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CITY OF GERALDTON-GREENOUGH

Coastal Processes Study - Greys Beach to Sunset Beach

A Project of the Coastal Vulnerability and Risk Assessment Program

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City of Geraldton-Greenough
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Government of **Western Australia**
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PROJECT 301012-01151 - COASTAL PROCESSES STUDY - GREYS BEACH TO SUNSET BEACH

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EXECUTIVE SUMMARY

The City of Geraldton-Greenough commissioned WorleyParsons to undertake a coastal processes study, which can be used to support decision making on the most appropriate techniques to manage the coastal zone between Grey's Beach in the south to Sunset Beach in the north. The aim of the future coastal zone management is to maintain beach stability by implementing a preferred option for coastal protection. The preferred management option needs to address the observed erosion whilst maintaining amenities of the area and minimising the economic cost to the community.

The study approach is to:

- Assess coastal sediment transport in the region
- Discuss suitable coastal management methods
- Propose coastal protection options
- Propose recommendations for coastal management planning

Coastal Sediment Transport Assessment

The coastal dynamics of the region has been assessed following a review of historical studies in the area and an analysis of the sediment budget. This has resulted in a number of key observations, primarily as follows:

- The section form Point Moore to Glenfield Beach is dynamic with significant seasonal and annual variations
- Town beach is relatively stable but is exposed to crosshore transport during storm events;
- The section between the Batavia Coast Marina and the offshore breakwater has remained stable with replenishment. North of the breakwater, erosion is observed. A long stretch of shoreline (Mabel St to Chapman River) is relatively stable, slightly in accretion;
- In the absence of stabilisation work, Grey's Beach and Sunset Beach have been eroding.

Coastal Management Methods

In order to identify the developed areas likely to be at threat in the next 20 years, owing to the current shoreline evolution and predicted climate changes, a methodology based on the State Coastal Planning Policy (SCPP) has been applied to the study coastal zone. From the coastal vulnerability assessment for the period considered (up to 2030), the areas identified where erosion is likely to threaten existing assets include:

- The section North of the detached breakwater

- Sunset Beach
- South of Chapman River (Frederick Street)
- Grey's Beach

The areas requiring Active Beach Monitoring to detect future threat to the existing development are:

- The section between Elphick Avenue and Champion Bay Rise
- The section in the area of Morris Street and Cecily Street.
- Point Moore (along the Car Park)
- Pages Beach
- Town Beach

Over a longer timescale, from the coastal vulnerability assessment to 2110, the whole coastline is predicted to be at threat in the next 100 years. Climate change and sea level rise have the very real potential to have a significant impact on the Geraldton coast, affecting natural and cultural values, infrastructure and built assets on private and public land. The response to climate change and sea level rise needs to be both pro-active and reactive which involves actually responding to changes as they occur.

In order to select the most appropriate coastal protection solution(s) for the area requiring beach erosion management, a review of existing options has been proposed ranging from “Do Nothing” or “Managed Recession” options to Beach Nourishment, Buried Seawall, Groynes, Detached Breakwater Artificial Reefs or Beach Drainage System.

Coastal Protection Options

At Geraldton, beach renourishment in combination with supplementary coastal structures such as groyne or buried seawalls to reduce the impacts of erosion processes and to provide a last line of defence are all plausible solutions.

Coastal protection solutions have a significant impact on the social amenity of the beaches. As such, the selection of an appropriate solution must include contribution from the local community. It is also important that this process includes accurate technical and descriptive presentation of the behaviour of the coastline in response to various solutions. As part of this study, the potential range of coastal protection scenarios has been the subject of public presentation and consultation process. Main outcomes from this workshop relate that the local community have preferences as follows:

- To adopt a Managed Recession approach or Beach Nourishment options;

- To avoid and/or minimise the construction of hard structures other than for the section north of the detached breakwater.

A high level cost estimate and an estimate of Net Present Values (NPV) for different coastal protection options revealed that along:

- The Northern Beaches a coastal management strategy has to be maintained. The values of coastal assets to be protected justify the implementation of a coastal structure based on a buried seawall combined with a groyne and sand nourishment.
- Sunset Beach, the “Managed Recession” option appears as expensive as a coastal protection structure based on buried seawall combined with beach nourishment.
- South of Chapman River, a buried seawall would be more economical than a “Do Nothing” option while along the Grey’s Beach, a “Do Nothing” option would be the most economical.

After evaluation of coastal protection options, the use of a buried seawall with ongoing nourishment and dune management offers a balanced solution with a high level of aesthetic outcome and protection of coastal infrastructure; it would appear to meet most of the objectives of the working group.

Recommendations for Coastal Management Planning

To maintain the targeted profile, an Annual Management Programme is suggested, involving Beach Monitoring and an Active Beach Nourishment Programme through improvement of the current Sand Bypassing Programme.

The implementation of coastal structures along specific areas can be made step by step. Feedback from the Beach Monitoring Programme would allow assessment of the coastal protection influence and adjustment of the Annual Management Programme accordingly. This will allow the City of Geraldton-Greenough to maintain the targeted programme, and implement structures in the medium term in line with these refined observations.

This approach also recognises the importance that once coastal structures are selected they do become difficult to vary and therefore refinement of the preferred type, extent and shape should be based on longer term monitoring and measurement. In fact, the refinement of the replenishment programme may reduce dramatically the degree of the structures required, making the deferment of the implementation of the structure of greater value whilst replenishment is optimised in line with the short term programme.

1. INTRODUCTION & BACKGROUND

The City of Geraldton-Greenough commissioned WorleyParsons to undertake a coastal processes study, which can be used to support decision making on the most appropriate techniques to manage the coastal zone between Grey's Beach in the south to Sunset Beach in the north.

This area of coastline is a dynamic area where coastal processes are a result of various physical phenomena with waves being an important key driver. Longshore currents are generated by the incident breaking waves and are responsible for the present and ongoing shoreline evolution. The implementation of coastal protection solutions requires a sound understanding of the regional and local coastal processes and this study works to:

- Quantify the coastal processes;
- Identify and assess protection options.

1.1 Key Partners

The key partners are the contributing organisations overseeing implementation of Coastal Management Planning for the study area:

- City of Geraldton-Greenough (CGG)
- Geraldton Port Authority (GPA)
- Department of Transport (DoT)
- Northern Agricultural Catchments Council (NACC)

1.2 Study Area

The area along the Geraldton-Greenough shoreline is sheltered by a series of offshore reefs as shown in Figure 1-1. The presence of these reefs implies the occurrence of complex wave transformation processes nearshore such as wave breaking, diffraction and refraction and creation of nearshore currents driving the sediment transport processes. At a large temporal and spatial scale, these reefs are responsible for the creation of the Geraldton tombolo (Point Moore).

About 9 kilometres south of Geraldton and just north of the Greenough River mouth, a series of inshore reefs works to reduce the magnitude of the longshore sediment transport. North of Champion Bay (about 10 kilometres north of Geraldton), the tombolo shaped shoreline of Drummond is also sheltered by inshore reefs. This section of shoreline from the Greenough River mouth to Drummond (as shown in Figure 1-1) is therefore likely to belong to a large-scale sediment cell. Within this cell, two secondary cells can be defined. The southern cell extends from the Greenough River mouth to Point Moore. The northern cell extends from Point Moore to Drummond. The Greenough River and the Chapman River act as sources of sediment in each cell. These two cells exchange sediment through the boundary located at Point Moore, between Grey's Beach and Pages Beach.

The study area extends from Grey's Beach to Sunset Beach and includes Town Beach and the Northern Beaches. Figure 1-2 presents this area.

1.3 Beaches within the Study Area

Grey's beach is located along the John Willcock Link, on the Southern part of the Geraldton tombolo. It consists of a sandy beach backed by a small dune. The sea floor is mainly sandy with some patches of seagrass.

Point Moore and Explosive Beach form the western part of the Geraldton tombolo. The area is bounded inland by John Willcock Link and includes coastal reserves. The nearshore area is a complex system of exposed reefs and deeper channels under 0 to 10 metres of water. The beaches are large sandy beaches.

Pages Beach extends from Point Moore to the southern breakwater of the Geraldton Port and consists of a relatively flat sandy beach. The sea floor is mainly sandy with some patches of seagrass.

The Town Beach section consists of an artificial sandy beach with a gentle slope towards the waterline and a sandy seafloor. This section has recently been redeveloped to offer a recreational area along the foreshore.

North of the Batavia Coast Marina, the Northern beaches are short sandy beaches with a sea floor mainly composed of reefs with patches of sand or seagrass. The beaches are backed by low dunes of around 1 to 4 metres height and/or are bordered by a thin vegetation line in front of man-made areas including paths, shelters and grassed areas.

North of the Chapman River, Sunset Beach is characterized by a 10 to 15 metre wide sandy beach which is backed by dunes of around 6 to 8 metres height. The seafloor is characterized by reefs covered by scattered seagrass and patches of sand.

1.4 Background

The Point Moore reef system has caused the formation of the Geraldton Tombolo. The reefs, together with the expansion of the Geraldton Port over the last 60 years and the development of the Batavia Coast Marina, are responsible for driving significant movement of sand along the coast of Champion Bay. During recent years, acute erosion in certain areas (as shown in Figure A) has become more pronounced and frequent. These areas can become quickly degraded especially during episodic winter storms.

Historic movement of the coastline since 1942 was assessed using shoreline positions obtained from aerial photos. As the waterline is dependent on the oceanographic conditions (wave height and wave setup, tide level, etc) it is recommended to use the vegetation line as a reference for the shoreline position (State Coastal Planning Policy 2.6). This method, using controlled photogrammetry, is limited in accuracy (+/- 5 meters). However, the general trend of the shoreline evolution can be obtained from analysis of the data over suitably long time periods. It is feasible to estimate the rate of evolution, especially along the eroding sections of coast. The variations of sediment volume of the beaches can also be evaluated in order to assess the sediment transport along the coast.

Numerical modelling studies were undertaken by CES (2001a) to evaluate the impact of the Port Enhancement Project (PEP). The wave propagation within Champion Bay was simulated for various cases and the sediment transport estimated using the wave characteristics along the coast. The aim was to determine the effects of deepening and widening the shipping channel and extending the northern breakwater on the current sediment dynamics of the bay. The study concluded that the PEP would result in more wave energy striking the coast from the west at some 100 to 200 metres north of the Batavia Coast Marina and at the beach south of Chapman River. The presence of the port structure would contribute to a deficit of sand on the northern beaches. The ongoing erosion of these beaches has warranted the need for some intervention and the creation of the proposed framework for coastal protection.

1.5 Data Available and the Northern Beaches Stabilisation Programme

The Northern Beaches Stabilisation Programme (NBSP) was developed in 2004 through agreement from a joint agency working group with representation from the City of Geraldton, Geraldton Port Authority, Department for Planning and Infrastructure and the Department of Environment with technical support from MP Rogers and Associates and URS Australia. It aims to provide a long term stable foreshore through replacing the natural littoral drift of sand blocked by the Port and the Batavia Coast Marina structures via sand bypassing processes and stabilisation works. Requirements from the NBSP include, in particular, beach monitoring, referred as Quantum Surveys hereinafter.

This study aims to incorporate the latest data (to April 2010) made available by the Northern Beaches Stabilisation Programme. This includes historical shoreline position from aerial photos and survey data. Shoreline movements from recent years provide information on sediment transport for Grey's Beach, Point Moore, Explosive Beach and north of the Chapman River while the survey data provides information on sediment transport and volume evolution for Pages Beach, Town Beach and Northern Beaches. The period covered by this survey is from 2004 to 2009.

The study shoreline has been divided into sections for the purposes of this study. These sections refer to the characteristics of the shoreline evolution and/or the locations of the sand removal/nourishment. Table 1.1 presents the link between the sections and the transects. Transect names refer to the Quantum Survey denomination. Figure 1-2 presents the beach section areas and Figure B-1 the related transects.

For Pages Beach, transects P5 and P6 or section SP2 correspond to the area from which the sand is generally removed for sand bypassing purposes.

For Town Beach, the three sections correspond to the three stretches of shoreline between the groynes.

For the Northern Beaches, section SN1 extends from the northern breakwater of the Batavia Coast Marina (BCM) to the offshore breakwater, 400m northward. This section corresponds to Marina Beach. The northern limit of section SN2 corresponds to Mabel Street. This section corresponds to Beresford Beach. Section SN3 extends northward up to the Chapman River and corresponds to St Georges and Bluff Point Beach.

Table 1.1 Beach Sections and Beach Transects Denominations

Beach	Section	Transect (Quantum Surveys)
Pages Beach	Section SP1	Transects P1 to P4
	Section SP2	Transects P5 & P6
Town Beach	Section ST1	Transects T1 to T3
	Section ST2	Transects T4 to T6
	Section ST3	Transects T7 to T9
Northern Beaches	Section SN1: Marina Beach	Transects N1 to N6
	Section SN2: Beresford Beach	Transects N7 to N13
	Section SN3: Bluff Point Beach and St Georges Beach	Transects N14 to N23

1.6 Objectives of the Report

The requirements by the City of Geraldton-Greenough (CGG) for coastal zone management (Figure 1-3) are as follows:

- **Glenfield Beach and North Sunset Beach**: Maintain beach stability and amenity;
- **Sunset Beach**: Decide on preferred option for coastal management in view of the observed erosion to maintain amenity of the area while minimising the economic cost to the community;
- **St Georges Beach and Bluff Point Beach**: Maintain beach stability and amenity;
- **Beresford Beach and Marina Beach**: Maintain swimming beach and beach amenity north of Batavia Coast Marina and decide on preferred option for coastal management in view of the observed erosion north of breakwater while minimising the economic cost to the community;

- **Town Beach:** Maintain swimming beach and beach amenity and decide on preferred option for coastal management in view of the observed erosion while minimising the economic cost to the community;
- **Pages Beach:** Maintain beach stability and beach amenity and sediment bypassing source;
- **Explosive Beach and Point Moore:** Maintain beach stability and beach amenity;
- **Grey's Beach:** Decide on preferred option for coastal management in view of the observed erosion to maintain amenity of the area while minimising the economic cost to the community.

This study aims to contribute to a better understanding of the coastal processes in order to propose adequate coastal management solutions according to the CGG objectives.

The performance and effectiveness of various coastal management solutions have been discussed to best support decision making on the most appropriate techniques to manage the coastal zone between Grey's Beach to Sunset Beach. This report addresses the areas as identified below to support the decision making processes:

- Coastal Sediment Transport Assessment: using information from a review of the previous studies, a desktop study has been undertaken based on available data and implementing a numerical study to assess the longshore sediment transport, the sediment budget along the Geraldton Coastline has been estimated;

- Coastal Management Methods: after considering the impact of recent foreshore development and current coastal managing policy in Geraldton, and assessing the coastal setback distances for a 20 year timeframe and a 100 year timeframe, a review of available coastal protection options has been carried out;

- Discussion on Coastal Protection Options: Results of the Coastal Sediment Transport Assessment and outcomes from the Coastal Management Methods have been discussed to propose adequate coastal protection options. A workshop was held on 24 March 2010 in Geraldton to present these options to seek public comments and feedback on preferred solutions. The outcomes from these presentations were the basis of the assessment of the social acceptance of the various options;

- Recommendations for Coastal Management Planning: recommendations have been presented on both short term and medium term consideration in order to implement the current coastal management planning of the Geraldton shoreline.

2. COASTAL SEDIMENT TRANSPORT ASSESSMENT

2.1 Contribution from Other Studies

PAGES BEACH

Existing studies indicate that Pages Beach has been significantly in accretion since 1942. The coastal vegetation line has moved seaward by more than 100 metres over the past 50 years, depositing a large amount of sediment south of the Harbour.

There have been investigations into the sediment dynamics of the coast from the Port to Separation Point; MRA (1994 and 1996) indicate that in the period between 1942 and 1992 there has been about 20,000 to 30,000 m^3/year (cubic metres per year) of sand trapped in the area from the Port to Separation Point. This sand appears to have been transported from the beaches and reefs to the south, as well as some derived from the seagrass meadows and on the reefs in the area. MRA (2001) has estimated that the annual average rate of accumulation varies from about 18,000 m^3/year to 28,000 m^3/year.

In recent times, the Geraldton Port Authority has extracted some of the accumulated sand at Pages Beach for use as reclamation and nourishment of the Northern Beaches.

NORTHERN BEACHES

Studies relating to the Northern Beaches indicate that this stretch of shoreline from the Batavia Coast Marina to the Chapman River has been relatively stable or slightly in erosion since 1942. However, it has been demonstrated that implementation of coastal development has influenced the sediment transport along Champion Bay. These structures are likely to have limited the natural rate of sand feeding the Northern Beaches to about 10,000 m^3/year to 15,000 m^3/year (CES 2001) and are believed to be responsible of the increase of erosion observed recently at certain locations (as shown in Figure A)

Over recent years, a large amount of sand was placed along the northern beaches. For the period 1991 to 2001, 30,000 m^3 to 50,000 m^3 of sand (MRA, 2001) were used for renourishment. This contributed to maintain the shoreline at a relatively stable position.

As part of the Geraldton Northern Foreshore Stabilisation and Enhancement Strategy, a nourishment of 89,000 m^3 of sand was undertaken in 2004. This sand was sourced from the Southern Transport Corridor project (STC sand). A survey of the nourished beach was carried out during the following four months and an average northward sediment transport of 50,000 m^3/year has been estimated (Bailey, 2005)

In late 2005, a detached breakwater located about 400m north of BCM was constructed in order to reduce the sediment transport, protect the foreshore from storm events and stabilise the shoreline.

