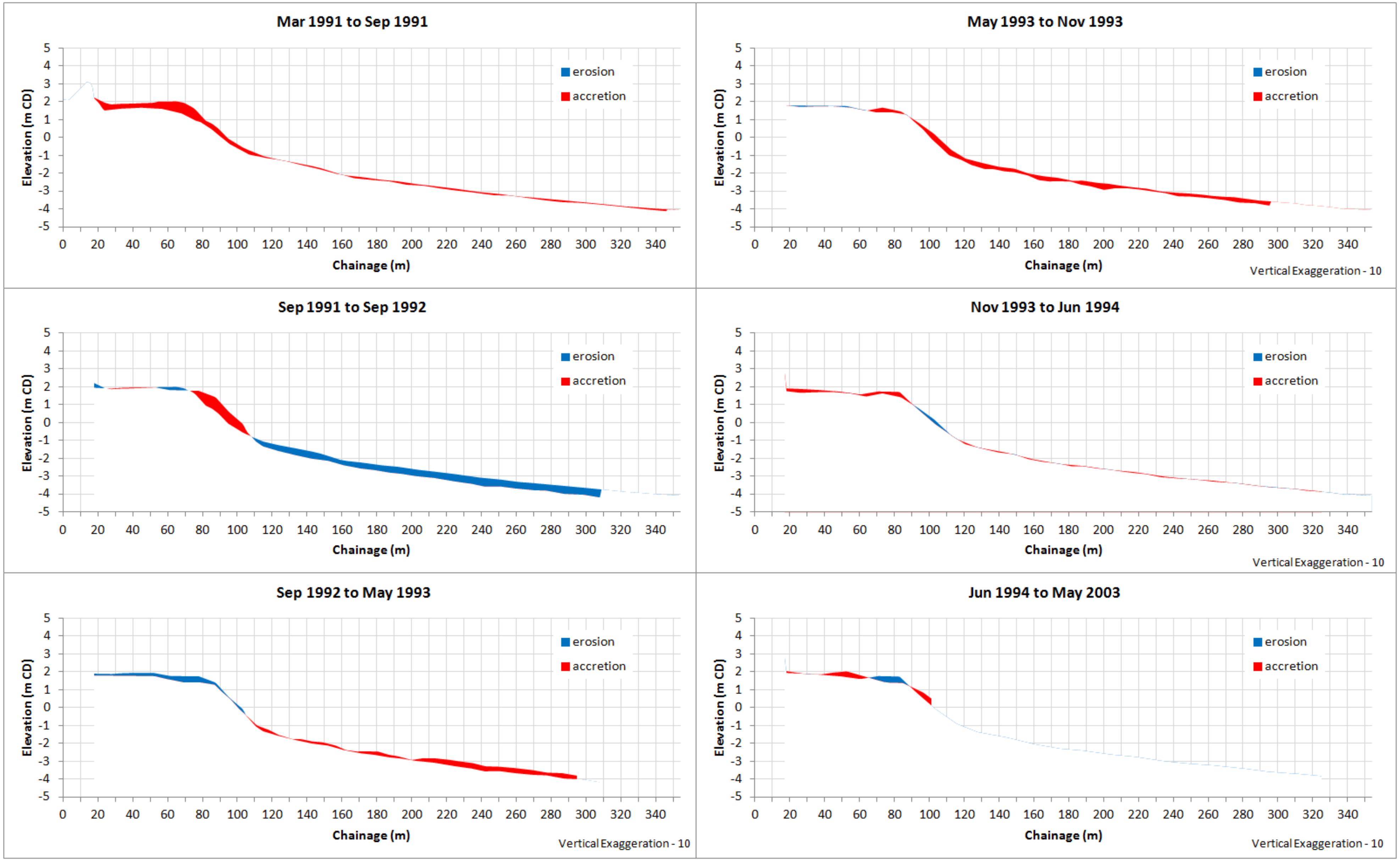
Date	Shoreline Movements	Comment
Feb 1957	Shore Coastal (2009)	
Oct 1962	Shore Coastal (2009)	
Dec 1965	Shore Coastal (2009)	
26 Oct 1969	DMH (1989), Shore Coastal (2009)	Prior to Construction of Inner Harbour
11 Jan 1971	DMH (1989)	No Yacht Club Groyne
14 Feb 1972	DMH (1989)	No Yacht Club Groyne
22 Oct 1973	DMH (1989)	Both Groynes
21 May 1974	DMH (1989)	
Nov 1974	Shore Coastal (2009)	
13 Feb 1975	DMH (1989)	Inner Harbour spoil on eastern half of foreshore
28 Nov 1975	DMH (1989)	
16 Nov 1976	DMH (1989)	
14 Dec 1977	DMH (1989)	
6 Apr 1978	DMH (1989)	
11 Nov 1978	DMH (1989)	
25 Jan 1979	DMH (1989)	
23 Jan 1980	DMH (1989) Shore Coastal (2009)	
8 Dec 1980	DMH (1989)	
14 Dec 1981	DMH (1989)	
2 Dec 1982	DMH (1989)	
7 Dec 1983	DMH (1989)	
7 Dec 1985	DMH (1989) Shore Coastal (2009)	
31 Dec 1985	DMH (1989) Shore Coastal (2009)	
20 Feb 1987	DMH (1989)	
17 Dec 1987	DMH (1989)	
Nov 1991	Shore Coastal (2009)	
Jan 1996	Shore Coastal (2009)	
1999		
Mar 2000	Shore Coastal (2009)	
Dec 2004	Shore Coastal (2009)	
Jan 2008	Shore Coastal (2009)	