North of the Chapman River

The studies of the aerial photos have shown that Sunset Beach, located north of the Chapman River, has experienced significant erosion since 1942. MRA (2003) estimated the rate of shoreline recession along Sunset Beach to be 0.5 m/year to 0.69 m/year on average. However, most of the erosion activity occurred between 1942 and 1980.

North of Sunset Beach the shoreline has been relatively stable or in accretion. From 1988 to 2000, the rate of accretion has been estimated to be 0.5 m/year.

Dynamics of the Chapman River Mouth

The Chapman River mouth generally has a sand spit blocking the river from the ocean. The river flow discharge varies annually. The mouth is likely to open every year between May and August (MRA, 2003). At the time of opening, it has been estimated that between 3,000 m^3/year and 16,000 m^3/year of sand can be lost. This loss of sand from the Chapman River mouth is likely to impact on the adjacent shoreline. The sand transported offshore is deposited and forms a sand bar and a quantity of sand is likely to be redistributed along the shoreline by the longshore transport. Both phenomena contribute to the Chapman river mouth closure. The amount of sediment likely to be lost during a flooding event has been estimated to be 13,000 m^3/year on average. However, the quantity of sand redistributed along the coast remains unknown.

Table 2.1 presents the records of the annual total stream discharge volume of the Chapman River for several years. In 2006 and 2007 the discharge was almost nil. For the other years, this discharge is relatively constant with an average of about 4,000 Megalitres per year.

Table 2.1 Stream Discharge Volume for the Chapman River (Utakarra station, source Department of Water)

Year	Annual total (MegaLitres per year)
2004	3,125
2005	4,201
2006	125
2007	30
2008	5,013

2.2 Desktop Study

2.2.1 Sand Bypassing Programme

As part of the Northern Beaches Stabilisation Programme (NBSP), the Geraldton Port Authority (GPA) has to provide a certain amount of beach sand for nourishment purposes in order to maintain long-term shoreline stability. This sand is primarily sourced at the extreme eastern end of Pages Beach. The GPA has to contribute an annual quantity of 12,500 banked m^3/year of sand.

Table C.1 presents the origin, destination and volume of sand, which has been used for sand nourishment since 2003 (source: Geraldton Port Authority – June 2010). Table 2.2, Table 2.3 and Table 2.4 show the volumes of sand respectively removed along Pages Beach and distributed along Town Beach and the Northern Beaches. Periods have been defined to correspond with the date the beach surveys were carried out.

Since July 2003, the GPA has contributed to the sand bypassing program by extracting around 16,000 m^3/year on average from Pages Beach (10,500 m^3 since March 2004) and depositing around and 750 m^3/year on average along Town Beach (800 m^3 since March 2004) and around 15,000 m^3/year on average along the Northern Beaches (11,500 m^3 since March 2004). The remaining quantities of extracted sand were used for new reclaim access tracks and the additional quantities of deposited sand were STC sand.

Table 2.2 Sand Extraction along Pages Beach (volumes in m^3)

Period \ Position	07/2003 03/2004	03/2004 09/2004	09/2004 03/2005	03/2005 09/2005	09/2005 03/2006	03/2006 09/2006	09/2006 09/2007	09/2007 11/2009	11/2009 05/2010	07/2003 05/2010
Section SP2	25,836	848	4,356	-	-	14,328	8,658	25,944	13,207	93,177

Table 2.3 Sand Distributed along Town Beach (volumes in m^3)

Period \ Position	07/2003 03/2004	03/2004 09/2004	09/2004 03/2005	03/2005 09/2005	09/2005 03/2006	03/2006 09/2006	09/2006 09/2007	09/2007 11/2009	11/2009 05/2010	07/2003 05/2010
Section ST2	-	-	-	-	-	-	-	4290	-	4290

Table 2.4 Sand Distributed along Northern Beaches (volumes in m^3)

Period \ Position	07/2003 03/2004	03/2004 09/2004	09/2004 03/2005	03/2005 09/2005	09/2005 03/2006	03/2006 09/2006	09/2006 09/2007	09/2007 11/2009	11/2009 05/2010	07/2003 05/2010
Section SN1	10,784	2,790	4,356	-	-	14,328	8,658	24,733	6,381	72,030
Section SN2	5,608	2,790	-	-	-	-	-	-	6,826	15,224
Section SN3	244	283	-	-	-	-	-	2,110	-	2,637
Total	16,636	5,863	4,356	-	-	14,328	8,658	26,843	13,207	89,891

2.2.2 Beach Profile Monitoring

Since March 2004 Quantum Surveys Pty Ltd has been undertaking cross section surveys of the shoreline from Pages Beach north to the Chapman River mouth, including Town Beach. This involves a series of surveyed lines starting from above the beach and extending into the water to a level of approximately –1 m CD (Geraldton Port Datum). The surveys have been conducted on a bi annual basis for the period March 2004 to September 2006. Two additional surveys were carried out in September 2007 and November 2009. The surveys have been undertaken generally one to two weeks after beach nourishment. Selected survey results are presented in Appendix B. Figure B-1 shows the location of the profiles at which the surveys have been performed.

Data processing of these surveys has been undertaken in order to evaluate the evolution of the shoreline of the study area. The variations in volume (compared to the volume reference of March 2004) have been calculated for each surveyed profile. Results of this analysis are presented for Pages Beach, Town Beach and the Northern Beaches.

PAGES BEACH

Surveys have been undertaken along six profiles, referred as P1 to P6 in Figure B-1. The beach has been significantly in accretion over the last five years (2004 to 2009). The rate of accretion is relatively consistent along the beach; the surveys showing a similar behaviour of the beach for each profile. As an example, Figure B-2 presents a plot of the data along profile P5.

Analysis of the volume evolution, compared to the volume in March 2004, is presented in Figure 2-1. Section SP1 (blue line) has been in constant accretion since 2004. Although the sand used for the sand bypassing has been removed from Section SP2, the volume of this section of Pages Beach (red line) has been increasing for the past 5 years, except for the period March to September 2005. Overall, the total volume of Pages Beach has increased by about 33,000 m^3.

The total volume of sand extracted from section SP2 since March 2004 is about 65,000 m^3 or, on average, 10,500 m^3/year. The results of this survey data analysis indicate that the volume of sand extracted each year from Pages Beach could be increased up to 17,000 m^3/year and has still no effect in the stability of Pages beach.

TOWN BEACH

Surveys have been undertaken along nine profiles, referred to as T1 to T9 in Figure B-1. Three sections were defined.

After a period of volume reduction the beach has been relatively stable over the last 3 years (2006 to 2009). The surveys show a similar behaviour of the beach for each profile. As an example, Figure B-3 presents a plot of the data along profile T6.

Analysis of the volume evolution, compared to the volume in March 2004, is presented in Figure 2-2. The three sections ST1, ST2 and ST3, represented by the blue, red and grey line respectively, have been stable since September 2005 after adjustment of the beach profiles. No significant change in volume can be noticed since then. This reveals the absence of longshore sediment transport and exchange between the three sections in stability.

The total reduction of sand over 5 years is about 14,800 m^3. However since September 2005, the reduction of sand is about 2,400 m^3. On average, the net rate of erosion is about 1,500 m^3/year.

In 2009, sand nourishment of 4,290 m^3 was provided to regenerate a buffer area against storm erosion. Information from the CGG indicates that beach nourishment has been undertaken in the recent years. In 2009, an additional volume of about 5,000 m^3 of sand was used for nourishment. While the three groynes were designed to stabilize the artificial beach of Town Beach, unanticipated rip cells transporting sediment offshore could be at the origin of this lose of sand. The Quantum surveys do not reveal the presence of offshore bars but these surveys only extend to a maximum depth of 1 metre.

NORTHERN BEACHES

Surveys have been undertaken since 2004 along 23 profiles by Quantum Surveys, referred to as N1 to N23 in Figure B-1. The shoreline has been divided into three sections (Figure 1-2). It is reminded that section SN1 corresponds to Marina Beach, section SN2 corresponds to Beresford Beach and section SN3 corresponds to St Georges and Bluff Point Beach.

Figure 2-3 presents the evolution of the beach volume for each of the three sections compared to the beach volume in March 2004.

The shoreline evolution for Section SN1 is represented by the blue line in Figure 2-3. This section (from BCM to the offshore breakwater) in 2004 held a reference volume of 89,000 m^3 and since then the beach has been regularly eroding until the construction of the offshore breakwater in October

2005. In addition to this coastal structure, sand nourishments have been undertaken in order to retain the beach width; the total amount of sediment deposited until November 2009 is about 47,000 m^3. Such efforts have enabled maintaining the profiles to the current position and the beach has remained relatively stable since (small variation of 2000 m^3/year).

The volume variations of the second section SN2 (from the breakwater to Mabel Street) is presented in Figure 2-3 (red line). The shoreline had been in accretion for the period March 2004 to September 2006. This is explained by a northward longshore transport of sediment from the section SN1. It was estimated that more than 38,000 m^3 of sand was shifted north per year (Figure 2-5). This value corresponds to the 50,000 m^3/year estimated from another survey (Bailey, 2005). After the construction of the offshore breakwater, the amount of sand transported along the coast was reduced and the volume of the beach has been continuously decreasing. Despite nourishment (about 9,000 m^3 of sand over five years), the beach is now at the same position as in 2004; for this section the beach profiles in November 2009 match the beach profile in March 2004. However, the volume variations since September 2007 have been relatively small (decrease of 2,400 m^3/year).

Section SN3 extends northward up to the Chapman River. The green line in Figure 2-3 represents its volume variations. This section had been accreting irregularly since September 2004 to reach a volume increase of 54,000 m^3 in September 2007. This volume increase is likely to be due to a northward littoral drift. The volume has been slightly decreasing (1,000 m^3/year) despite a sand nourishment along the profiles 13 and 14. Moreover, the data shows seasonal variations for the period 2004 to 2006: the volume increases in winter and decreases in summer (Figure 2-5).

The variations of the total volume of sand along the three sections of the Northern Beaches are shown in Figure 2-3 (black line). The quantity of sand lost along the Northern Beaches was estimated to be about 20,000 m^3 since September 2004 despite 60,000 m^3 of sand deposed for nourishment during the same period (pink line in Figure 2-3).

The Mean Sea Level lines (MSL, 0.847m AHD) were extracted from the profile survey data and are presented in Figure 2-4. The blue line and the red line represent the MSL for March 2004 and November 2009 respectively. The graph illustrates the impact of the offshore breakwater on the beach stabilisation by sheltering the beach and reducing the longshore sediment transport in section SN1. However, a strong sediment transport has affected the beach in Section SN2. One can observe a northward displacement of the volume of sand just north of the breakwater.

The sand discharged from the Chapman River during a flooding event in winter is likely to be at the origin of the accretion observed along the northern part of the section SN3. Due to a lack of information relative to the sediment transport processes during a flooding event, this assumption can not be confirmed at this stage.

Figure 2-5 presents an estimate of the sediment transport across the sections. Positive values are for northward transport. The blue line and the red line represent the sediment transport across sections SN1 and SN2 and across section SN2 and SN3 respectively. Just after the nourishment of 89,000 m^3 in 2004, an important quantity of sand had been transported northward. It was calculated that an average of 30,000 m^3/year to 40,000 m^3/year has drifted from section SN1 to SN2 and has probably deposited along SN2. Since the construction of the offshore breakwater, the volume transported has been reduced to 5,000 m^3/year to 19,000 m^3/year. This range of values is consistent with the predicted volume of 10,000 m^3/year for which the breakwater was designed (MRA, 2002 and WP, 2004). However, because of the breakwater's presence, the volume of sediment transported between the sections SN2 and SN3 increased between September 2005 and September 2006 from 13,000 m^3/year to 36,000 m^3/year. This rate rapidly decreased down to 16,000 m^3/year as the quantity of sediment available along the beach rapidly decreased.

The volume of sediment crossing the boundaries of the section SN3 is indicated in Figure 2-5 (grey dashed line). There is an important seasonal variation of the sediment transport along this profile. On an annual average, the sediment transport is northward. Since the construction of the breakwater, this volume variation has been reduced from 50,000 m^3/year to 19,000 m^3/year.

2.2.3 Shoreline Long Term Evolution

Due to a lack of information from the previous studies concerning the northern part of the shoreline of Champion Bay and Grey's Beach, an analysis of the vegetation line evolution has been undertaken. It should be noted that a general trend of the shoreline evolution can be assessed through this method but its accuracy is limited.

Northern Part of Champion Bay

The shoreline positions from 1942 to 2007 were analysed. Figure 2-6 shows the relative crosshore position of vegetation lines compared to the shoreline position in 2000 for different years. It shows that the shoreline sections on both sides of the Chapman River have been subject to significant evolution since 1942; from 40m seaward to 21m landward. This indicates the naturally occurring longshore sediment gradients together with coastal development and the influences of the Chapman River are having a significant impact on the shoreline evolution over the whole of Champion Bay. Importantly this demonstrates the need to look at the whole Bay as one unit.

Sunset Beach, just north of the river mouth is affected by the Chapman River flooding events. This beach has been largely eroded since 1942, especially the southern part. While the beach seems to have recovered from 1980 to 2000, in only four years the beach had been eroded again from 8 to 20 metres.

North Sunset Beach has also been eroding since 1942 but at a slower rate. Several dune blowouts can be found along this beach. The most important is located between the longshore positions 5500m and 6000m. These geological formations contribute to the beach erosion phenomena.

Along the northern part of Champion Bay, Glenfield Beach, located between North Sunset Beach and Drummond Point, has accreted since 1942 and seems to be relatively stable since 2000, although slight erosion has taken place in recent years.

Table 2.5 presents the volumetric erosion or accretion rates for the three beaches.

Table 2.5 Volumetric accretion / erosion rates

Beach section	Rate (m^3/year)
Glenfield Beach	-6,000 to 5,000
North Sunset Beach	-6,000 to 1,000
Sunset Beach	-6,000 to 2,000
Total	**-10,000 to 0**

Explosive Beach

The shoreline positions from 1942 to 2007 were analysed. Figure 2-7 shows the relative crosshore position of vegetation lines compared to the shoreline position in 1942 for different years. The longshore distance is measured from the groyne located along the western edge of Pages Beach up to the eastern limit of Grey's Beach.

The analysis shows that the shoreline was in accretion between 1942 and 1988. The shoreline has been relatively stable along the beach since 1988.

Point Moore

The shoreline positions from 1942 to 2007 were analysed. Figure 2-7 shows the relative crosshore position of vegetation lines compared to the shoreline position in 1942 for different years. The longshore distance is measured from the groyne located along the western edge of Pages Beach the up to the eastern limit of Grey's Beach.

The analysis shows that the shoreline was in accretion between 1942 and 1992. Since 1992, the shoreline has been variable with a net recession between 1992 and 1997, accretion between 1997 and 2007, and with a position in 2007 similar to 1992.

Grey's Beach

The shoreline positions from 1942 to 2007 were analysed. Figure 2-7 shows the relative crosshore position of vegetation lines compared to the shoreline position in 1992 for different years. The longshore distance is measured from the western limit of Grey's Beach (the 0 m location corresponding to Point Moore). It shows that the shoreline has been receding between the longshore positions 0 metre to 800 metres. From the longshore position 800 metre to Separation Point, the shoreline has been accreting.

John Willcock Link is located along the eroding section of Grey's Beach shoreline. The minimum distance between the road and the vegetation line is 18 metres. Moreover, there is no longer a buffering area between the beach and the car park. At the car park location, it was estimated that the long term rate (since 1942) of erosion is about 0.4 m/year, and the rate of erosion for the period 1992 to 2007 is about 1.5 m/year. Along the eroding section of Grey's Beach, the long term rate of erosion is on average about 0.2 m/year. The erosion over the recent years (1992-2007) ranges between 0.3 m/year and 1.1 m/year and is on average about 0.6 m/year. Considering an active beach height of 4 metres, an estimate of the annual volume eroded is 800 m^3/year on a long term trend and 2,000 m^3/year during the recent years. Over the last two years (2008 and 2009), the need for nourishment of about 6,000 m^3 to 7,000 m^3 confirms this recent erosion trend.

2.3 Wave Climate Assessment

Waves are an important driver of coastal processes and sediment transport. Sediment can be stirred up by the breaking waves, making it available for movements. Longshore currents are also generated by the breaking waves. Longshore sediment transport is strongly dependent on wave period, wave height and the angle at which the wave breaks relative to the seabed contours (Figure 2-13).

2.3.1 MIKE21SW Modelling

Model Description

To adequately predict longshore sediment movement, the wave climate has been numerically modelled on a regional scale (Indian Ocean Model) and a refined scale. The MIKE21 Spectral Wave (SW) module, developed by the Danish Hydraulic Institute (DHI), has been used for the wave modelling. The wave transformation has been calculated using the MIKE21 SW model, which represents the state of the art in wave spectrum transformation modelling. MIKE21 SW includes a spectral wind-wave model and simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. This model takes into account effects of refraction, diffraction and wave breaking.

Refined Scale Model Domain and Bathymetry

The refined scale model has been set up covering the area between Jurien Bay and Kalbarri and extending approximately 100km offshore. The refined model domain and bathymetry are shown in Figure 2-9 and Figure 2-10.

Model Setup

Key model parameters are presented in Table 2.6.

Table 2.6 Key model parameters for the refined scale wave model

Parameter	Value
Time-step	10 min
Frequency Discretisation	28 bins with logarithmic scale, 0.004-1.1
Directional Discretisation	10° bins over 360° rose
Spatial Resolution – Outer refined area	10 – 5 km
Spatial Resolution – Middle refined area	1 – 2 km
Spatial Resolution – Nearshore area and offshore reefs	0.1 – 0.3 km

INPUT DATA

WIND FORCING

Wind conditions have been obtained from the Bureau of Meteorology at three locations as shown on Figure 2-9: Kalbarri, North Island and Geraldton Airport. A 10 year time series of wind was also extracted from WAVEWATCH III (WW3). WW3 is a third generation wave model developed at NOAA/NCEP and includes wind data at a resolution of 1º Latitude by 1.25 º Longitude. It has been adopted in addition to the site measurement data to provide modelled wind data for the period of interest for the refined scale model area.