Appendix C Monthly Wind Speed & Direction Frequency Plots 1995-2013

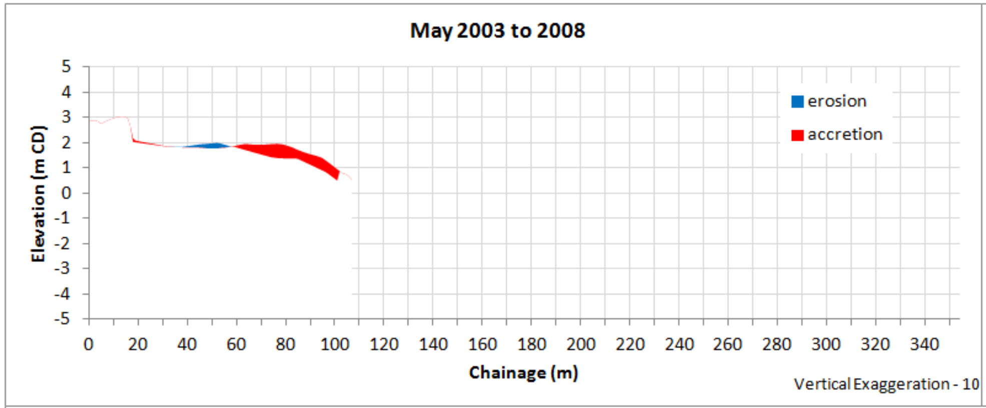


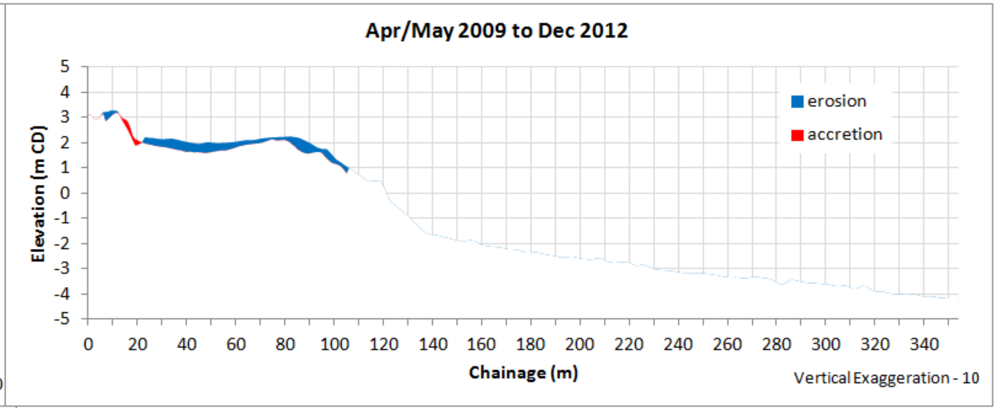
Appendix D Beach Profile Changes

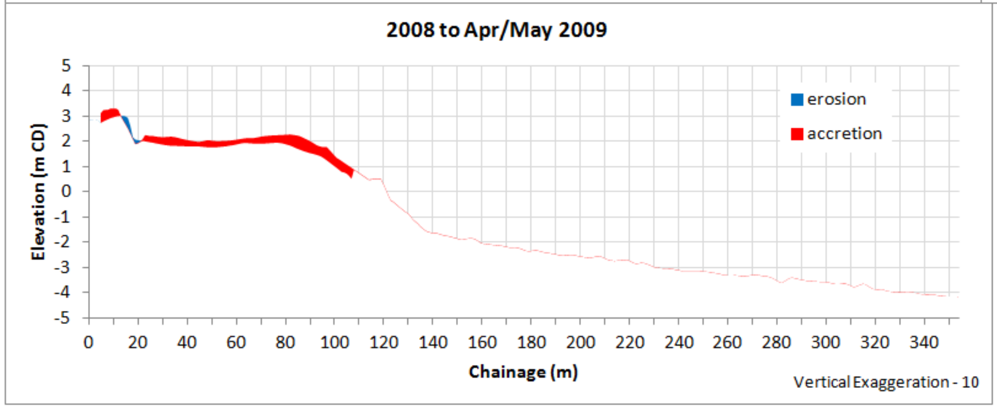
Profile 2 - Western Koombana Beach



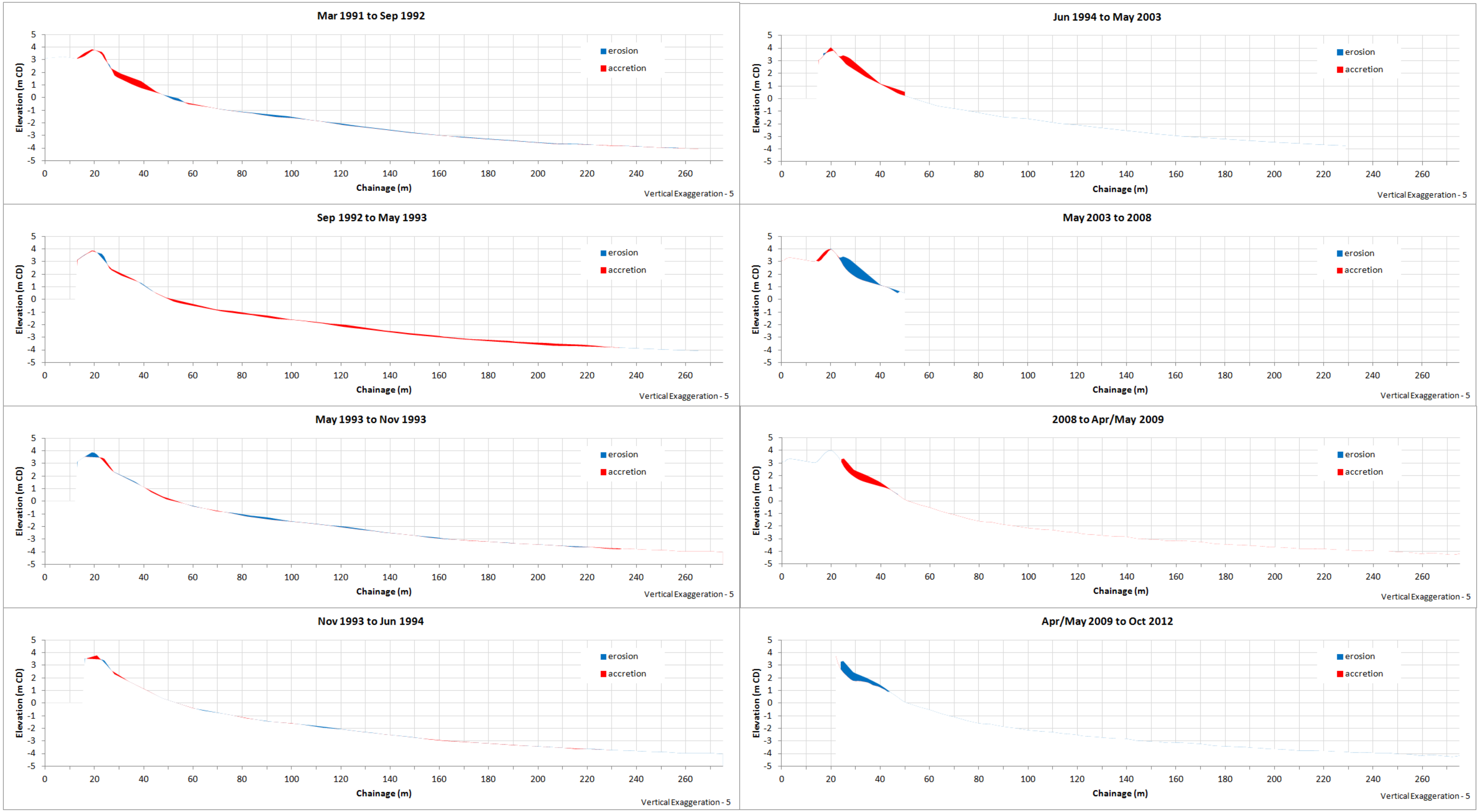
Profile 2 (continued)- Western Koombana Beach



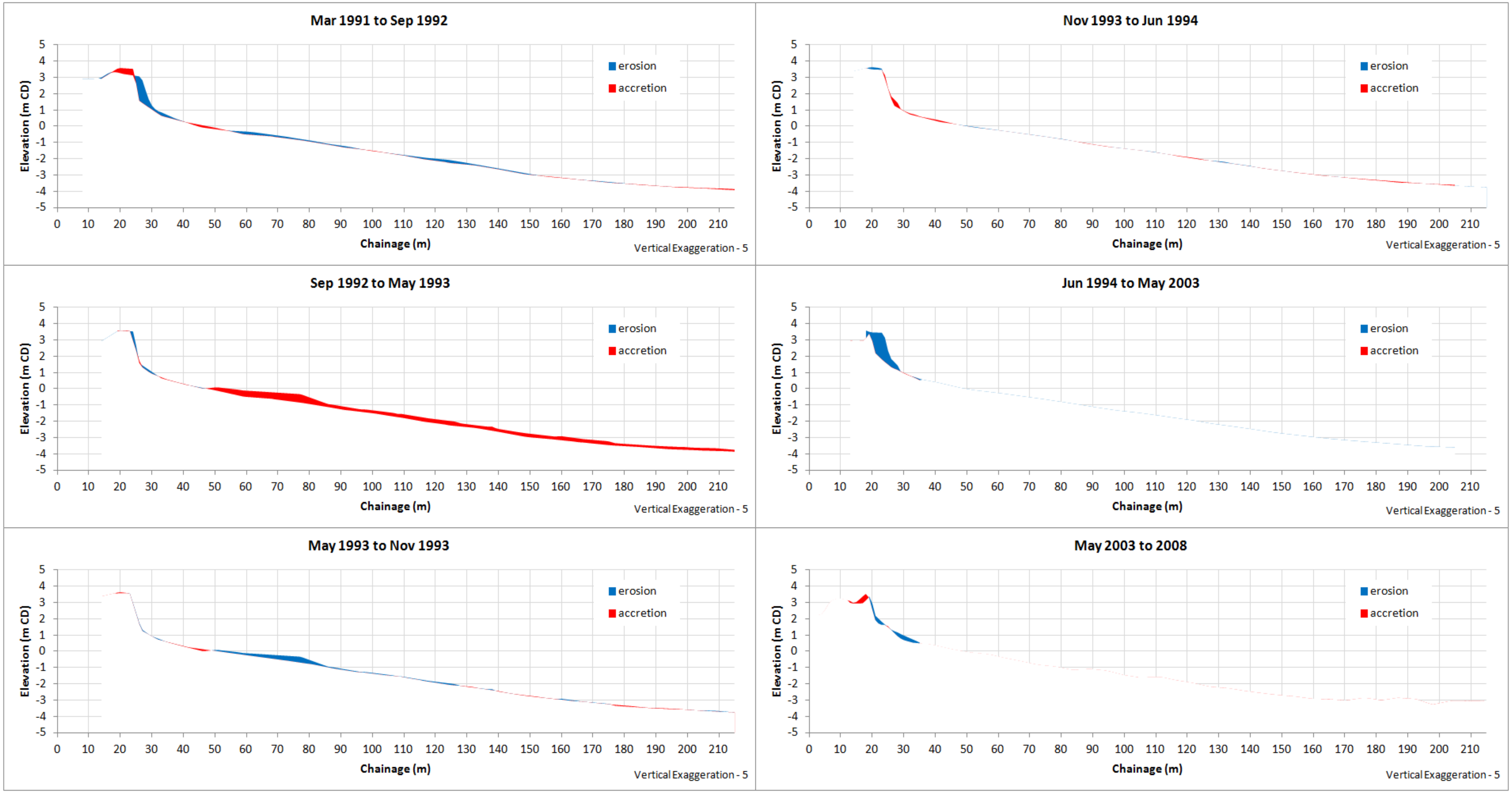




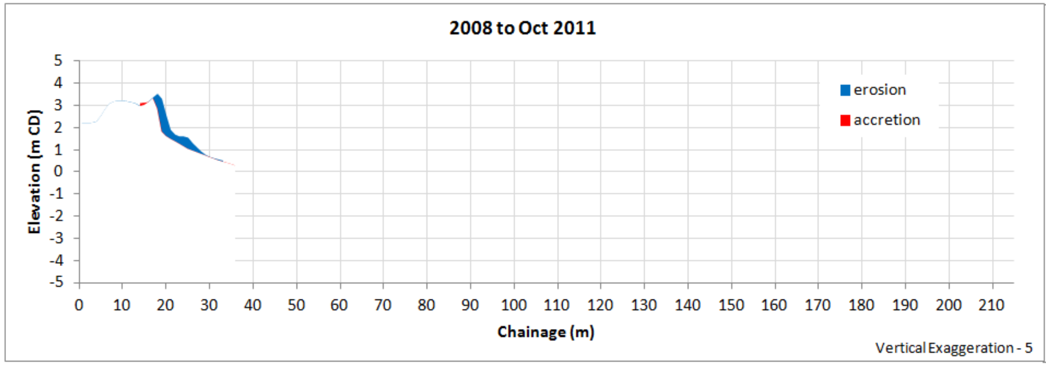
Profile 7 - Central Koombana Beach

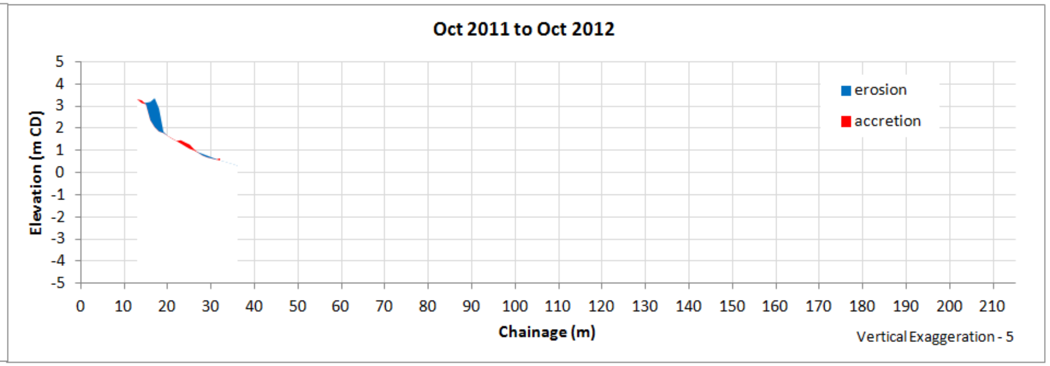


Profile 14 - Eastern Koombana Beach



Profile 14 (continued) - Eastern Koombana Beach



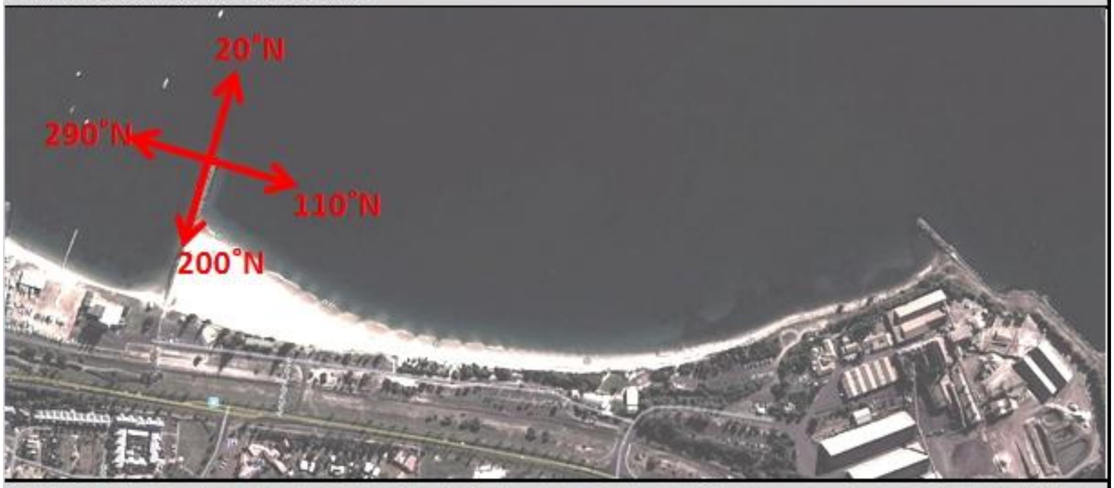


Appendix E Photo-monitoring Locations

Photo-Monitoring Details

Location ID	KB1
Location	End of Koombana Yacht Club Groyne
GPS Co-ordinates	Approx. 33° 19.096'S, 115° 38.687'E

Photo Location and Orientations



Baseline Photographs (18/02/2013 9:00am)

Photo Reconstruction Details

Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB2
Location	Middle of Koombana Yacht Club Groyne
GPS Co-ordinates	Approx. 33° 19.151'S, 115° 38.666'E