WAVE FORCING

Wave parameters obtained from the Indian Ocean model have been applied along the wet boundary of the refined local scale model.

HYDRODYNAMIC FORCING

Time series of water elevation at Geraldton have been obtained from the Department of Transport (DoT). This data was used to force the MIKE21 SW model and the water level parameter was uniformly applied over the domain.

MODEL VALIDATION

Initial simulation runs have been carried out to validate the model. Wave data, provided by DoT for the period 1998 to 2007 were extracted from MIKE21SW hourly at the Jurien Bay wave buoy location (114.91444 E; 30.29166 S). A comparison of wave measurement and model results for the significant wave height and peak period parameter is presented in Figure 2-11 (wave measurements are represented by the black lines and the model results are represented by the red lines).This shows good agreement between the modelled data and the measured data.

As requested by DoT, wave data have also been extracted at four points in the area along the Geraldton Port entrance channel (Figure 2-10). This data was provided to DoT to enable comparison with measured data (see Appendix E).

It should be noted that the wave modelling has been undertaken to obtain the hindcast wave data for shoreline movement modelling purposes only and the presented results shall not be used as basis for any other engineering work.

SIMULATION SCENARIO

The MIKE21 SW model was run to simulate wave conditions at the site for the 10 year period: 1998 to 2007.

2.3.2 Wave Hindcast Results

The nearshore wave data was extracted at four locations along the study shoreline. The extracted points are shown in Figure 2-12. The coordinates of these points are presented in Table 2.7.

Wave roses for the four points are presented in Appendix D, Figure D-1 to Figure D-4. Joint Frequency Tables are also presented in Table D.1, Table D.3, Table D.5 and Table D.7. The simulation indicates similar wave height conditions at each of the sites. Due to the water depth limitation, significant wave heights were limited to 3.3m and the average significant wave height is about 1.2m. However wave periods are relatively long, with an average Tp of 12s.

As expected, the wave direction varies depending on the location along Champion Bay which drives the sediment transport. While the waves offshore of the reefs near Point Moore are characterised by a southwest direction, the refraction and diffraction effects within the Bay affect the wave directions. The predominant wave direction ranges from westerly at profile 1, westerly and south-westerly at profile 2 and south-westerly at profiles 3 and 4. Compared to the beach shoreline orientation, an average northward sediment transport direction is therefore expected. However, during storm events in winter, the wave direction can be in the range West to North West. The sediment transport during storm events is therefore expected to be southward.

The results of the modelling show the distribution of the wave energy along the study area. The central section (profile 2 and 3) is more exposed to the wave action than the southern part of the Northern Beaches.

Table D.2, Table D.4, Table D.6 and Table D.8 present the wave height statistics for each of the output points and for each year. Table 2.8 present a statistical analysis of the hindcast wave data for the years 1998 to 2007 at profile 1. Over the period 1998 to 2007, the wave climate inside Champion Bay seems relatively constant. The years 1999, 2003 and 2007 appear to be the more severe.

Table 2.7 Wave Model output point coordinates for the sediment transport model

Output point	Coordinates in UTM (WGS84)	
	Easting	**Northing**
Profile 1	266675	6816674
Profile 2	266756	6817970
Profile 3	266803	6821370
Profile 4	266461	6822816

Table 2.8 Statistical analysis of hindcast wave at profile 1:

	all	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
min	0.16	0.36	0.42	0.31	0.34	0.35	0.34	0.39	0.40	0.41	0.16
mean	0.93	0.88	0.95	0.87	0.86	0.95	0.94	0.90	0.96	0.90	1.01
median	0.86	0.82	0.90	0.82	0.79	0.86	0.85	0.84	0.85	0.83	0.91
80%ile	1.12	1.01	1.17	1.04	1.01	1.17	1.13	1.05	1.16	1.05	1.23
95%ile	1.65	1.52	1.52	1.50	1.51	1.76	1.80	1.58	1.75	1.62	1.86
max	2.91	2.47	2.62	2.24	2.46	2.54	2.87	2.67	2.78	2.64	2.91
std	0.33	0.28	0.30	0.29	0.30	0.37	0.39	0.33	0.36	0.31	0.38

calm
average
stormy

2.4 Longshore Sediment Transport Assessment

2.4.1 LITPACK Model Description

The Danish Hydraulics Institute's LITPACK model (DHI, 2009) has been used to model the sediment transport processes. LITPACK is able to predict net littoral drift though its module LIDRIFT by applying a cross shore profile, sediment characteristics and wave conditions. Though its module LITLINE, LITPACK simulates the coastal response to variations in the longshore sediment transport capacity resulting from natural and artificial features coastal profile development and medium term coastal evolution. LITPACK can model the impact of coastal structures.

Longshore sediment transport is strongly dependent on wave period, wave height and the angle at which the wave breaks relative to the seabed contours. The angle that a wave breaks with respect to the beach alignment determines the direction in which the sand will move along the beach. (As shown in Figure 2-13)

For the purpose of reporting the results of this analysis, the concepts of Gross Sediment Transport and Nett Sediment Transport are important to the observed dynamics and one defined as noted below;

- *Gross Sediment Transport* refers to the total volume of sediment being transported along the coast, parallel to the shoreline. This includes transport which is taken offshore by waves and transported along the nearshore zone by waves and currents.
- *Nett Sediment Transport* refers to the overall result of sediment transport taking into account its direction.

Nett sediment transport is always quoted with a direction (the predominant direction of transport). Gross transport does not have a direction. A high gross figure and a low nett figure for a location indicates that there is a large volume of sand moving but it is changing direction in response to the seasons, and also to the passage of individual storms.

2.4.2 Model Setup

The LITPACK model was set up to best simulate the sediment transport parameters. The model domain covered an area within the northern breakwater of the BCM to the northern part of Glenfield Beach.

As mentioned in Section 2.1, depending on the position along the study shoreline the sea bed is composed of reef covered by patches of seagrass or sand. The model has been set up to consider this particular seafloor configuration for sediment transport purposes.

Key model parameters are presented in Table 2.9

Table 2.9 Key LITPACK Model Parameters

Parameter	Value
Time-step	1 hour
Profiles: crosshore spatial resolution	0.3 m
Shoreline: longshore spatial resolution	10 m

2.4.3 Input Data

Shoreline Position and Beach Profiles

The required inputs for LITPACK are the spatial contour of Mean Sea Level (MSL), the dune line and the offshore contour (taken from an average water depth of 40 metres). These contours were extracted from the bathymetric survey data provided by DoT and aerial photography.

Bathymetric and topographic survey results provided by DoT and Quantum surveys were used to define the cross shore beach profiles at four locations along the model domain. The four profiles extended to the 6m metres water depth contour where the hindcast wave data were prepared. The sand extracted from Pages Beach for the sand bypassing is fine with a grain size D50 of 0.14 mm (MRA, 2003). The STC sand used for the nourishment in 2004 is characterised by a grain diameter

D50 of 0.25 mm (MRA, 2003). Along the northern beaches (especially the southern part) the sand is fine with a D50 of 0.22 mm (CES 2001). Further north (Chapman River) the sand is coarser, nominally D50=0.3 mm (CES 2001). The sand along Sunset Beach is coarse sand with a grain size D50 of 0.35 mm (MRA, 2003).

Wave Data and Hydrodynamic Forcing

Time series of water elevation at Geraldton has been used to force the LITPACK model with the water level parameters uniformly applied over the domain.

Hindcast wave data obtained from the MIKE21 SW model along the Geraldton shoreline is assumed to be representative of the medium term wave climate and have been applied in the LITPACK simulations. Root mean square wave height, zero up crossing wave period and peak spectrum wave direction are the main parameters used to force the LITPACK model.

Simulation Scenario

To simulate medium term (i.e. 20 years) trends in shoreline evolution in the study area a 20 year simulation was run using the LITPACK model. The 2007 shoreline position was used as the initial shoreline position and the model was forced using the hindcast wave data set. The resulting shoreline development represents the predictal cumulative effects of littoral drift and diffusive processes.

Model validation and limitation

The LITPACK model simulates both sediment transport and shoreline evolution.

The longshore sediment transport module (LITDRIFT) was set up to consider the particular configuration of the sea bed. This was done by adjusting the roughness parameter and validated by comparing the calculation results with survey data (Section 2.2.2).

Regarding the shoreline evolution modelling with the LITLINE model, it is likely that nearshore reefs extend to land and are overlaw by sand on the dry beach area. This type of beach is generally referred as hard bottom beach and the quantity of sediment available is limited. Along the northern beaches these nearshore reefs can be seen at several locations (Hosken St, Dean St, north of Mark St). While the Quantum Survey data informs on the temporal volume variations of sediment along the northern beaches, no information is available regarding the quantity of sediment available. For medium term modelling of the shoreline evolution a sandy beach has been assumed and, as a consequence, the shoreline evolution development presented herein should be considered as conservative estimate of the medium term shoreline evolution trend.

Moreover, it should be noted that whilst the LITPACK numerical model considers longshore sediment transport, it does not include crosshore sediment transport which may be induced during storm events. However, the crosshore transport is generally nil over one year and an annual average shoreline position can be considered. The shoreline modelled developments represent this average shoreline.

2.4.4 Results

LONGSHORE SEDIMENT TRANSPORT

The potential nett transport of sand is presented in Table 2.10 for the year 2007, where negative values indicates southward potential net transport and positive values indicate northward potential net transport. At profiles 1, 2, 3 and 4 the direction of the potential transport was mainly northward, ranging from 11,000 m^3/year to 24,000 m^3/year. This indicates exchanges between the different sections of the shoreline with an average northward littoral drift. The gross transport is higher than the net transport indicating that the southward winter storm longshore transport mobilises a large amount of sediment in the area, especially at profile 3 where the differential in transport is larger. This means that there is a large seasonal variation in beach and dune profiles.

These results agree with previous modelling study results (CES 2001) which estimated a northward sediment transport along the northern beaches of between 7,000 m^3/year to 11,000 m^3/year. The results differ at Sunset Beach where the CES study determined a southward sediment transport however they qualify this apparent anomaly with the statement: “the nearshore bathymetric survey data is not accurate enough and therefore the wave refraction computations are inaccurate particularly with respect to nearshore direction”.

The present longshore sediment transport modelling improves the understanding of the coastal processes of the region by confirming the presence of a northward net sediment transport along the Northern Beaches and Sunset Beach. As a consequence of this northward net sediment transport, the Northen Beaches and Sunset Beach are linked and any shoreline change along the Northern Beach can influence the evolution of the shoreline at Sunset Beach in a medium term.

Table 2.10 Example of potential nett and gross transport across each profile: year 2007

Profile	Net Transport (m^3/year)	Gross Transport (m^3/year)	Ratio Gross/Net
1	24,000	34,000	1.4
2	11,000	15,000	1.4
3	11,000	27,000	2.5
4	17,000	19,000	1.1

MEDIUM TERM SHORELINE EVOLUTION

As mentioned in Section 2.4.3, the shoreline evolution development presented in this report should be considered as indicative of the shoreline evolution trend. The results are however expected to be conservative. Analysis of the outcome is important as it demonstrates the need for an adequate coastal protection management plan.

Figure 4-1 and Figure 4-2 present the medium term shoreline evolution over a 20 year period along the Northern Beaches and Sunset Beach in the case of no human intervention. This demonstrates that these beaches would show gradual recession and an increased area of beach and development placed under threat of erosion.

As shown on Figure 4-3, continuation of the present Northern Beaches Stabilisation Programme will not prevent shoreline erosion north of the detached breakwater. This shows that an adjustment of the programme is required. It is however possible to prevent the erosion in this area by increasing the sand bypassing volumes as presented in Figure 4-4.

2.5 Assessment of Sediment Budget along the Geraldton Coastline

The coastal transport processes in Champion Bay have been assessed based on the review of the historical studies combined with processing and analysis of data regarding the vegetation line positions and the 5 year profile survey data. Figure 2-14 and Figure 2-15 present a summary of the results, which are described below.

The study shoreline can be split into one main cell and five sub cells. The main sediment cell corresponds to Champion Bay. Despite a certain amount of sand entering through the southern boundary, the sediment budget of this cell is in deficit. The total volume of sand is estimated to be -21,500 m^3/year on average, including 13,000 m^3/year of discharge from the Chapman River. A certain quantity is drifted towards Drummond cove through the Drummond Point northern boundary while the remaining quantity is likely to be deposited offshore.

Within the Champion Bay main cell, Sub Cells 1, 2, 3, 4 and 5 correspond to Pages Beach, Town Beach, the Northern Beaches (cells 3 and 4) and Sunset / Glenfield beaches respectively. Sub Cell 5 and 6, corresponding to Point Moore and Grey's Beach, which is outside the main cell of Champion Bay. Cells 3, 4 and 5 comprise the main part of the study shoreline.

Sub cell 1: Pages Beach

The sand, entering Champion Bay by littoral drift along the beach of Point Moore and through the inshore reefs, is mainly deposited along Pages Beach. Even with sand removal for bypassing purposes of about 5,000 m^3/year to 13,000 m^3/year and 10,500 m^3/year on average, Cell 1 has been accreting over recent years at a rate of 10,000 m^3/year to 21,000 m^3/year and 17,000 m^3/year on average. The Geraldton harbour and channel infrastructure act as a barrier stopping the longshore drift processes so no sand is naturally transported from this area to the other sub cells.

SUB CELL 2: TOWN BEACH

The survey data analysis revealed that Cell 2 has not been subject to significant strong erosion over the past 5 years and therefore can be considered as independent from the three other sub cells constituting Champion Bay. However, this beach is subject to natural erosion (1,500 m^3/year on average) during strong storm events and a certain quantity of sand is likely to be transported offshore towards the port entrance channel.

SUB CELL 3 AND 4: NORTHERN BEACHES

In Cell 3, the Batavia Coast Marina has stopped the natural northward littoral drift preventing the sand to enter the northern boundary of the cell. This lack of sediment is likely to be the origin of the observed erosion. In spite of sand nourishment events (5,000 m^3/year to 13,000 m^3/year and 12,500 m^3/year on average in the period 2004 to 2009), it was determined that about 22,800 m^3/year of sand was lost from Cell 3 over the years of this analysis. A certain amount of these sediments is deposited along Cell 4. It was determined that about 4,200 m^3/year of sand were accumulating along Cell 4 over the years of this analysis.

SUB CELL 5: SUNSET BEACH AND GLENFIELD BEACH

Over the past 60 years, the southern part of Cell 5 has been in erosion while the northern part, in the direction of Drummond Point, has been accreting. Sunset Beach, at the southern boundary, is influenced by the Chapman River during flooding events which lead to a significant quantity of sediment in the beach system transported offshore. Moreover, the bar breach occurs generally during a storm event, which increases the potential for strong erosion. The presence of inshore reefs off the Chapman River and Sunset Beach is likely to contribute to the bar reforming during the other periods of the year (especially the dry season) by reducing the littoral drift and causing sand deposit.

The average impacts of these processes manifest themselves in reduced value of sediments in the system and erosion along the stretch of shoreline north of these reefs. This erosion is accelerated by the significant dune blowout along North Sunset Beach. It was estimated that about 0 m^3/year to 10,000 m^3/year of sand has been lost in Cell 5 over the past 60yrs and about 6,000 m^3/year on average over the recent years.

SUB CELL 6: POINT MOORE AND EXPLOSIVE BEACH

Sub Cell 6 is located between the Champion Bay Cell and another cell extending down to the Greenough River. It is expected that this Sub Cell is the interface between the two main cells. This cell is however relatively stable. It has been in relative equilibrium since 1992. The volume variations along Explosive Beach and Point Moore are less than 2,500 m^3/year.

SUB CELL 7: GREY'S BEACH

Sub Cell 7 is located outside the Champion Bay Cell and belongs to another cell extending down to the Greenough River. The cell (Grey's Beach) is located between Separation Point and Point Moore. It is not expected to have any significant quantity of sediment entering from the Separation Point boundary owing to the inshore reef blocking the sand transport. This cell has been losing about 800 m^3/year over the past 60 years and about 2,000 m^3/year on average in over the last years.

THE CHAPMAN RIVER

Between Sub Cells 4 and 5, the Chapman River is estimated to discharge about 3,000 m^3/year to 16,000 m^3/year and 13,000 m^3/year on average during the wet season. During events when the bar is breached sediment is transported offshore and then redistributed along the shoreline.

However, the understanding of the Chapman River's role in the sediment transport processes is limited at this stage and without substantial analysis, the historical survey data is important to provide an appreciation of the beach dynamics.

GERALDTON HARBOUR CHANNEL

A significant quantity of sediment has been depositing in the Geraldton Harbour Channel. This required dredging of 40,000 m^3 of sediment in 2002/2003. This siltation is driven by the saturation of Pages Beach and the area seaward adjacent to the port breakwaters providing a mechanism for sediment to be transported to the channel.

3. COASTAL MANAGEMENT METHODS

Successful long-term coastal management solutions have to directly address and work with the natural physical processes responsible for the erosion problems. Therefore, an understanding of the function and effectiveness of various coastal structures is required, along with the social acceptance of the various options.

3.1 Impact of Recent Foreshore Development and Management Policy

The following discussion includes observations, which can be drawn, from recent developments and management methods being adopted on the Geraldton coastal zone.

3.1.1 Geraldton Port Harbour and the Recent PEP

The Geraldton Port Harbour has a long history of development. The construction of the Port facilities began in 1857 with the first town jetty. In 1893, a new 290 metre jetty was completed northwards from Durlacher Street. A 670 metre breakwater was completed in 1926 and the Fishing Boat Harbour was added in 1963. The Construction of Berth 4 commenced in May 1964 and in 1975 a 213 metre berth, designed to accommodate vessels of up to 27,000 tonnes displacement was added. Recently, in 2003, the Port Enhancement Project (PEP) was undertaken to deepen the harbour basin and channel, as well as to upgrade three of the six berths.

Significant work has been completed in the Geraldton area concerning the Port development impact on the shoreline evolution, especially along the Northern Beaches. Based on historical vegetation and waterline movement, MRA (2001) suggested that the development of the Harbour has affected longshore sediment transport by reducing the natural littoral drift. Based on wave and sediment transport modelling, CES (2001) advised that the effect of the PEP would be to intensify the sediment transport processes by about 20%. Owing to more wave energy striking the coast from the west at some 100 to 200 metres north of the Batavia Coast Marina and south of Chapman River, the rate of sediment transport, following the PEP, was expected to be about 10,000 m^3/year to 15,000 m^3/year.

For recent years, the rate of sediment transport north of the detached breakwater has been evaluated at about 16,000 m^3/year (Section 2.2.2), confirming the CES results.

It has to be noted that the sediment budget analysis showed that a higher volume of sediment can be transported north of the Batavia Coast Marina. This was up to 40,000 m^3 after the beach nourishment of 89,000 m^3 with STC sand in 2004. This demonstrates that the potential littoral drift can be significantly higher as soon as the quantity of sand available along the beaches increases.

3.1.2 Detached Breakwater

A detached breakwater was constructed in 2005, designed to stabilise the shoreline just north of the Batavia Coast (section SN1). After its construction the eroded volume of sand was reduced to between 5,000 m^3/year and 19,000 m^3/year (see Section 2.2.2), permitting the beach in SN1 to be stabilised via ongoing nourishment.

However, north of the detached breakwater, a gradient in transport has been created equal to the reduction in transport created by the detached breakwater. This is causing exacerbated shoreline recession and recent erosion problems in this beach section, despite ongoing nourishment.

3.1.3 Northern Beaches Stabilisation Programme

As detailed in section 2, five years of Northern Beaches Stabilisation Programme has resulted in the following:

- Town beach is relatively stable but is exposed to crosshore transport during storm events
- A large quantity of sediment remains available along Pages Beach which has been accreting over the last five years
- The section between the Batavia Coast Marina and the offshore breakwater has been stabilised. However north of the breakwater, erosion is observed despite nourishment, indicating a deficit in the amount of nourishment being applied. A long stretch of Shoreline (Mabel St to Chapman River) is relatively stable, slightly in accretion.
- In the absence of stabilisation work, Grey's Beach and Sunset Beach have been eroding.

3.2 Assessment of Coastal Setback Distances

3.2.1 State Coastal Planning Policy and Sea Level Rise

STATE COASTAL PLANNING POLICY

In order to propose adapted coastal protection strategies for the study over the next 20 years, an assessment of the appropriate setback distance has been undertaken in line with the Western Australian Planning Commission's "Statement of Planning Policy No 2.6 – State Coastal Planning Policy" (SCPP). The calculation of setback in line with this policy allows the areas of high risk of impact from erosion to be highlighted. This analysis will confirm the observations made in the field. The policy provides setback guidelines to protect developments from erosion processes.

The setback calculation provides for the coastal processes that may occur within the planning lifetime and includes setback distances for:

- An extreme storm sequence – based on modelling of extreme ocean conditions: **S1**
- Chronic erosion or accretion – based on historic surveys of shoreline change: **S2**
- Future sea level change: **S3**

This method is based on a planning horizon of 100 years for new developments and its aim is to avoid the need for active management of the coastal processes.

For the assessment of setback distances for this study, a planning horizon of 20 years has been adapted. It was however identified during the discussion with the Partners that a review of the 100 year horizon is relevant to provide appreciation of the larger term horizon.

In additional to the three setback distances, a factor of safety of 10m (S4) has been allowed to account for likely accuracy of the data and possible error in the models (MRA, 2001).

The determination of the S1 distances requires the modelling of the impact of a sequence of storms on the shore at the study sites. Such modelling result values have been sourced from previous studies (MRA, 2001). As recommended by the SCPP, in the absence of modelling, such as when data is unavailable, the default value of 40 metres has been used (based on modelling of a typical exposed sandy shore).

Where a coastal protection structure is present, the SCPP recommendations for an Infill classified area have been applied. Therefore, a minimum setback of S1 has been applied. An exception is for the seawall case where only the safety distance (S4) has been applied because these structures are normally designed to prevent inland intrusions of the sea. For the detached breakwater case (between section SN1 and SN2), while it diminishes the wave action, the structure dimensions are reduced and therefore a conservative approach has been adopted.

The determination of the distance S3, related to the future seal level change, is discussed in the following section.

The use of the criterion described above results in a setback distance that will provide a reasonably low risk of coastal erosion threatening the lease area in the coming 20 year case and 100 year case. If the setback distance of the existing development were less than the recommended setback, then it would highlight the need to manage the risk by either application of coastal structures or further active management of the coastal processes.

SEA LEVEL RISE DUE TO CLIMATE CHANGE

The influence of potential sea level rise is significant and the accuracy of estimates is also still under development.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the United Nations Environment Programme and the World Meteorological Organisation. It is responsible for providing the international community with authoritative advice on scientific, technical and economic issues relating to climate change. The IPCC's Third Assessment Report concluded in 2001 that global warming had accelerated in recent decades. The recently released Fourth Assessment Report (2007) increases the level of scientific certainty upon which climate change projections are made and provides stronger evidence that the majority of global surface warming is attributable to increases in greenhouse gas emissions associated with human activities.

Increasing global temperature has a direct impact on sea level in a number of ways including:

- Increased water temperature causing the water to expand
- Melting of land based ice into water, which then flows into the oceans, and
- Ice sheets on land breaking up and calving into the ocean (“dynamic response of ice sheets”)

The latest IPCC’s report (2007) gives projections across all the emission scenarios by the end of the 21st century. Accelerated melting of the Greenland and Antarctic ice sheets is predicted to increase the upper ranges of projected sea level rise by a further 0.1 m to 0.2 m. Figure 3-1 shows the range of average global predicted sea level rise over the next century. It is notable that all scenarios predict a rise in sea level.

Based on post IPCC research, plausible high end scenario (“High Emission Scenario: A1FI”) values for Sea Level Rise, from the Department of Climate Change and Energy Efficiency report “Climate Change Risks to Australia's Coasts” (2009) are given in Table 3.1. Values are presented for the years 2030 (20 year timeframe) and 2100. For the year 2110 (100 year timeframe), another 0.1m has been added to the 2100 value, as recommended by DoT.

Table 3.1 Sea Level Rise Values (difference from 2010 level) according to the High End scenario

Year	2030	2100	2110
Sea Level Rise (m)	+0.2	+1.1	+1.2

3.2.2 Coastal Setback for a 20 Year Timeframe

For the assessment of setback distances for this study, a planning horizon of 20 years has been adapted. This reduced planning horizon is sustainable on the basis that active management of coastal process could be implemented if required for the existing developments.

Therefore, for the long-term trends caused by the coastal dynamics of the area, 20 times the average annual historical erosion trend as measured from shoreline movement plots is applied. This would provide a buffer for the coming 20 years.

For S3 (the long term trend caused by possible changes in climate change) an allowance of 0.2 metre rise in sea level is included and a 20 metres erosion of sandy beach to accommodate the likely recession to 2030.

Table 3.2 summarizes the S1, S2, S3 and S4 components and the total recommended coastal setback to each section of the shoreline in line with this approach. The set back distances should be measured from the current line of vegetation for the sandy coast. It has to be noted that these recommended setback distances are for existing developments and not new developments. These recommended distances are the minimum from a coastal engineering point of view and they are made on the basis that the foreshore is properly managed.

Table 3.3 presents a comparison of the recommended coastal setback distances and the actual coastal setback distances. The recommended setback distances are presented on Figure 3-2, Figure 3-3, Figure 3-4, Figure 3-5 and Figure 3-6 for the Northern Beaches, for south of Chapman River, Sunset Beach and Grey's Beach respectively.

For some sections, it appears that the recommended coastal setbacks are not met. For the sections where the shoreline has a history of erosion or the beach width does not present a sufficient buffer for storm erosion, a beach protection management action is required to prevent threat to the existing development. These sections are indicated with a red colour shading in Table 3.3.

For the sections where the shoreline is, however, stable or in accretion and the beach width presents a sufficient buffer for storm erosion and/or an existing structure protects them from extreme storm erosion, no immediate action is required but active monitoring is recommended. These sections are indicated with an orange colour shading in Table 3.3. The active beach monitoring is defined in Section 5.3.1.

On the basis of a 20 year horizon, the following conclusions can be drawn from this coastal setback assessment:

- The recreational facilities in the foreshore reserve can be located within this setback distance but will have a higher risk of being threatened by coastal erosion in the coming 20 years.
- For the section SN1, the setback is not sufficient to meet the minimum setback requests. North of the Batavia Coast, the actual setback distance is only 30m. However, this section has been maintained as described in Section 2.5 (sheltered by a seawall and breakwater and maintained with ongoing nourishment).
- Along sector SN2, the actual setback distance compared to the minimum required setback is not sufficient for the majority of the developed area. An active coastal protection program needs to be developed for this area.
- For the sector SN3, except for the northern part (north of Fuller Street), the recommended setback distance is matched for the majority of the shoreline or a sufficient buffer against storm erosion is present. Active monitoring is recommended.
- The section near Fuller Street is already protected by a seawall against beach erosion during storm events. Other than during maintenance work, no particular management should be required for this section.
- South of Chapman River (Frederick Street), the setback distance is not sufficient for four houses and the beach would not be wide enough in the event of extreme storm erosion.

- North of the Chapman River, the section corresponding to Sunset Beach is threatened by erosion. In particular, several houses located in the Caravan Park are far closer to the vegetation line than it is recommended.
- For the sections North Sunset Beach and Glenfield, the setback distances are sufficient.
- At Pages, currently in accretion, a groyne protects the car park and recreation area. Along the eastern side of the beach, some infrastructure from the port might be at risk in the event of an extreme storm if a sufficient sand buffer is not maintained in their vicinity.
- At Point Moore and along Explosive Beach the setback distances are sufficient other than for the Car Park but the beach is currently stable and a sufficient buffer against storm erosion is present.
- Along the eastern part of Grey's Beach, the setback distances are sufficient.
- Along the western part of Grey's Beach, the setback distance is not sufficient. The road, the car park and the pathway would be at threat according to the recommended setback distances (85 metres). Private infrastructure is however located at a minimum distance of 100 metres.
- Along Town Beach, the majority of the foreshore is already protected by a seawall against beach erosion during storm events. Other than during maintenance work, no particular management should be required for this section.

On the basis of this analysis, it can be concluded that the areas requiring beach protection management to avoid threat to the existing development are:

- The section north of the detached breakwater
- Sunset Beach (mainly along the Caravan Park)
- South of Chapman River (Frederick Street)
- Grey's Beach (mainly along the Car Park)

The areas requiring Active Beach Monitoring to detect future threat to the existing development are:

- The section between Elphick Avenue and Champion Bay Rise
- The section in the area of Morris Street and Cecily Street.
- Point Moore (along the Car Park)
- Pages Beach
- Town Beach

Table 3.2 Recommended setback distances for each section of the shoreline for a 20 year timeframe

Coastal section		Recommended Coastal Setback Distances (m)				
		S1 Storm erosion	S2 Erosion trend	S3 Climate change	S4 Safety factor	Total Setback
East Grey's Beach		40	0	20	10	70
West Grey's Beach		40	15	20	10	85
Point Moore		40	0	20	10	70
Explosive Beach		40	0	20	10	70
West Pages Beach		40	0	0	10	50
East Pages Beach		40	0	20	10	70
Town Beach		0	0	0	10	10
SN1: Marina Beach		10	0	20	10	40
SN2: Beresford Beach		10	15	20	10	55
SN3	Bluff Point Beach	25	0	20	10	55
	Near Fuller st	0	0	0	10	10
	Frederick st	25	0	20	10	55
Sunset Beach		10	15	20	10	55
North Sunset Beach		10	10	20	10	50
South Glenfield Beach		40	0	20	10	70

Table 3.3 Comparison of recommended and actual setback distances for the 20 year timeframe

Coastal section		Setback distance to Infrastructures (m)	
		Recommended	Actual
East Grey's Beach		70	80 to 120
West Grey's Beach		85	0 to 70 first habitations at 100m
Point Moore		70	90 to 15 Light house at 100m and first habitations at 140m
Point Moore (Car Park)		70	40 to 50
Explosive Beach		70	140 to 220
West Pages Beach		50	10 to 40
East Pages Beach		70	0 to 135
Town Beach		10	0
SN1: Marina Beach		40	30 to 60
SN2: Beresford Beach		55	20 to 50
SN3	Bluff Point beach	55	45 to 90 Except boat ramp access area
	Near Fuller st	10	0
	Frederick st	55	15 to 25
Sunset Beach		55	20 to 90
North Sunset Beach		50	100 to 120
South Glenfield Beach		70	>170

3.2.3 Coastal Setback for a 100 Year Timeframe

For a planning horizon of 100 years, an indicative assessment of setback distances has also been undertaken. For the long-term trends caused by the coastal dynamic of the area, 100 times the average annual historical erosion trend as measured from shoreline movement plots is applied. For S3 (the long term trend caused by possible changes in climate change), an allowance of 1.2 metre rise in sea level is included and a 120m recession of sandy beach to accommodate the likely recession to 2110.

Table 3.4 summarizes the S1, S2, S3 and S4 components and the total recommended coastal setback to each section of the shoreline in line with this approach. Table 3.5 presents a comparison of the recommended coastal setback distances and the actual coastal setback distances.

The recommended setback distances are presented on Figure 3-2, Figure 3-3, Figure 3-4 and Figure 3-5 for the Northern Beaches, south of Chapman River and Sunset Beach respectively.

Based on this approach (High End Scenario), the whole coastline is predicted to be at threat in the next 100 years. Climate change and sea level rise have the very real potential to have a significant impact on the Geraldton coast, affecting natural and cultural values, infrastructure and built assets on private and public land. The response to climate change and sea level rise needs to be both pro-active and reactive which involves actually responding to changes as they occur.

It is noted that these estimates are based on the projection of current estimates over a very long timeframe and in particular estimates of sea level change which have very large estimate averages over this timeframe. However, it is an important observation that with those estimate accuracy ranges, much of the coastline would be under threat and coastal protection options must be effective over this timeline.

Table 3.4 Recommended setback distances for each section of the shoreline for a 100 year timeframe

Coastal section		Recommended Coastal Setback Distances (m)				
		S1 Storm erosion	**S2 Erosion trend**	**S3 Climate change**	**S4 Safety factor**	**Total Setback**
East Grey's Beach		40	0	120	10	170
West Grey's Beach		40	60	120	10	220
Point Moore		40	0	120	10	170
Explosive Beach		40	0	120	10	170
West Pages Beach		40	0	0	10	50
East Pages Beach		40	0	120	10	170
Town Beach		0	0	0	10	10
SN1: Marina Beach		10	0	120	10	140
SN2: Beresford Beach		10	75	120	10	215
SN3	Bluff Point Beach	25	0	120	10	155
SN3	Near Fuller st	0	0	0	10	10
SN3	Frederick st	25	0	120	10	155
Sunset Beach		10	60	120	10	200
North Sunset Beach		10	50	120	10	190
South Glenfield Beach		40	0	120	10	170

Table 3.5 Comparison of recommended and actual setback distances for the 100 year timeframe

Coastal section		Setback distance to Infrastructures (m)	
		Recommended	**Actual**
East Grey's Beach		170	80 to 120
West Grey's Beach		220	0 to 70 first habitations at 100m
Point Moore		170	90 to 15 Light house at 100m and first habitations at 140m
Point Moore (Car Park)		170	30 to 50
Explosive Beach		170	140 to 220
West Pages Beach		50	10 to 40
East Pages Beach		170	0 to 135
Town Beach		10	0
SN1: Marina Beach		140	30 to 60
SN2: Beresford Beach		215	20 to 50
SN3	Bluff Point beach	155	45 to 90 Except boat ramp access area
	Near Fuller St	10	0
	Frederick St	155	15 to 25
Sunset Beach		200	20 to 90
North Sunset Beach		190	100 to 120
South Glenfield Beach		170	>170

3.3 A Review of Available Coastal Protection Options

In order to select the most appropriate coastal protection solution(s) for the area requiring beach erosion management (highlighted in the previous section), a review of existing options is proposed hereinafter, as summarised in Figure 3-7:

- Do Nothing / Managed Recession
- Dune Management
- Beach Nourishment
- Seawall and Buried Seawall
- Groynes
- Detached Breakwaters
- Artificial Reefs
- Beach Drainage
- Material for Coastal Structure Construction

3.3.1 Do Nothing

With this option, no interference with the natural coastal processes will occur. On one hand, the associated fiscal cost could appear less than that associated with implementing coastal management options.

However, the popular beach amenity would suffer from episodic erosion. It will result in a lack of adequate beach width and access to the beach. The amenity of the beach would be reduced and the foreshore infrastructure would remain at risk of erosion and eventually being damaged or lost from erosion processes. Moreover the cost for lose of land or infrastructure might be higher than the cost of another coastal management option.

3.3.2 Managed Recession

This option consists of sacrificing a part of the foreshore and relocating infrastructure to an adequate development setback to allow the beach to respond naturally to the coastal processes and develop a more suitable alignment. Existing infrastructure would be relocated in an orderly fashion, rather than a response to storm damage. In the meantime, the eroded material entering the system during foreshore recession would often reduce or prevent erosion further along the coast.