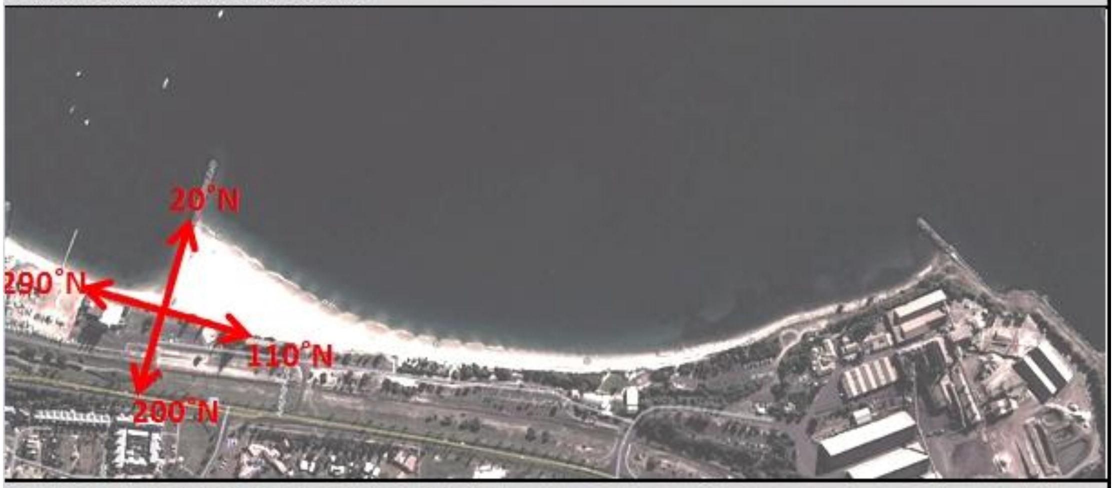
Photo Location and Orientations

Baseline Photographs (18/02/2013 9:00am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB3
Location	Start of Koombana Yacht Club Groyne
GPS Co-ordinates	Approx. 33° 19.187'S, 115° 38.651'E

Photo Location and Orientations



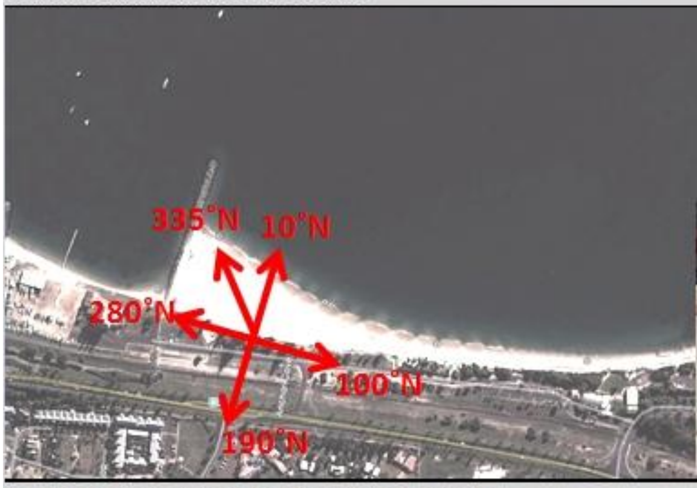
Baseline Photographs (18/02/2013 9:50am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details

Location ID	KB4
Location Note	Stairs to the east of Kiosk
GPS Co-ordinates	Approx. 33° 19.204'S, 115° 38.712'E

Photo Location and Orientations



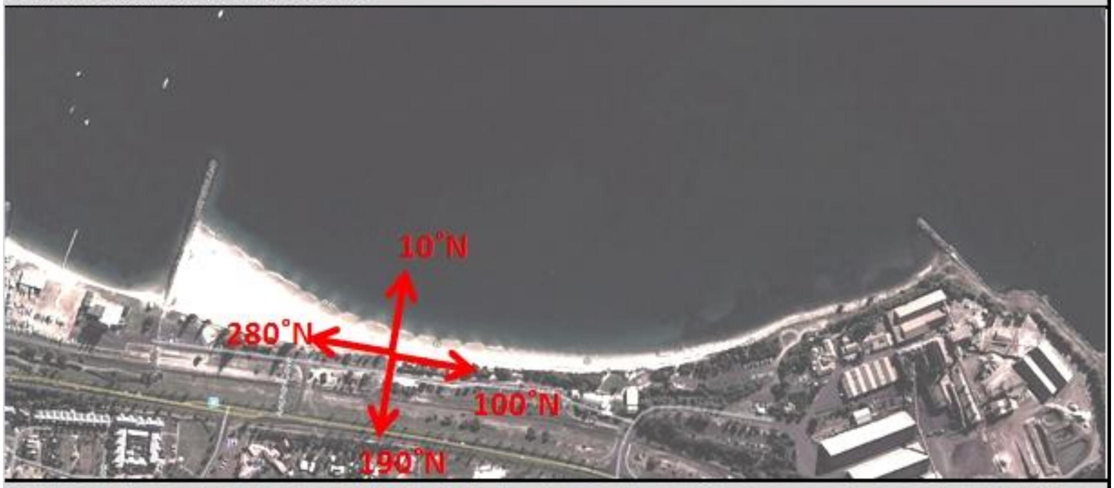
Baseline Photographs (18/02/2013 9:50am)

Photo Reconstruction Details

Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB5
Location Note	Lifeguard Tower
GPS Co-ordinates	Approx. 33° 19.219'S, 115° 38.823'E