However, a section of the foreshore would be sacrificed. The beach would be relatively narrow while the foreshore recedes. The beach would also require maintenance works to provide adequate beach access, remove undermined vegetation and batter the eroded scarps to ensure public safety.

Specific studies and actions will be required to guide Managed Recession appropriately.

3.3.3 Dune Management

The dunes present on the foreshore play an important role in providing a buffer to erosion. It should be considered good practice to implement a dune management plan despite any coastal protection options selected.

During intense storms, sand is removed from the beach to form an offshore bar, which includes erosion of the sand buffer reserves held in the dunes. The maintenance of sufficient sand storage relies on effective dune management, which is based on maintenance of a satisfactory vegetative cover. This requires the introduction of appropriate plant species and defined access/walkways over the dunes to maintain their health. Beach vegetation stabilises the sand that returns during calm weather. Plants have an important function of stabilising seaward of the permanent dune crest and act to modify the local onshore wind field to enhance sand deposition onto the dune field. These areas provide a 'buffer zone' that stores the sand so that during storm events it is available to naturally protect the coast.

Dune management is very successful where a wide dune area is or was previously present and there is an abundant source of sediment. Where only a small width of beach is present, dune management can be applied in conjunction with other coastal protection measures that result in the widening of the beach. However, existing coastal processes need to be considered before dune management is applied.

3.3.4 Beach Nourishment

GENERAL CONSIDERATIONS

Where there is insufficient sediment on a beach to meet storm erosion or long-term sediment loss, additional sediment can be placed by mechanical means, as is presently done along the northern beaches. Beach nourishment involves the artificial placement of sand onto a beach to replace sand that has been lost through erosion. The nourishment forms a 'buffer' against storm erosion and erosion processes from longshore sediment gradients. It is recommended where nourishment is undertaken, that it occurs over the whole beach profile including the part of the beach below the water out to depths where storm waves are breaking.

Beach nourishment promotes amenity and natural character in the form of a wide sandy beach and generally, it does not have adverse effects on adjacent areas. Beach nourishment can provide total protection if sufficient sand is used.

Beach nourishment is in many cases undertaken in conjunction with some form of sand retention device such as groynes (Cottesloe, WA), submerged reefs (Narrowneck, Queensland), or detached breakwaters, as is the case of the beach north of the Batavia Coast Marina. This combination of coastal protection methodologies is undertaken to slow or reduce the amount of nourishment and if necessary address the restraints where insufficient source materials are available or the source is unsustainable.

Beach nourishment works within the influence of naturally occurring coastal processes and provides a buffer zone in the form of beach sand. It has a positive impact on the beach amenity and aesthetics in the form of a wide sandy beach. Sand retention devices can be implemented to increase the residence time of the nourishment material, or provide a last line of defence if the risk of storm erosion to developments is high.

Beach nourishment projects have the potential to cause substantial effects on the biota residing in the nearshore area. These effects can be quantified only though the results of monitoring programs. Short term impacts include direct burial of the animals that reside in the area and lethal or damaging doses of turbidity. Long term impacts include a long term source of turbidity which affects light penetration and altered sediment compositions which can affect the type of animal that will inhabit the area.

SAND GRAIN SIZING

The equilibrium beach profile is predicted by the “Bruun profile”. This physical low establishes a relationship between the grain size and the beach slope after reworking by the wave action. The larger the sediment grain size the steeper the slope. Therefore, if the sediment used for beach nourishment purpose is smaller than the original sand in terms of grain size, an increased quantity of sediment is required to match the expected beach profile.

North of the Batavia Coast Marina and at Sunset Beach the sand particle diameter (D50) is approximately 0.35 mm. The sand at Pages Beach and from the STC Project are about 0.2 mm and 0.25 mm respectively. MRA (2003) predicted that a significant portion of the sand nourishment would be lost from the beach under the action of the waves; more than half of the sand would be lost though beach profile rework. Processing of the transect survey data undertaken in section 2.2 confirmed this prediction. In one year, about 50% of the 89,000 m^3 of sand used for the original STC sand nourishment north of the BCM has been lost through wave action. From the Shore Protection Manual (1984), the overfill factor associated with the STC sand for a beach nourishment along Champion Bay is 1.9 so a predicted loss of 48%.

Quantities of beach nourishment need to consider the influence of this parameter. In fact, the deficiency observed in quantities of nourishment on the northern beaches can be partly explained by this difference.

3.3.5 Seawall and Buried Seawall

Seawalls or revetments are shore parallel structures that are put in place to impose a landward limit to coastal erosion and to provide protection to the area behind it. Seawalls are designed to protect the land and associated land-based amenities behind them and can be described as “a last line of defence” to coastal erosion.

Seawalls are commonly built of many materials including rock, concrete, steel, timber, geotextiles, tyre mattresses, or specially designed armour units. Isolated sections of seawall may exacerbate erosion on unprotected sections of a beach. Continual maintenance of the structures will be required along with nourishment of the beach in front to make this solution effective.

Seawalls are designed to protect the land and address the effects of erosion rather than the cause. They have a negative impact on the beach amenity, access and aesthetics if a proper beach nourishment program is not associated with this option. The beach is generally narrowest along the seawall due to negative impact.

However, by combining seawall, beach nourishment and dune management, a buried seawall allows the maintenance of the beach amenity and aesthetics, and provides a last line defence again storm erosion.

Figure 3-7a and Figure 3-7b illustrates the schematic impact of a seawall on the shoreline evolution. Without beach replenishment, beach erosion is generally observed downdrift of the structure. If correct beach replenishment is applied, the seawall does not influence the sediment transport and no negative impact on the shoreline adjacent to the structure is expected. Moreover, there is no negative impact on the beach along the buried seawall as it is designed to support a dune system.

The buried seawall along Town Beach, in combination with beach nourishment, contributes to the protection of the foreshore amenity. It provides protection against wave action during storm events where the buffering volume of sand has been transported offshore. However, as experienced during recent storms, the seawall could be extended along the full extent of the beach to fully protect the foreshore development.

3.3.6 Groynes

Groynes are coastal structures built of similar materials as seawalls, but oriented approximately shore-normal. They function best on beaches with a predominant longshore transport direction as they form a cross-shore barrier, which traps sand that moves along the shore with the littoral drift.

As described on Figure 3-8a and Figure 3-8b, the width of the beach tends to increase on the upstream side. This reduces sand supply down-drift of the groyne and erosion can result. Groynes may have an impact on swimming safety, aesthetic impacts and may reduce the alongshore beach access. It may be necessary to use groynes throughout the entire littoral cell in order to balance the longshore sediment transport.

Downstream erosion can be avoided by filling the groyne embankment under a beach nourishment programme, and dune management measures can be used both up-drift and down-drift to accommodate changes in the beach and dune systems. Moreover, it is good practise to saturate the updrift area with sand.

Groynes do not reduce the cross-shore movement of sand during storms. Their effect is to build up a sand buffer. It is therefore possible to design a groyne with adequate dimensions in order to obtain a buffer zone wide enough to absorb erosion during storm events (Figure 3-8a). Along the downdrift section, a seawall can be constructed to protect the inland development against storm erosion.

3.3.7 Detached Breakwaters

Detached breakwaters are oriented approximately parallel to the beach and at some distance offshore. They have been used typically along coastlines with small tidal fluctuations to reduce wave energy and thus control the longshore sand transport processes.

Detached breakwaters provide protection by reducing the energy in their lee and thereby, reducing gradients in sediment transport potential that cause coastal erosion. Material is deposited in the zone of reduced wave energy forming a salient or tombolo.

In general, detached breakwaters are suited to coastlines that require higher levels of protection at sensitive points. They should be used in situations where there is no alongshore net sediment transport. After construction, a large quantity of sand and regular renourishment has to be provided in order for the beach to reach an equilibrium profile as shown in Figure 3-9 .

In case of sensitive downdrift beaches, the breakwaters can cause downdrift erosion, and due to the high annual variability in longshore transport, their effectiveness can be limited.

Along the Northern Beaches, the longshore sediment transport is significant. The existing breakwater north of the Batavia Coast Marina was designed to create a stable pocket beach. Because of the formation of tombolo, the sand bypassing has been significantly reduced. The quantity of sand bypassing is less than the potential sediment transport, resulting in erosion downdrift of this breakwater.

3.3.8 Artificial Reefs

These structures are another form of detached breakwater. Wave energy is dissipated on the reef resulting in less energy at the beach in the lee of the reef and the deposition of sediment by balancing wave energy transmission over the crest and around the structure.

A good example of a multi-purpose reef is the Narrowneck reef on the Gold Coast in Queensland, Australia. The Narrowneck case also has an on-going beach nourishment scheme in place for the Gold Coast.

They can provide shoreline protection with low environmental impact. Because the structure is underwater, visual aesthetics are not impaired. Artificial reefs can improve marine ecology and improve fish stocks. There is no, or low, negative aesthetic, access or safety impacts, and amenity value can be enhanced

One disadvantage of a reef that it forms a hazard to navigation and has to be placed far from the shipping channel.

Artificial reefs could be an attractive solution to apply at Geraldton. However, this type of device is relatively new and the number of structures existing around the world is still limited. It should also be noted that they can have similar characteristics as groynes and breakwaters. The design of these structures is complex and their perceived performance is significantly affected where high seasonal and annual variability in transport processes is observed. Moreover there would be a significantly higher investigation cost and would require a specific and expensive strategy of monitoring / implementation over several years.

As documented by Ranasinghe (2006), contrary to expectations, the majority of submerged structures constructed to date have resulted in shoreline erosion in their lee: “Before engineering design guidelines can be developed for submerged coastal protection structures, a fundamental research challenge is to establish the mechanisms that cause erosion or accretion in their lee”.

However, there is growing interest in the concept that the submerged structure can be optimised to enhance local surfing conditions. Surfing is a stimulus for industry, job creation and tourism. Improving local recreational facilities increases a regions ability to attract regional and national surfing contests, particularly weekend events in autumn and winter, which provide massive boosts for the local tourism industry and help stimulate job creation.

There is therefore a need for a specific socio economic impact study for the submerged coastal structure option, as was made for the Mohamet’s artificial Surfing Reef study (Rafanelli, 2004).

3.3.9 Beach Drainage

Beach drains comprise perforated land drain pipes buried below the upper beach surface, and connected to a pump and discharge. The concept is based on the principle that sand will tend to accrete if the beach surface is permeable due to an artificially lowered water table. The system is largely buried and therefore has no visual impact.

The system actively lowers the water table in the swash zone encouraging sand deposition. The deposited sand forms an upper beach berm that protects the dune face during storm events that might otherwise cause erosion.

Benefits are greatest on micro-tidal and high value amenity beaches where landscape issues preclude the use of other management approaches. Important backshore assets should not rely on drainage systems for erosion protection during storms, even as a temporary measure.

Installation costs can be relatively low, but maintenance and management commitments are high. Although the drains should increase upper beach volume during low to moderate wave conditions they will not be significantly effective during storms, with the result that beach draw down may lead to exposure of the pipework and system failure.

This option is not recommended as suitable for the Geraldton shoreline owing to its inefficiency during moderate wave conditions and storms.

3.3.10 Material for Coastal Structure Construction

Several alternatives exist to the use of rock in the construction of coastal structures. Another alternative is the use of geotube or geotextiles. They are large tubes fabricated from high strength woven geotextile, which can be use in place of rock armoured seawall, groynes or breakwaters. Geotextiles are permeable fabrics which are able to hold back materials while allowing water to flow through. Typically, these tubes are strategically positioned in the desired location and filled with a sand slurry mixture to form a permanent structure. These tubes are generally about 1 to 2m in diameter though they can be sized for any application. The tubes can be used singularly or stacked to add height and can be constructed to any length depending on the required use.

Experience has shown that geotubes are vulnerable to damage by vandals, which can lead to reduced effectiveness of the structure through loss of fill material. Geotubes have also been known to sag with time, resulting in reduction in the design height and thus the effectiveness of the structure. Moreover, positioned on rocky seabed as it is the case in Geraldton, the geosynthetic material can be damaged.

Owing to the relative availability of rock in the region and the problems and unknown associated with the effectiveness and longevity of geotubes, the use of rock materials is recommended at Geraldton where the coastal structures are adopted as part of a coastal management solution.

3.4 Social Impacts of Selected Options

The coastline from Grey's Beach to Sunset beach is intensively used for a range of activities. The diversity of the coastal setting and nearshore and inshore reefs are part of this valuable community asset. The entire coastline is well utilised for recreation including swimming (where possible), walking, jogging, riding (on the dual path or on the sandy beaches), snorkelling on the inshore reefs, windsurfing (especially along the Northern part of the Northern Beaches), rock lobster fishing on and around the reefs, sailing (using of the boat ramp at St George's Beach for launching), picnicking and barbecues.

It is therefore a necessity to maintain the beach amenities and aesthetics in order to maintain the attractiveness of the area. Experience has shown that the use of coastal structures is typically less desirable from a social perspective in these circumstances and it should be limited to a few critical locations because of their visually intrusive nature and potential interference to beach users and coastal residents.

Sand nourishment requires the presence of trucks and earthmoving equipment on the beach. Earthmoving equipment is loud to beach users and residents. This work requires beach access to be limited during the works, disturbs beachside residents and prevents visitors from using the beaches. Transport of material has a minor impact on the road user for the duration of the works

The use of pipeline systems can minimise the need for earthmoving machinery and trucks on beaches and suburban roads. Nevertheless, some negative impacts on the community will be associated with the strategy. For example, a significant but short-term consequence will be the effect on beach amenities and public safety during construction of pipelines and booster stations. It is likely that some beach areas will need to be fenced. A piping system would cause some inconvenience due to noise levels and reduced amenities but the sand is transferred at a much higher rate than the method of trucking.

In the case of the Geraldton-Greenough shoreline, the quantities of renourishment are small and typically do not warrant present bypassing systems.

3.5 Environmental Impact of Selected Options

Possible environmental impacts from the dredging and replenishment programme and the construction of seawalls or breakwaters in critical locations include construction on seagrass meadows, turbidity during construction causing light attenuation and/or sedimentation, impacts on benthic fauna, creation of conditions suitable for pest species, and environmental effects on sand source areas. The use of trucks for sand bypassing (or land imported sand) will result in greenhouse gas emissions.

The potential impacts shall be monitored and minimised as much as possible to reduce the risks to the coastal ecosystem. Detailed assessments of this risk would be required as part of the design and environmental assessment process. However, benthic fauna are generally capable of quick recovery if disturbed. Dune rehabilitation works shall be undertaken in affected areas where dune flora and fauna are disrupted.

4. DISCUSSION OF COASTAL PROTECTION OPTIONS

4.1 Coastal Processes

Based on the literature review of historical work and sediment budget analysis carried out by WorleyParsons, the sediment transport of the region has significant spatial and temporal variations that are driven by the bathymetry and wave climate. WorleyParsons has also carried out numerical modelling of wave and sediment transport to assess the shoreline evolution along the Geraldton-Greenough coastline.

The results of this study have shown a number of key observations, which define the background of the coastal dynamics for this area as follows:

- The coastal cell between Point Moore and Glenfield beach is a well defined cell where a significant amount of survey and historical data sets exist which allow sediment budgets to be assessed;
- The sediment transport potential within this cell is dynamic and can have significant annual variation;
- The sediment budget of this cell is in deficit, on an annual average, with sediment being lost through the northern boundary and offshore.

Conditions at specific beaches, after five years of the Northern Beaches Stabilisation Programme, are summarised in Figure 2-15, from which the following observations can be drawn:

- Town beach is relatively stable but is exposed to crosshore transport during storm events;
- A large quantity of sediment remains available along Pages Beach which has been accreting over the last five years ;
- The section between the Batavia Coast Marina and the offshore breakwater has remained stable with replenishment. North of the breakwater, erosion is observed. A long stretch of Shoreline (Mabel St to Chapman River) is relatively stable, slightly in accretion;
- In the absence of stabilisation work, Grey's Beach and Sunset Beach have been eroding.

The WorleyParsons approach and scope of work focused on the general understanding of the coastal processes, as this is essential for design of successful coastal protection solutions. As demonstrated by the observations in the historical work as well as the modelling which has been undertaken for this study, the management strategies need to deal with:

- the high potential for longshore sediment transport between the Northern Beaches, Sunset Beach and Glenfield Beach;
- the influence of seasonal variations on the longshore transport, especially at Sunset Beach;

- The high potential impact of the Chapman River's role as primary sediment source/sink of the Champion Bay cell.

4.2 General Considerations

Successful long-term coastal protection solutions seek to directly address and work with the natural physical processes responsible for the erosion problems. At Geraldton, beach renourishment in combination with supplementary coastal structures to reduce sediment loss by alongshore and crosshore sediment transport or to provide a last line of defence are all plausible solutions. Due to the complexity of the coastal processes, involving changes at different spatial and temporal scales, a unique and universal solution does not exist to mitigate the coastal erosion problems. In many cases, the final solution is driven by aesthetics and social values.

From the coastal vulnerability assessment corresponding to a 20 year period, the areas requiring beach protection management are:

- The section North of the detached breakwater
- Sunset Beach
- South of Chapman River (Frederick Street)
- Grey's Beach

The areas requiring Active Beach Monitoring to detect future threat to the existing development are:

- The section between Elphick Avenue and Champion Bay Rise
- The section in the area of Morris Street and Cecily Street.
- Point Moore (along the Car Park)
- Pages Beach
- Town Beach

The "Do Nothing" or "Managed Recession" solution for the Northern Beaches and Sunset Beach (Figure 4-1 and Figure 4-2) will show gradual recession and an increased area of beach and development placed under threat of erosion. Analysis of the outcome is important as it demonstrates the need for an adequate coastal management plan.

As shown on Figure 4-3, continuation of the present Northern Beaches Stabilisation Programme will not prevent shoreline erosion north of the detached breakwater. Therefore, an adjustment of the programme is required.

Regarding the relative quantities of sand involved in the sediment transport processes in Geraldton (a few thousands of cubic metres compared to hundreds of thousands in the Gold Coast, for example), sand nourishment and dune management is a sound base case from which comparisons can be made. This sand nourishment option combines effectiveness, aesthetics and public safety aspects.

Sand for beach renourishment can be sourced from:

- Pages Beach (sand bypassing): present extraction is 10,500 m^3/year, which may be increased up to 17,000 m^3/year. As the sand from Pages Beach is finer than the sand along the other beaches, sand nourishment from this source requires larger quantities of sand. However, the present profile has to be maintained to ensure sufficient buffer against storm erosion.
- External sources of sand: sand with coarser grain size is recommended if external sand is used for beach renourishment.

In addition to the sand replenishment program, coastal structures can be used where required for local protection

Beach nourishment needs to be undertaken in conjunction with another form of sand retention device in order to reduce sediment loss by longshore and crosshore sediment transport.

Appropriate coastal structures for the study area can be:

- ***Groynes and sand replenishment***: used for beach stabilisation. The groynes have to be designed so that a balance is achieved between having a buffer for storm erosion and not trapping an excessive volume of sand. This is to minimise the amount of sediment required to fully saturate the area and the longshore sediment transport can continue.
- ***Buried Seawalls***: used as last line of defence against storms but would need to be combined with regular sand nourishment

Artificial reefs or detached breakwater, whilst adaptable for this area, would require significantly higher investigation cost and a specific and expensive strategy of monitoring and implementation over several years. The design and performance of these structures is complex and warrant this level of investigation.

To assist in the selection of a suitable combination of costal protection components, Table 4.1 compares the listed options in term of effectiveness, aesthetic and public safety. The green colour shading indicates that the option is highly recommended and fully meets the requirement (effectiveness, aesthetic or public safety. The yellow colour shading indicates that the option is recommended and meets the majority the requirement of the column providing certain conditions. Orange colour shading indicates potential negative impact on the considered requirement.

Table 4.1 Comparison of coastal protections

	Effectiveness	Aesthetics	Public Safety
Do Nothing or Managed Recession	Most effective as no human interaction with natural processes	Intrusion on beach aesthetics if human made structures which will be engulfed by the sea are not dismantled	Public access to the beach Need for a retreat plan in case of threat to infrastructure and consider relocation of residents and dismantlement to prevent sea pollution
Nourishment and Dune Management	Most effective in areas of low alongshore sediment transport, unless used in conjunction with control measures Sustainable issues related to source	Positive aesthetic impacts, as long as similar colour and grain size is used.	No negative impacts to public safety unless courser grain size is used (can lead to stronger plunging waves)
Buried Seawall	Effective as a last line of defence against storm erosion can result in erosion downward of the littoral drift if not associated with regular nourishment	No intrusion on beach aesthetics if associated with beach nourishment and dune management Immediate intrusion on beach aesthetics and natural character after a storm event if sand cover is lost. Can be re-instated quickly without damage.	No negative impacts to public safety unless Not associated with beach nourishment: strong currents and increase wave agitation adjacent in the vicinity of the structure
Groynes and replenishment	Most effective when there is a predominant alongshore transport Allow sand bypassing and beach sand retention Can exacerbate downstream erosion	Intrusion on beach aesthetics and natural character and can block alongshore beach access if rock is used instead of geotextile.	Public access to the structure if not associated with beach nourishment, can creates strong offshore directed wave driven circulation currents adjacent to the groyne
Detached Breakwaters and replenishment	Most effective in areas with low longshore sediment transport. Can exacerbate downstream erosion	Exposed crest reduces the natural character of the coast feeling of being enclosed	If existence of a tombolo, can create strong offshore directed wave driven circulation currents Potential safety problems on the structure, since emerged part
Submerged Reefs and replenishment	Theoretically effective in areas where erosion is driven by waves May need to be improved	Very low aesthetic impacts, since always covered by water.	Increased public safety: lower waves and currents at the beach. Can cause navigation problems

4.3 Coastal Protection Options: Area Specific Options

4.3.1 Northern Beaches

Along the Northern Beaches, the following options could mitigate coastal erosion issues:

- Increasing the sand renourishment volumes and deposition by 10,000 m^3/year north of the detached breakwater (Figure 4-4): an adjustment of the NSBP would allow maintaining the present shoreline position providing 22,500 m^3/year of sand renourishment. However, if the beach was maintained at its present position, there would not be sufficient buffer to protect infrastructures such as the pathway, barbecue, picnic areas, etc;
- buried seawall of 300m combined with regular renourishment of 22,500 m^3/year (Figure 4-5)
- groyne, located 400m north of the breakwater, with an initial sand replenishment of about 100,000 m^3 and ongoing renourishment of 22,500 m^3/year would allow a buffer to be established against storm erosion (Figure 4-6);
- Similar option than the above item but with an additional 150m seawall north of the groyne to prevent threat from any unexpected downdrift erosion or rip current cell (Figure 4-7).

4.3.2 Sunset Beach

Implantation of structures such as a groyne, detached breakwater or artificial reef is not recommended near the Chapman River due to the high seasonal and annual variability of the longshore transport direction in this area and the complexity of sediment dynamics at the Chapman River Mouth. The river can indeed discharge a large quantity of sediment, which may bury or expose the structure, potentially causing unpredictable behaviour at river mouth and upstream. Moreover, such structures are also likely to interact negatively with the river discharge (for example by blocking the discharge flow). Therefore, a structure having no impact on the sediment transport such as the implementation of buried seawall is preferred in this application.

At Sunset Beach, in the absence of an erosion control solution (Figure 4-2), the Caravan Park and adjacent public car parks may be threatened. The following options could mitigate coastal erosion issue and provide sufficient buffer against storm erosion to protect the Caravan Park and other developments:

- initial beach nourishment of 100,000 m^3 combined with regular renourishment of 10,000 m^3/year;
- Buried seawall of 300m combined with regular renourishment of 10,000 m^3/year (Figure 4-8).

4.3.3 South of Chapman River

South of Chapman River, the shoreline is relatively stable but the setback distance is not sufficient according to the 20 year coastal vulnerability assessment.

As described above, the implantation of structures such as a groyne, detached breakwater or artificial reef is not recommended near the Chapman Rive. A buried seawall of 150m should provide the required protection for the developments in this area (Figure 4-9)

4.3.4 Grey's Beach

At Grey's Beach, following the same basis of avoiding impact on sediment transport, similar options could mitigate coastal erosion issues and provide sufficient buffer against storm erosion to protect the car park:

- Initial beach nourishment of 10,000 m^3 combined with regular renourishment of 2,000 m^3/year
- Buried seawall of 150m combined with regular renourishment of 2,000 m^3/year (Figure 4-10).

4.3.5 Net Present Value

Table 4.2 presents a high level cost estimate of different options ranging from beach renourishment to groyne and seawall. The costs have been estimated for the different individual options presented above and correspond to the costs for the different annual volume of sand bypassing, initial nourishment and the different costal structures ("40m groyne and 150m seawall" or "300m seawall" for the Northern Beaches, "300m seawall" for Sunset Beach, "150m seawall" south of Chapman River, "50m seawall" for Grey's Beach). Details of these estimates are presented in Appendix F.

For a high level estimate of the financial outcomes of the various options including up-front costs and ongoing maintenance, a Net Present Value assessment is necessary. For this purpose, the Net Present Value of cost over a 20 year period is presented in Table 4.3 for different options based on indicative costs.

In finance, the Net Present Value (NPV) of a time series of cash flows is defined as the sum of the present value of the individual cash flows. NPV is a standard method for using the time value of money to appraise long-term projects. The discount rate is an interest rate a central bank charges depository institutions that borrow reserves from it. Therefore, for a study case, three different discount rates were used in order to provide an indicative range of NPVs.

Indicative values of NPVs for the "Do Nothing" or "Managed Recession" solution are also presented to allow comparison. For the "Do Nothing" options, NPVs have been calculated considering the present value of the assets (roads, houses, various infrastructures etc) on threat according to the 20 year coastal vulnerability assessment. The "Managed Recession" option is specific of sunset Beach. For this option, the cost to move the facilities back has been considered.

In the evaluation of options for Geraldton, the use of buried seawall with ongoing nourishment and dune management offers a balanced solution with comparative NPV meeting the high level of aesthetic outcome expected by the public whilst producing the level of protection required to existing coastal infrastructure. It would appear to meet most of the objectives of the working group.

The following notes can be drawn:

- Along the Northern Beaches, the value of the calculated NPV of the "Do Nothing" option is more than 12 times the cost of the most expensive proposed coastal protection option. Therefore, a costal management strategy has to be maintained.

- Along Sunset Beach, NPVs are similar for the "Managed Recession" option and the most expensive proposed coastal protection option based on a 300m buried seawall.

- South of Chapman River, the calculated "Do Nothing" option NPV value is more than 2.5 times the NPV value of the most expensive proposed coastal protection option based on a 150m buried seawall.

- Along the western part of Grey's Beach, NPV for the "Do Nothing" option is significantly less (more than 3 times) than the NPV for the most expensive proposed option based on a 50m buried seawall.

Table 4.2 High level costing

Option	Cost ($1000)
Sand renourishment 10,000 m^3	120
Sand renourishment 12,500 m^3	162
Sand renourishment 22,500 m^3	225
Additional 2000 m^3 of bypassing	29
Initial nourishment 100,000 m^3	306
40m Groyne	299
50m buried seawall	236
150m buried seawall	790
300m buried seawall	1,523

Table 4.3 High Level Estimate of Net Present Value of Cost over a 20 year period

Scenario	NPV ($million) at different discount rates		
	4%	7%	10%
Northern beaches			
Do Nothing	-56.4	-54.8	-53.3
Present Northern Beaches Stabilization Programme	-2.2	-1.7	-1.4
Increase of bypassing up to 22,500 m^3/year	-3.1	-2.4	-1.9
Construction of 300m buried seawall + 22,500 m^3/year bypassing	-4.5	-3.8	-3.3
Construction of groyne + initial nourishment + 22,500 m^3/year bypassing	-3.4	-2.7	-2.3
Construction of groyne+ 150m buried seawall + initial nourishment+ 22,500 m^3/year bypassing	-4.2	-3.5	-3.0
Sunset Beach			
Managed Retreat	-2.2	-2.1	-2.1
Initial nourishment of 100,000 m^3 and nourishment of 10,000 m^3/year	-1.8	-1.4	-1.2
Construction of a buried seawall+ initial nourishment+ 22,500 m^3/year bypassing	-3.0	-2.6	-2.3
South of Chapman River			
Do Nothing	-2.0	-1.9	-1.8
150m buried seawall	-0.8	-0.7	-0.7
Grey's Beach			
Do Nothing	-0.3	-0.3	-0.3
Nourishment of 2,000 m^3/year	-0.4	-0.3	-0.2
Construction of a buried seawall + nourishment of 2,000 m^3/year	-1.1	-1.0	-1.0

4.4 Partners and Local Community Feedback

This section relates the main outcomes from the workshop consultation process held on the 24th March 2010. Workshop Slides are presented in Appendix H.

Information collected during the workshop regarding the attendees' preferred coastal protection option taking into account social, ecological, economic and cultural, have been summarised and are presented in Table G.1. Each option listed in section 4.2 has been evaluated for each factor with (1) considered as the lowest rating and (5) considered as the highest rating. The maximum number of votes for any factor is 90. The results of collating the information show the following facts:

4.4.1 Northern beaches

The majority of participants have favoured the option "Construction of Groyne + 150m buried seawall + initial nourishment+ 22,500 m^3/year renourishment" as a preferred solution.

The comments indicate concern that the present replenishment program does not fully address the erosion problems in this area. Members of the community seem to feel that beach nourishment is inefficient and therefore they would prefer structural options.

The group of respondents did understand that the implantation could be staged until the groynes being the final stage of the developments.

4.4.2 Sunset Beach

The majority of participants have favoured the "Do Nothing/ Managed Recession" option as a preferred solution.

While the beach nourishment and replenishment options are considered as a suitable option in term of social and environmental factors, this is does not meet economic requirements. The buried seawall is not considered as a suitable option for Sunset Beach.

4.4.3 South of Chapman River

The participants expressed their needs for more information about the necessity of protecting the developments with a buried seawall for the section South of Chapman River.

4.4.4 Grey's Beach

At Grey's Beach, the majority of participants have favored the option of "Managed retreat" as a preferred solution. Further nourishment, associated or not with buried seawall, is not considered as an economical option.

4.4.5 Other Comments on Coastal Protection

The questions raised during the presentation highlighted the demands for coastal structures made from alternative material such as geotextiles.

Some participants also showed interest in a submerged structure such as an artificial reef for a coastal protection solution.

Some participants expressed the need for more community participation though education /awareness of ecological processes and how they impact on people, local government, building bylaws and agency and policy restraints.

5. COASTAL MANAGEMENT PLANNING

The following recommendations have been drawn from the technical investigation as well as findings from the public consultation.

5.1 General Recommendations for Coastal Management Planning

From the coastal vulnerability assessment for a 20 year timeframe, four of the areas require beach protection management (South of Chapman River, Sunset Beach, Grey's Beach and the section north of the detached breakwater).

Along Sunset Beach and Grey's Beach, currently in erosion, there is a possibility for a Managed Recession option or beach nourishment option. For these sections and the section South of Chapman River, the local community does not support the construction of hard structures.

Along the section north of the detached breakwater, the current erosion processes and the proximity of developed areas justify the need for active coastal management planning. The construction of hard structures could be required.

5.1.1 South of Chapman River

This section of shoreline is not subject to strong erosion. There is therefore no direct sign that this area is at risk. However, the assessment of the required coastal setback (Section 3.2) demonstrated that this area could be at risk and would require a coastal management plan for the next 20 years.

This area will be positively impacted if additional nourishment is implemented to the south, as it is downdrift from the areas subject to renourishment. This being the case, it is preferred to monitor and assess this location if the renourishment programme is implemented to the south.

5.1.2 Sunset Beach

Sunset Beach has a history of erosion over the past 60 years. With an average rate of erosion of about 0.7 m/year, the seaward 30 to 40 metres of the Caravan Park is at risk of erosion. There are currently two leases for the Caravan Park (one for the half seaward field and one for the half landward field). At the expiration of the leases, the City of Geraldton-Greenough can change the seaward boundary if required to allow enough buffer for managed beach recession, and renourishment to the south can positively influence this area.

The decision to allow managed recessions based on the land available for the Caravan Park has to be compared with the cost of protected options. If the Managed Retreat option is selected, a coastal management plan could be required for the houses north of the Caravan Park.

5.1.3 Grey's Beach

Grey's Beach has a history of erosion over the past 60 years. The rate of erosion has increased over recent years and the Car Park and adjacent road are currently threatened.

However, there is a minimum setback distance of about 90 metres regarding the developed area. If the Managed Retreat option is selected, the City of Geraldton-Greenough could change the seaward boundary of the plot to allow enough buffer for managed beach recession, by modifying the road and car park layout.

5.1.4 North of the Detached Breakwater

This area is currently subject to erosion. This study demonstrated the need for coastal protection structures to protect this area.

A proposed solution combines a buried seawall and groyne, which would allow creation of a sandy beach acting as a buffer against storm erosion. These items could be staged with buried seawall and beach nourishment followed by implementation of the groyne,

Another solution would consist of the construction of a submerged structure to reduce the sediment transport. The effect would be to reduce the wave energy but it would not totally protect the shoreline.

5.2 Short Term Management Planning: Annual Coastal Management Programme

Regarding the relatively small quantities of sand involved in the sediment transport processes in Geraldton (in the order of 10,000 m^3 compared to 100,000 m^3 on the Gold coast for example), sand nourishment and dune management is highly recommended to maintain the beach profiles, taking into account effectiveness, aesthetics and public safety aspects.

The Northern Beaches Stabilisation Programme (NSBP) was developed in 2004 to provide a stable foreshore through sand bypassing processes and stabilisation works. The current requirements from the NBSP include, in particular, beach monitoring. Results of the desktop study as part of the works presented herein demonstrates the importance of having this accurate and detailed beach monitoring database including beach profiles, shoreline positions and sediment transport data.

Processing of the data demonstrated the high annual variability of the volumes of the beaches as shown in particular at Pages Beach and the Northern Beaches (section 2.2.2). The sand nourishment volumes proposed for sand bypassing in section 4.2 correspond to the averaged trend of volume variation based on sediment transport modelling; this provided an average estimate of how the current sand bypassing volumes should be adjusted to maintain the existing shoreline position and the associated estimated cost.

The volume of sand required to maintain the beach stability varies from year to year, mainly depending on the wave climate and the severity of winter storms. For example, the additional volume of sand required to maintain the beach profile north of the Batavia Coast Marina has varied from 15,000 m^3/year to 5,000 m^3/year since September 2006 as presented in Table 5.1.

The Beach Management Programme aims to maintain a proposed profile over the long term by combining Beach Monitoring and Beach Nourishment on a yearly basis.

Table 5.1 Yearly average variations along the section north of the Batavia Coast Marina since September 2004

Period	09/2004 09/2005	09/2005 09/2006	09/2006 09/2007	09/2007 11/2009
Volume variation (m^3/year)	-14,700	-12,500	-7,900	-4,600

5.2.1 Active Beach Monitoring

It is highly recommended to maintain and implement the existing monitoring programme. This programme ranges from shoreline surveys, aerial surveys, photographic records and volumes of sand used for the nourishments. Volumes of sand applied in the nourishment process can be recorded, including volume by source location, dates of placement, placement location, prevailing weather conditions, and before and after photographic records at the placement site.