Photo Location and Orientations

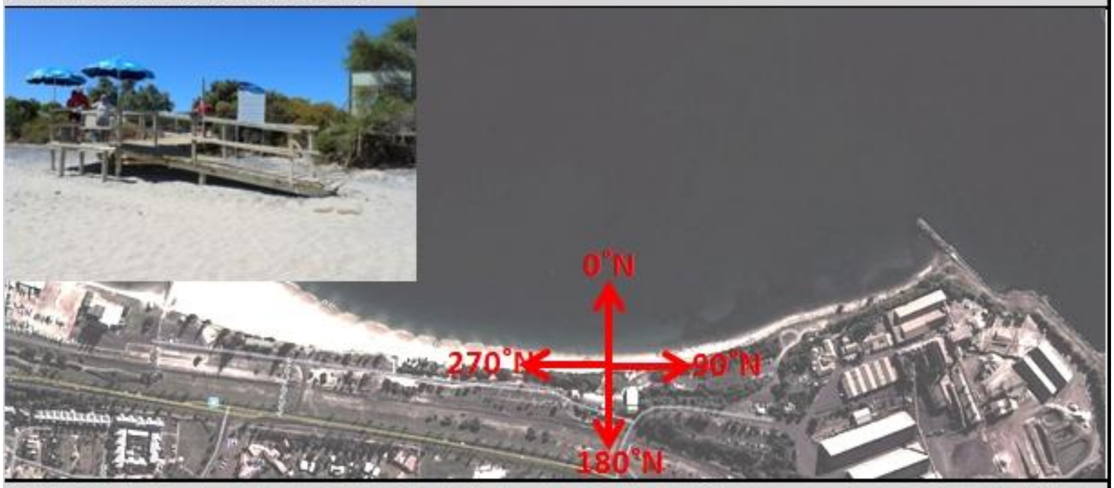


Baseline Photographs (18/02/2013 10:00am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB6
Location Note	Dolphin Discovery Centre Stairs
GPS Co-ordinates	Approx. 33° 19.228'S, 115° 38.994'E

Photo Location and Orientations

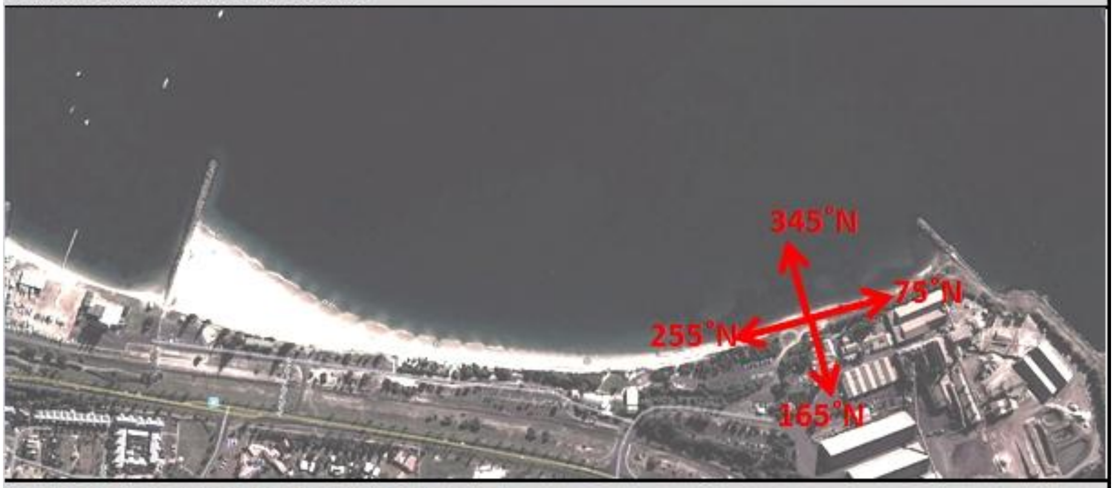


Baseline Photographs (18/02/2013 10:50am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB7
Location Note	Telecommunication Tower
GPS Co-ordinates	Approx. 33° 19.194'S, 115° 39.147'E

Photo Location and Orientations

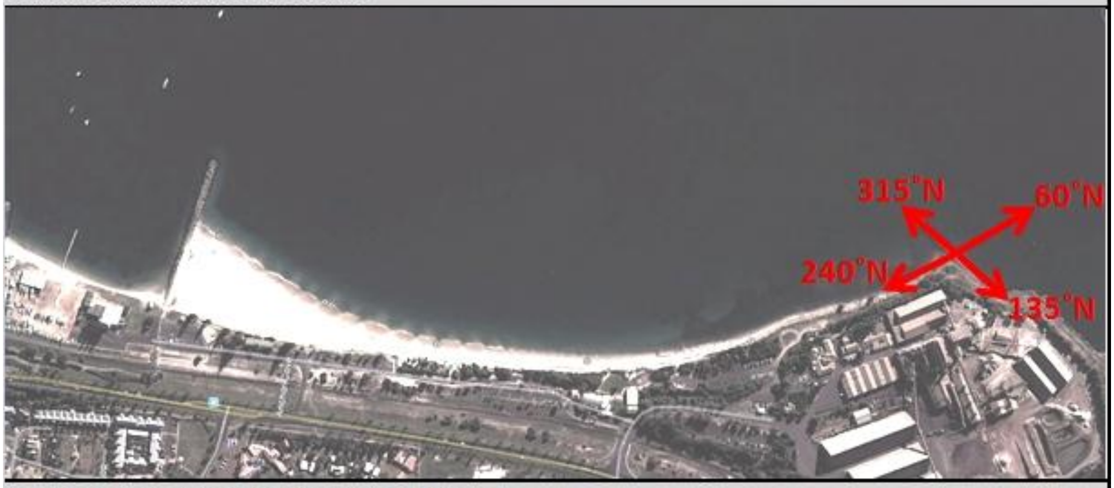


Baseline Photographs (18/02/2013 10:50am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Photo-Monitoring Details	
Location ID	KB8
Location Note	Busaco Point Groyne
GPS Co-ordinates	Approx. 33° 19.151'S, 115° 39.256'E

Photo Location and Orientations



Baseline Photographs (18/02/2013 11:00am)

Photo Reconstruction Details	
Date/Time	
Personel	
GPS Co-ordinates	
Weather	
Water Level	
Waves	
Observations	