The Active Beach Monitoring Programme measures deviations from the proposed profile. The survey should be undertaken as a minimum on an annual basis at the end of summer and prior to the onset of winter storms.

For an indication of the cost, the present Beach Monitoring Programme cost is about $8,500 per survey (indicated by GPA, June 2010).

Analysis of the collected data will allow refinement of the estimates of averages and level of variability in nourishment volumes.

5.2.2 Beach Nourishment

The sand characteristics used for the nourishment should be as close as possible to the characteristics of the sand at the study site (section 3.3.4). It is anticipated that beach nourishment will be undertaken in late summer (to avoid windy months as much as possible) and early winter each year, prior to the onset of winter storms in order to provide an erosion buffer for the winter

In the event of a major storm, which causes greater erosion than annual episodic storm events, specific actions must be carried out to resolve any resulting beach damage.

5.2.3 Annual Management

The objective is to maintain a targeted profile by using a yearly management programme involving the following steps (summarized on Figure 5-1):

- Monitoring
- Assessment of the amount of sand accreted or eroded each year
- Active beach nourishment

The beach nourishment can be undertaken through sand bypassing using sand sourced from Pages Beach or imported sand from external sources.

5.3 Medium Term Management Planning: Implementation of Coastal Structures

Options have been proposed to manage coastal vulnerability for the next 20 years (Section 4). The use of coastal structures is not supported by the local community at this time for most of the sections studied except for the section north of the detached breakwater.

From a general point of view, the implementation of coastal structures along specific areas can be made step by step. As the littoral drift is northward along Champion Bay, it is likely that it influences the sediment transport and the shoreline movement northward of it. Feedback from a Beach Monitoring Programme would allow assessment of the coastal protection influence and adjustment of the Beach Nourishment Programme accordingly to maintain a targeted programme, as summarized in Figure 5-2.

5.3.1 Coastal Protection Structures

In the evaluation of options for Geraldton, the use of a buried seawall with ongoing nourishment and dune management offers a balanced solution with comparative Net Present Value and ensures a high level of aesthetic outcome and protection of coastal infrastructure; it would appear to meet most of the objectives of the working group.

Partners and members of the local community expressed interest in the use of a submerged structure such as artificial reef for a coastal protection solution. For this type of coastal protection structure, there is a need for a specific socio economic study in conjunction with a specific and detailed design study.

5.3.2 Construction Material

The use of rock materials is recommended at Geraldton were coastal structures to be adopted (section 3.3.10).

Partners and members of the local community expressed their interest in the use of alternative material such as geotextiles. If the construction of a coastal structure is the chosen solution to protect the coast against erosion, such material can be considered for the design. However, while there is an increase demand for using these materials from local communities, the partners should be aware of the associated drawbacks as discussed in section 3.3.10. Structures made of geotextiles do have the advantage that they can be easily removed, have visually low impact and have good public acceptance as they can be easily traversed with relative safety.

Geotextiles have been recently applied at a number of locations around the world. For example, a recent project (late 2008) in Busselton, Western Australia managed by the Shire of Busselton and DoT, involved three groynes made of geotextile bags. Monitoring of these structures over the next 10 years would provide better understanding regarding the longevity of this type of material.

6. SUMMARY

The City of Geraldton-Greenough commissioned WorleyParsons to undertake a coastal processes study, which can be used to support decision making on the most appropriate techniques to manage the coastal zone between Grey's Beach in the south to Sunset Beach in the north. The aim of future coastal zone management is to maintain beach stability by implementing a preferred option for coastal protection. The preferred management option needs to address the observed erosion whilst maintaining amenity of the area and minimising the economic cost to the community.

6.1 Coastal Sediment Transport Assessment

Based on the literature review of historical work and sediment budget analysis carried out by WorleyParsons, it has been determined that the sediment transport of the region has significant spatial and temporal variations. Those variations have both natural and anthropogenic causes. For instance, the Port of Geraldton and the Batavia Coast Marina have created artificial obstacles to the natural littoral drift and the rate of sediment transport on the Northern Beaches has increased due to the Port Enhancement Project (PEP) works.

The results of this study have shown a number of key observations, which define the background of the coastal dynamics of the coastal cell between Point Moore and Glenfield beach. The sediment transport potential within this cell is dynamic and can have significant annual variation.

Conditions at specific beaches, after five years of the Northern Beaches Stabilisation Programme result in the following observations being made:

- Town Beach is relatively stable but is exposed to crosshore transport during storm events;
- A large quantity of sediment remains available along Pages Beach which has been accreting over the last five years;
- The section between the Batavia Coast Marina and the offshore breakwater has remained stable with replenishment, thanks to the NSBP. Moreover, during the recent years, this section has been subject to increased wave energy since the PEP works.
- North of the breakwater, erosion is observed. A long stretch of Shoreline (Mabel St to Chapman River) is relatively stable, slightly in accretion;
- In the absence of stabilisation work, Grey's Beach and Sunset Beach have been eroding.

6.2 Coastal Management Methods

In order to identify the developed areas likely to be at threat in the next 20 years, owing to the current shoreline evolution and predicted climate changes, a methodology based on the State Coastal Planning Policy (SCPP) has been applied to the study coastal zone. From the coastal vulnerability assessment for the period considered (up to 2030), the areas identified where erosion is likely to threaten existing assets include:

- The section North of the detached breakwater
- Sunset Beach
- South of Chapman River (Frederick Street)
- Grey's Beach

The areas requiring Active Beach Monitoring to detect future threat to the existing development are:

- The section between Elphick Avenue and Champion Bay Rise
- The section in the area of Morris Street and Cecily Street.
- Point Moore (along the Car Park)
- Pages Beach
- Town Beach

From the coastal vulnerability assessment for 2110, the whole coastline is predicted to be at threat in the next 100 years. Climate change and sea level rise have the very real potential to have a significant impact on the Geraldton coast, affecting natural and cultural values, infrastructure and built assets on private and public land. The response to climate change and sea level rise needs to be both pro-active and reactive which involves actually responding to changes as they occur.

In order to select the most appropriate coastal protection solution(s) for the area requiring beach erosion management, a review of existing options has been proposed:

- Do Nothing or Managed Recession does not interfere with the natural coastal processes. The associated fiscal cost could be less than that associated with implementing coastal management options.
- Beach nourishment promotes amenity and natural character in the form of a wide sandy beach and generally, it does not have adverse effects on adjacent areas. The influence of the sand grain sizing parameter has to be considered to determine the quantities of sand for beach nourishment.
- Buried seawall: by combining seawall, beach nourishment and dune management, a buried seawall allows the maintenance of the beach amenity and aesthetics, and provides a last line defence again storm erosion. If correct beach replenishment is applied, the seawall does not influence the sediment transport and no negative impact on the shoreline along and adjacent to the structure is expected.
- Groynes build up a sand buffer wide enough to absorb erosion during storm events.

- Detached breakwaters provide protection by reducing the energy in their lee. In case of sensitive downdrift beaches like in Geraldton, the breakwaters can cause downdrift erosion, and due to the high annual variability in longshore transport, their effectiveness can be limited.

- Artificial reefs are a specific form of detached breakwater. The design of these structures is complex and their perceived performance is significantly affected where high seasonal and annual variability in transport processes is observed. Moreover there would be a significantly higher investigation cost and would require a specific and expensive strategy of monitoring / implementation over several years.

- A beach drainage system is based on the principle that sand will tend to accrete if the beach surface is permeable due to an artificially lowered water table. This option is not recommended as suitable for the Geraldton shoreline owing to its inefficiency during moderate wave conditions and storms.

6.3 Coastal Protection Options

At Geraldton, beach renourishment in combination with supplementary coastal structures to reduce the impacts of erosion processes and to provide a last line of defence are all plausible solutions.

Sand for beach renourishment can be sourced from:

- Pages Beach (sand bypassing)
- External sources of sand

Some options for coastal structures include:

- Groynes and sand replenishment may be used for beach stabilisation and designed to achieve a balance between having a buffer for storm erosion and not trapping an excessive volume of sand.
- Buried Seawalls may be used as last line of defence against storms but would need to be combined with regular sand nourishment

A range of different coastal protection scenarios have been presented for the four areas identified as likely to be at threat over a 20 year timeframe:

- Section North of the detached breakwater: the “Do Nothing” option, the possibility to increase the sand volume used for the current sand bypassing programme and the construction of a buried seawall combined, or not, with a groyne and associated beach nourishment;
- Sunset Beach: the “Managed retreat” option, an initial nourishment followed by annual nourishment and the construction of a buried seawall associated with annual nourishment;

- South of Chapman River (Frederick Street): the “Do Nothing” option and the construction of a buried seawall
- Grey’s Beach: the “Do Nothing” option, an annual nourishment and the construction of a buried seawall associated with annual nourishment.

The selected solution for coastal protection will have a significant impact on the social amenity of the beaches. As such, the selection of an appropriate solution must include contribution from the local community. It is also important that this process includes accurate technical and descriptive presentation of the behaviour of the coastline in response to various solutions. This range of different coastal protection scenarios has been the subject of public presentation and consultation process. Main outcomes from this workshop consultation process, held on the 24th March 2010, relate that the local community have preferences as follows:

- To adopt a Managed Recession approach or Beach Nourishment options;
- To avoid and/or minimise the construction of hard structures other than for the section north of the detached breakwater.

Members of the Partners and of the local community expressed their interests regarding the use of a submerged structure such as an artificial reef. The design of these structures is complex and their perceived performance is significantly affected where high seasonal and annual variability in transport processes is observed. Such a structure can however provide massive boosts for the local tourism industry and help stimulate job creation. This option should be the subject of a specific socio-economic impact study.

A high level cost estimate and an estimate of Net Present Values (NPV) for different coastal protection options revealed that:

- Along the Northern Beaches a costal management strategy has to be maintained.
- Along Sunset Beach, NPVs are similar for the “Managed Recession” option and the most expensive proposed coastal protection option, which is a 300m buried seawall.
- South of Chapman River, the calculated “Do Nothing” option NPV value is more than 2.5 times the NPV value of the most expensive proposed coastal protection option based on a 150m buried seawall.
- Along the Grey’s Beach, NPV for the “Do Nothing” option is significantly less (more than 3 times) than the NPV for the most expensive proposed option based on a 50m buried seawall.

After evaluation of coastal protection options, the use of a buried seawall with ongoing nourishment and dune management offers a balanced solution with a high level of aesthetic outcome and protection of coastal infrastructure; it would appear to meet most of the objectives of the working group. These options have been assessed in this study and details of their anticipated performance are provided. Detailed design of such structures would require additional assessment where implemented.

6.4 Recommendations for Coastal Management Planning

To maintain the targeted profile, an Annual Management Programme is suggested, involving Beach Monitoring and an Active Beach Nourishment Programme through improvement of the current Sand Bypassing Programme.

The implementation of coastal structures along specific areas can be made step by step. Feedback from the Beach Monitoring Programme would allow assessment of the coastal protection influence and adjustment of the Annual Management Programme accordingly. This will allow the City of Geraldton Greenough to maintain the targeted programme, and implement structures in the medium term in line with these refined observations. This recognises the importance that once coastal structures are selected they do become difficult to vary and therefore refinement of the preferred type, extent and shape should be based on longer term monitoring and measurement. In fact, the refinement of the replenishment programme may reduce dramatically the degree of the structure required, making the deferment of the implementation of the structure of greater value whilst replenishment is optimised in line with the short term programme.