Appendix F Coastal Management Options Table

Option	Effectiveness	Constructability	Impacts	Adaptive Capacity	Pros	Cons
Managed Retreat	The Dolphin Discovery Centre requires a beachfront location and relocation is not feasible. This therefore cannot be considered a long-term management option. However, there are opportunities through this central section of this beach to establish and maintain a 10m natural dune buffer for coastal resilience. -Point Busaco revetment required to provide erosion protection along the eastern foreshore.	N/A	**Environmental** -Loss of dune habitat/trees and vegetation **Social/Safety** -Reduced level of access may increased pressure on beach and carparks adjacent to the KYCG -Increased pressure on other Bunbury Beaches **Economic** -High cost of relocating facilities **Amenity** -Increased beach scarping/narrowing of the beach -Increased exposure of rocky material on the beaches in front of the Dolphin Discovery Centre	N/A	-Coastal protection required is minimised -Not disruptive to coastal processes	-Dolphin Discovery requires beachfront location, therefore can only provide a solution in the short-term
Renourishment using coarse sand sourced from the Outer Harbour Sand Traps	-Increased beach and dune widths along Koombana beach increases the capacity to 'resist' erosion, with coarser than existing material likely to result in slower net westerly transport of sediments -Point Busaco revetment to provide erosion protection along the eastern foreshore	-Sand to be trucked, then distributed using land-based plant.	**Environmental** -Noise and atmospheric pollution during works -Potential turbidity during works **Social/Safety** -Trucks impacting on road users, local businesses and residents -Works impacting on beach users and the Dolphin Discovery Centre (note: time of the year of works can reduce this) -Potential for increased landward sand drift -Potential for ongoing renourishment to increase bypassing of sediments into the Yacht Club -Following initial redistribution of sediments and should an extreme event cause visually obvious erosion features on the beach (i.e. scarping, narrowing of the beach) there may be a perspective that beach nourishment is a waste of taxpayers money and an endless expense. **Economic** -Relatively high ongoing costs **Amenity** -Beach profile steepening due to coarser sediment	-Highly flexible, beach monitoring surveys can determine problem areas and frequency and volumes of renourishment exercises -If westerly transport of sediments high, the construction of groynes could potentially reduce future costs.	-Potential for less sand bypassing into Outer Harbour, however any benefits are likely to be relatively short-lived. -Highly flexible -Suitable high quality sand source within close proximity -Soft solution, not aesthically intrusive -Increased beach amenity through reduced dune scarping and less exposed rocky material. -Relatively low capital costs	-Potential for ongoing renourishment to increase the bypassing of sediments into Koombana Yacht Club (Note: groynes currently have capacity to hold more sediment) -Relatively high ongoing costs with renourishment likely to be required every 3-5 years -Impacts of works on the community -Increased beachface slopes
Periodic renourishment using fine material sourced from the wide sandy western beach	-Increased beach and dune widths along Koombana beach increases the capacity to 'resist' erosion. -The tendency for the beach to align to a more stable configuration, together with the mobile fine sand that exists on the western beach suggests net westerly transport of nourished material is likely to be high. -Point Busaco revetment to provide erosion protection along the eastern foreshore	-Sand to be trucked, then distributed using land-based plant.	**Environmental** -Noise and atmospheric pollution during works -Potential turbidity during works **Social/Safety** -Works impacting on beach users of the popular western beach and Dolphin Discovery Centre which is likely to be require to close to the public during works (note: time of the year of works can reduce this) -Reduced beach widths at the highly popular western beach **Economic** -Relatively high ongoing costs **Amenity** -Reduced beach widths at the highly popular western beach	-Highly flexible, beach monitoring surveys can determine problem areas and frequency and volumes of renourishment exercises	-Highly flexible -Soft solution, not aesthically intrusive -Increased beach amenity through wider beaches, less exposed rock fragments and reduced scarping -Not disruptive to coastal processes -Relatively low capital cost	-High ongoing costs associated with the anticipated rapid westerly transport of nourished material is likely to result in the need for annual renourishment exercises -Impacts of works on beach users -Impacts of works on the community
Groynes and renourishment using coarse sand sourced from the Outer Harbour Sand Traps	-The groynes restrict the westerly transport renourishment reducing ongoing costs. -Point Busaco revetment to provide erosion protection along the eastern foreshore	-Groynes to be constructed using land based plant -Sand to be trucked, then distributed using land-based plant following groyne construction. -Groyne construction most suited to favourable tide and weather conditions typically occurring in spring.	**Environmental** -Noise and atmospheric pollution during works -Potential downdrift dune habitat and vegetation loss -Potential turbidity during works **Social/Safety** -Disruptive to swimmers and beach users. -Works will impact on road users, local businesses, residents and beach users -Section of the beach will be required to close during construction -Rock armoured structures can impact on beach access and pose a hazard to beach users (trips, falls) **Economic** -High capital cost **Amenity** -Hard engineering solution, aesthically intrusive. Note: Due to the low energy nature of Koombana Beach, there is potential for use of Geotextile Sand Containers (GSCs) which are less intrusive than armoured rock , however would result in reduced effectiveness and durability. -Increased beach scarping and narrowing of the beach by downdrift erosion	-Ongoing renourishment of the groyne field can be used to accommodate future loss of material. -Revetments extending from the landward end of the groynes can be used to provide protection to infrastructure from downdrift erosion.	-Widened beach updrift (in front of Dolphin Discovery Centre). -Fishing opportunities -Low ongoing costs with future renourishment exercises likely to be relatively small and low frequency ,while maintenance are typically 1-2% capital p.a. for rock armoured structures depending of the design and construction.	-Relatively high capital costs -Aesthetically intrusive -Potential for downdrift erosion and existing narrow buffers may require that the road that fronts the carpark to the east of the Dolphin Discovery Centre be relocated/protected
Headland and renourishment	-Reduction of erosive forcing in the lee of the breakwater due to protection from wave action. Sediment accumulates forming a 'tombolo' connecting the shore to the structure restricting the westing transport of renourishment during ambient conditions. During extreme condition the tombolo may erode and sediments may bypass. -Point Busaco revetment to provide erosion protection along the eastern foreshore	-Likely to require a proportion of renourishment prior to construction to build a work platform for land based plant. -Construction most suited to spring during favourable tide and weather conditions.	**Environmental** -Noise and atmospheric pollution during works -Potential downdrift dune habitat and vegetation loss -Potential turbidity during works **Social/Safety** -Disruptive to swimmers and beach users. -Works will impact on road users, local businesses, residents and beach users -Section of the beach will be required to close during construction -Rock armoured structures can pose a hazard to beach users (trips, falls) **Economic** -High capital cost **Amenity** -Hard engineering solution, aesthically intrusive. -Increased beach scarping and narrowing of the beach by downdrift erosion	Ongoing nourishment could be used to accommodate potential loss of material, including downdrift effects. -Breakwater/groyne can be extended landward if material bypassing to the west is high	-Widened beach in the lee of the groyne/breakwater - Low ongoing costs with future renourishment exercises likely to be relatively small and low frequency ,while maintenance are typically 1-2% capital p.a. for rock armoured structures. -Fishing opportunities	-Relatively high capital costs -Aesthetically intrusive -Potential for downdrift erosion -The potential for westerly transport of sediment remains during extreme events

Option	Effectiveness	Constructability	Impacts	Adaptive Capacity	Pros	Cons
Detached headland and renourishment	Reduction of erosive forcing in the lee of the breakwater due to the protection from wave action. Sediment accumulates forming a 'salient', however the structure remains disconnected from the shore. Westerly transport is reduced, however during extreme conditions material is likely to actively bypass. -Point Busaco revetment to provide erosion protection along the eastern foreshore	-Likely to require offshore construction using barges.	**Environmental** -Noise and atmospheric pollution during works -Potential downdrift dune habitat and vegetation loss -Potential turbidity during works **Social/Safety** -Disruptive to swimmers, beach users and boating. -Works will impact on road users, local businesses, residents and beach users -Section of the beach will be required to close during construction E**conomic** -High capital cost **Amenity** -Hard engineering solution, aesthically intrusive. -Potential for increased beach scarping and narrowing of the beach by downdrift erosion	-Ongoing nourishment could be used to accommodate potential future erosion, including downdrift effects.	-Widened beach in the lee of the groyne/breakwater -Reduced ongoing costs -Reduced frequency of damage to access stairs at the Dolphin Discovery Centre and beach fencing	-High capital costs -Aesthetically intrusive -Potential for downdrift erosion -The potential for westerly transport of sediment remains - Any form of maintenance to an offshore structure is an extremely difficult and costly exercise and therefore should be designed to minimise the need for maintenance.
Rock Revetment, Extend the Point Busaco Revetment by 450m	Erosion protection provided to the entire Koombana Beach.	-Revetment to be constructed using land based plant	**Environmental** -Noise and atmospheric pollution during works -Damage to dune and vegetation during works **Social/Safety** -Works impacting on beach users (note: time of the year of works can reduce this) -Section of the beach will be required to close during construction -Rock armoured structures can impact on beach access and pose a hazard to beach users (trips, falls) E**conomic** -high capital cost **Amenity** -Hard engineering solution, aesthically very intrusive. -Increased reflectivity may steepen and lower the beach level resulting in a narrower beach, delay of beach recovery following storms and an increase in sand transported offshore	-Due to ongoing and potential increase in the net westerly transport of material, ongoing renourishment or deepening of the revetment may be required to prevent undermining.	-Protection provided to the whole of Koombana Beach. -Reduced ongoing costs with maintenance typically 1-2% capital p.a. for rock armoured structures	-High capital costs -Aesthetically intrusive -Potential for ongoing sediment losses to undermine the revetment in the future. -Increased reflectivity may steepen and lower the beach level resulting in a narrower beach, delay of beach recovery following storms and an increase in sand transported offshore
Groynes, renourishment & dune stabilisation (no Point Busaco revetment) using coarse sand sourced from the Outer Harbour Sand Traps and dune stabilisation	-In order to provide an adequate storm buffer while minimise the introduction of sand drift issues, a stable dune of approx. 20m is required. -The groynes stabilise the beach by restrict westerly transport of material. The length of the western groyne is anticipated to be in the order of 100m.	-Construction most suited to spring during favourable tide and weather conditions.	**Environmental** -Noise and atmospheric pollution during works -Downdrift dune vegetation and habitat -Potential turbidity during works **Social/Safety** -Disruptive to swimmers and beach users. -Works will impact on road users, local businesses, residents and beach users -Section of the beach will be required to close during construction -Rock armoured structures can impact on beach access and pose a hazard to beach users (trips, falls) -Potential for increased sand drift along the eastern beach E**conomic** -High capital cost -Potential for increased sedimentation of the Inner Harbour channel **Amenity** -Hard engineering solution, aesthically intrusive. -Increased beach scarping and narrowing of the beach by downdrift erosion	-Renourishment of the groyne field can be used to accommodate future erosion -Revetments extending from the landward end of the groynes can be used to provide protection to infrastructure from downdrift erosion. .	-Widened beach updrift including in front of the Dolphin Discovery Centre). -Reduced ongoing costs with maintenance typically 1-2% capital p.a. for rock armoured structures -Fishing opportunities	-Relatively high capital costs -Aesthetically intrusive -Potential for downdrift erosion to impact on infrastructure to the east of the Dolphin Discovery Centre -Potential for increased sedimentation of the Inner Harbour channel -Potential for increased sand drift

Appendix G Drawings

Drawing No.	Title
Coastal Processes	
SE001-2-1	Koombana Beach Coastline Movements
SS-2484-1-1A	Koombana Beach - Colour Coded Differences: 1991 to 2009
Coastal Management Options	
SE001-2-1	Renourishment Option
SE001-2-2	Groynes and Renourishment Option