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9. FIGURES

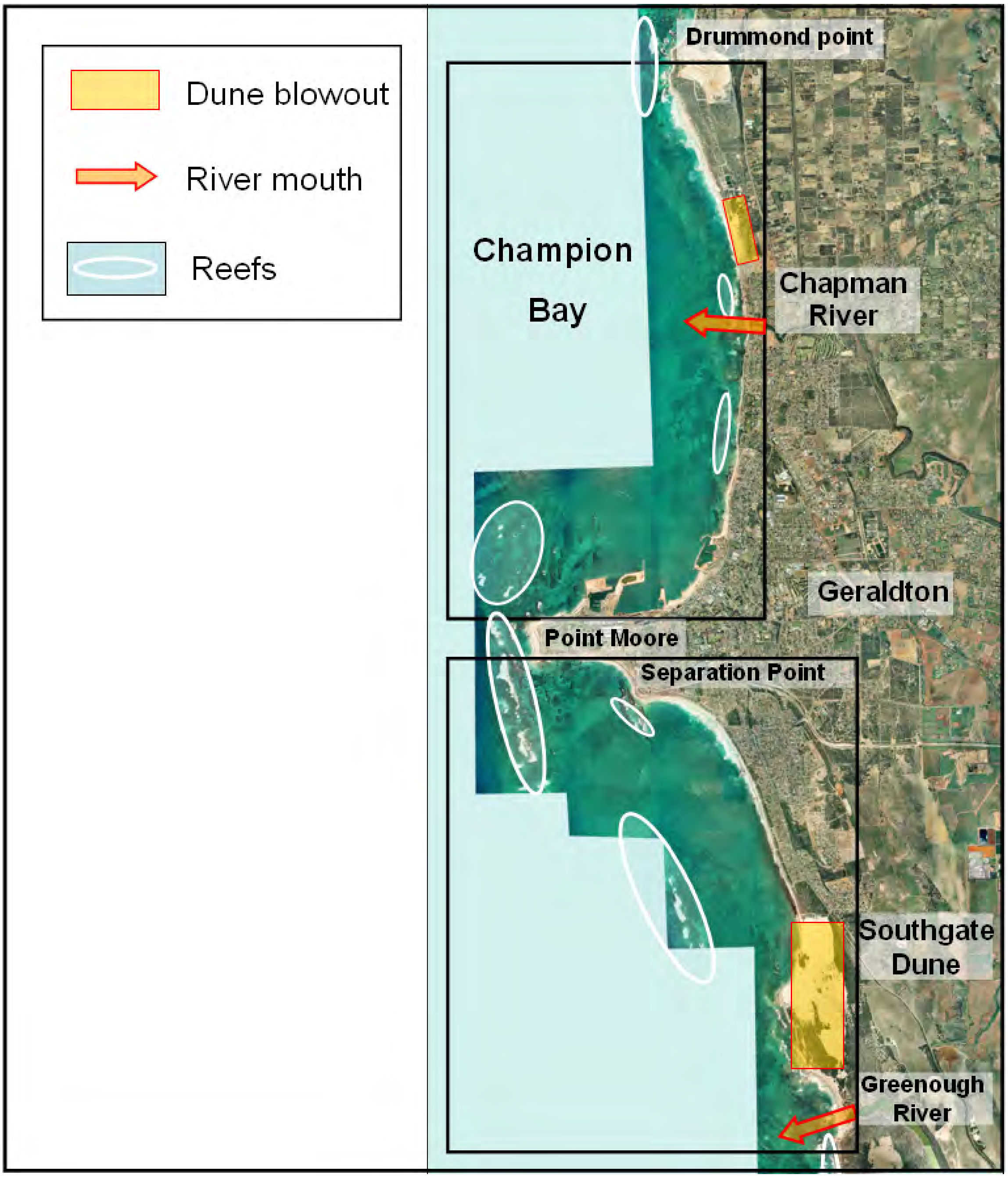

Figure 1-1 General view of the Coastline of Geraldton-Greenough

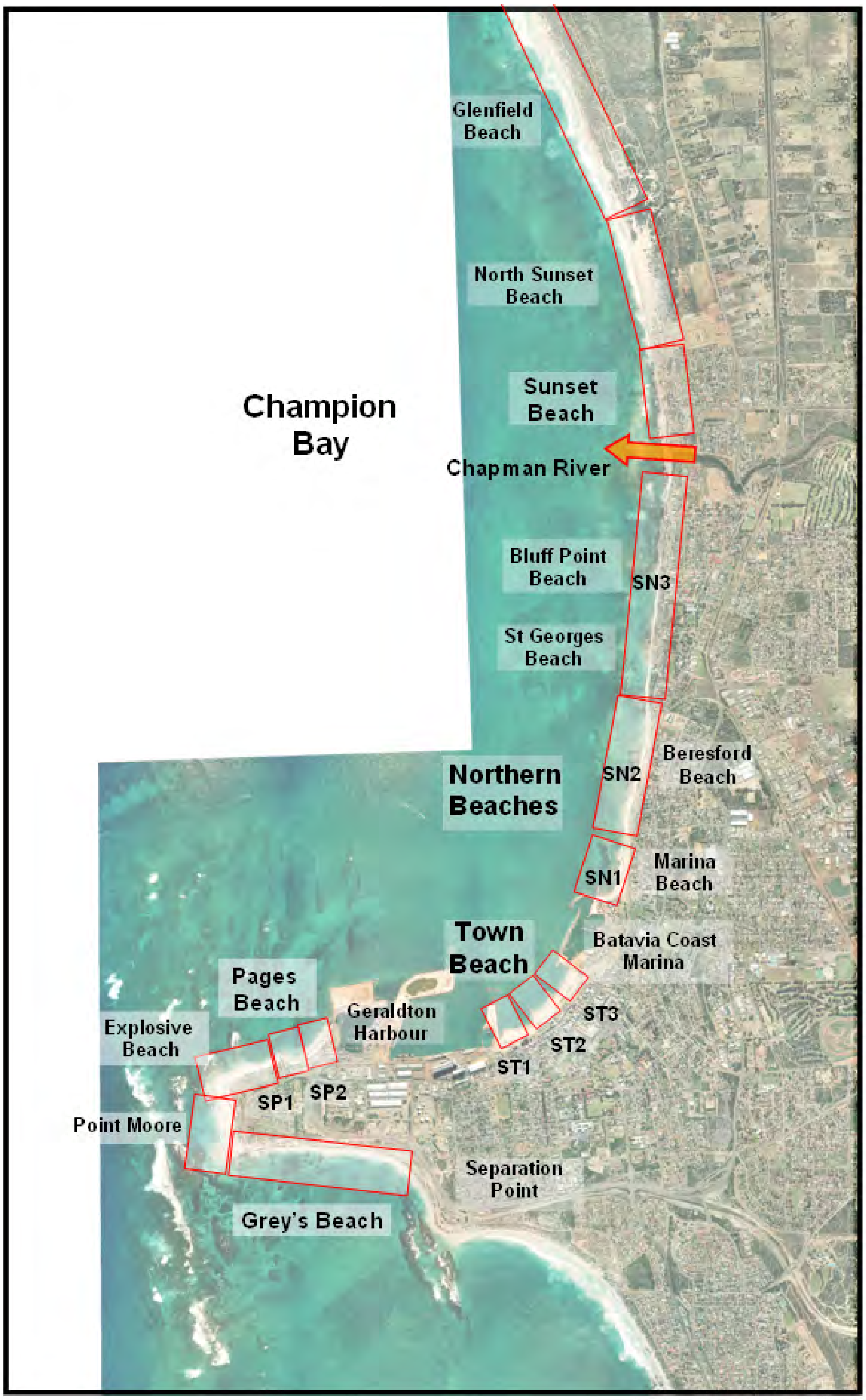

Figure 1-2 General view of the study area showing the different sections

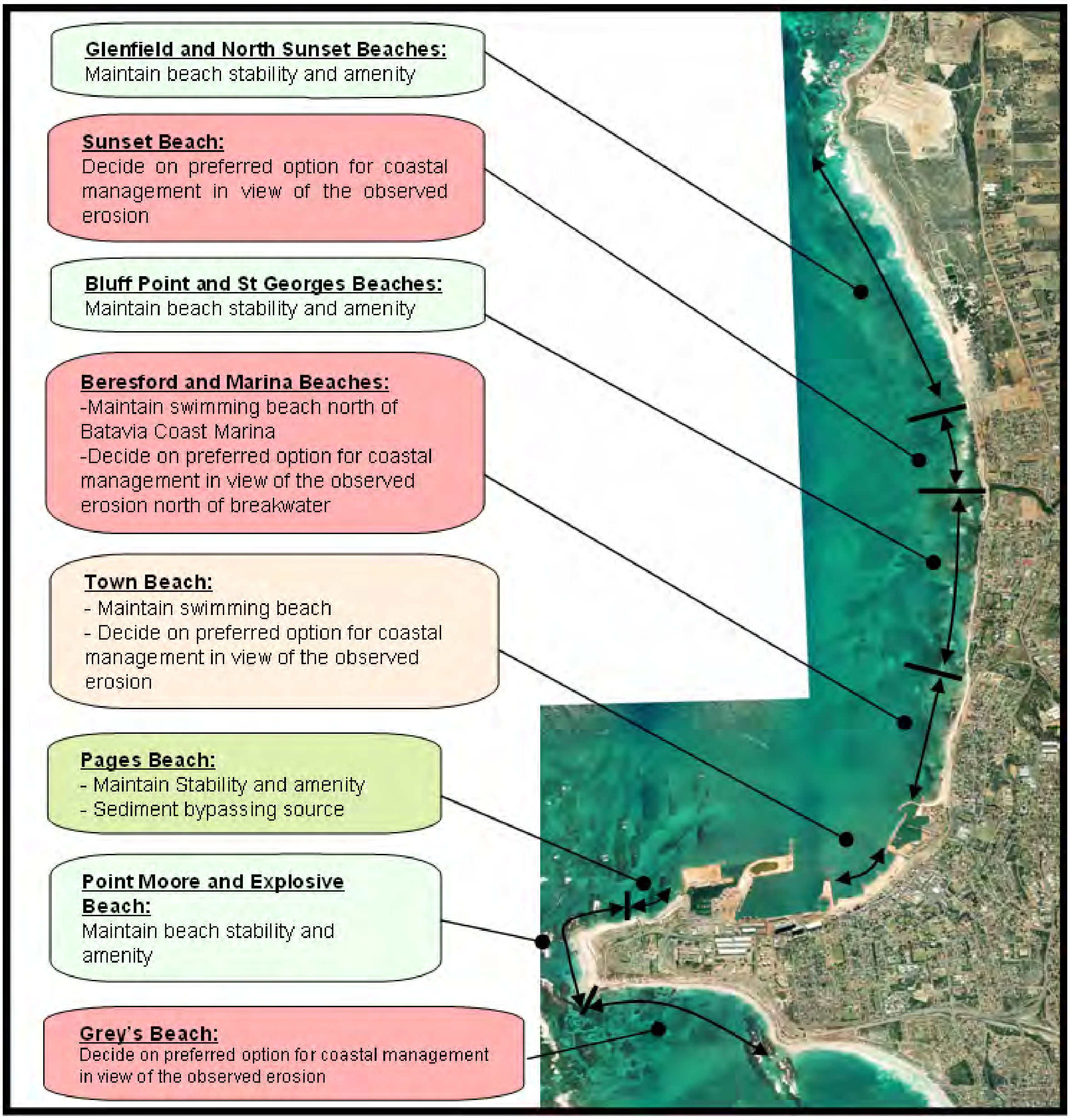

Figure 1-3 Requirements for Future Coastal Management

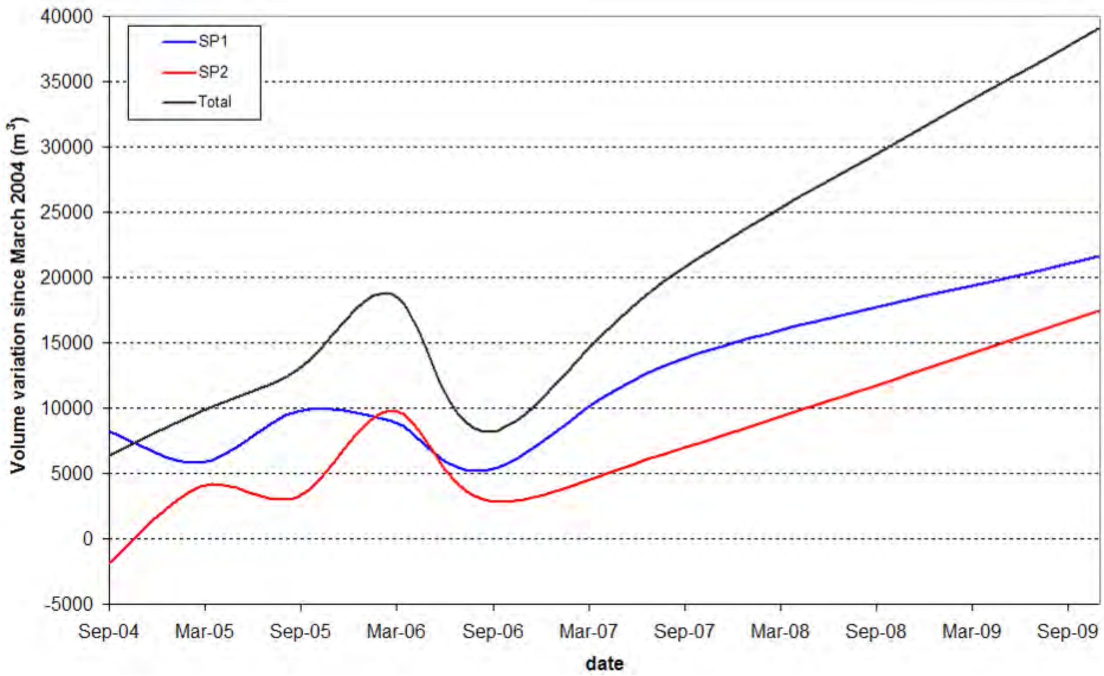

Figure 2-1 Sediment volume variations along Pages Beach since March 2004

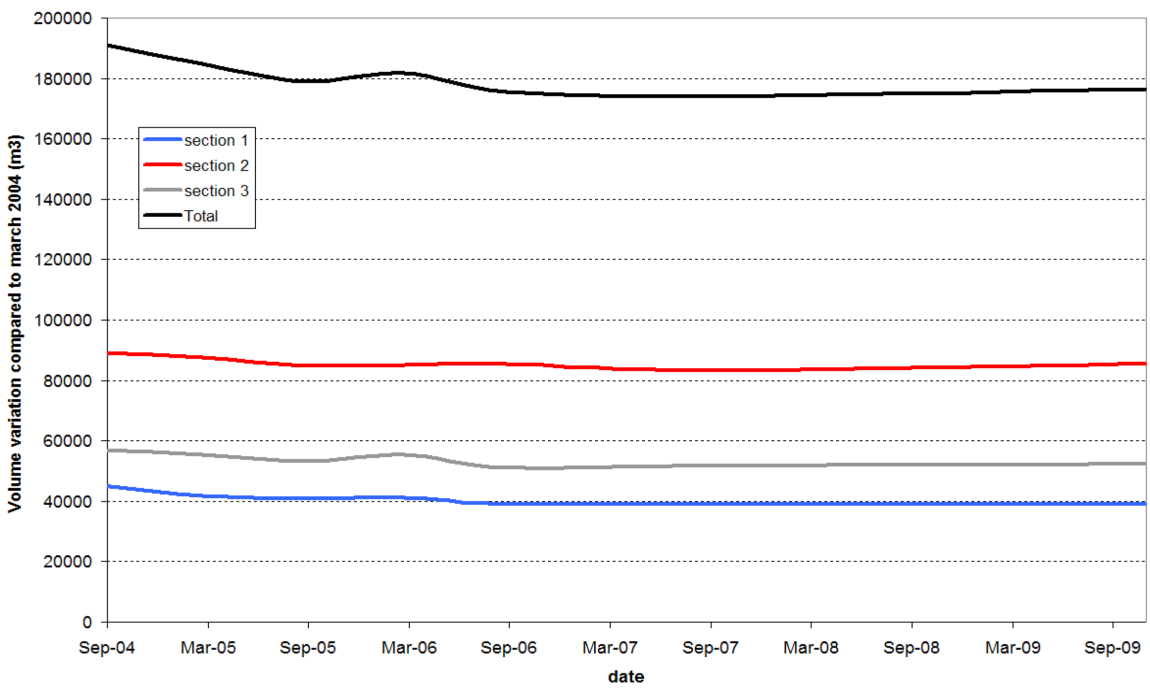

Figure 2-2 Sediment volume variations along Town Beach since March 2004

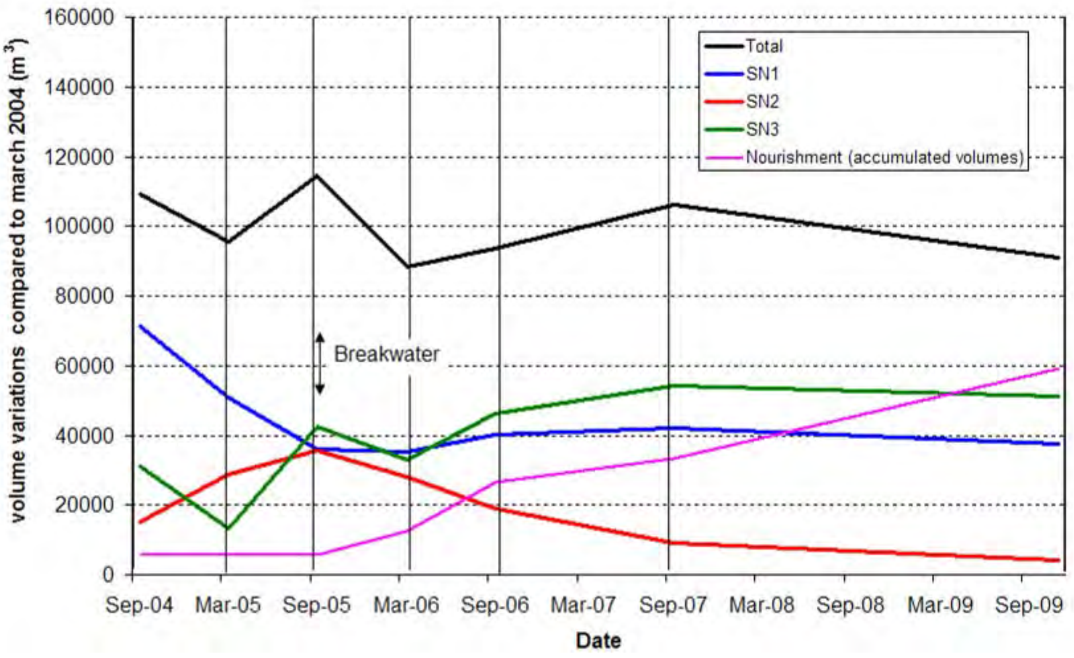

Figure 2-3 Sediment volume variation along the Northern Beaches since March 2004.

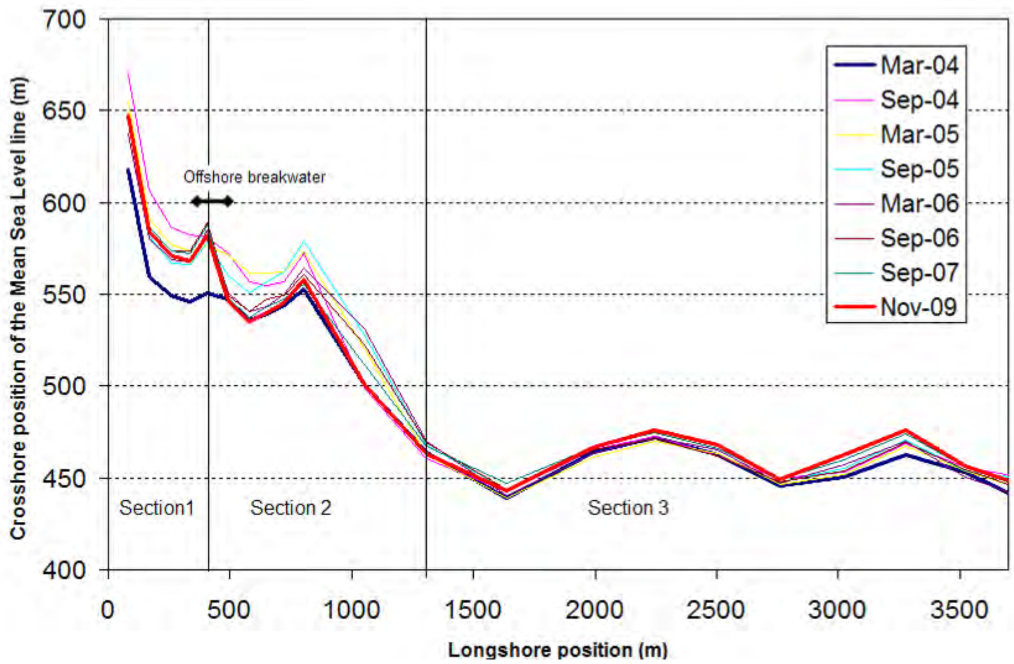

Figure 2-4 Crosshore positions of the Mean Sea Level lines along the Northern Beaches since March 2004

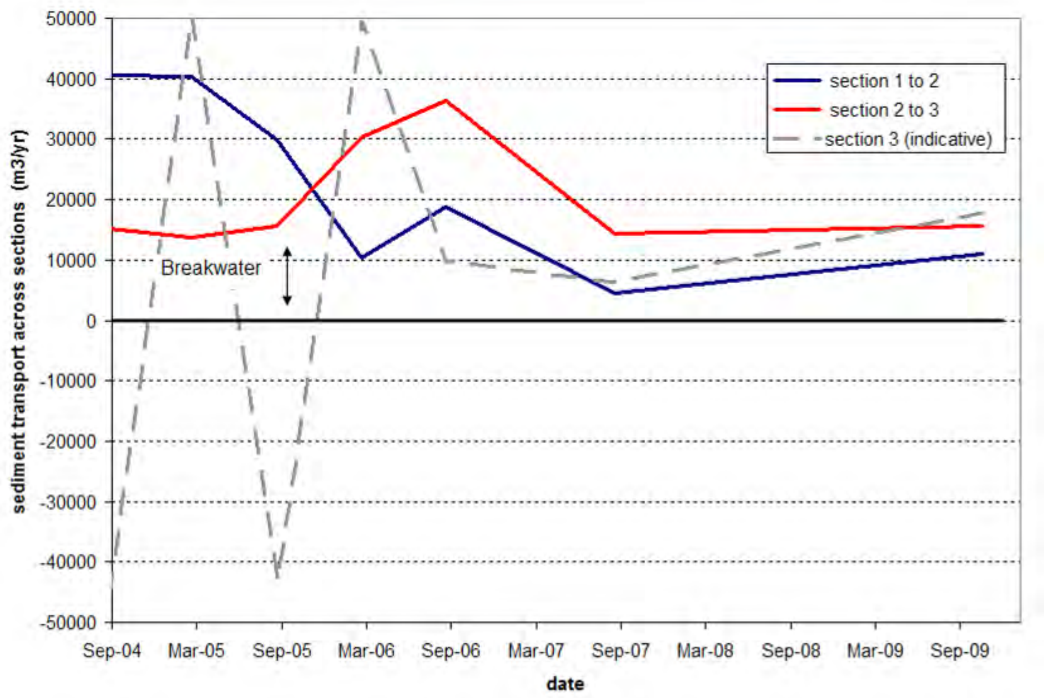

Figure 2-5 Sediment transport across the sections of the Northern Beaches (positive values are for northward longshore transport)

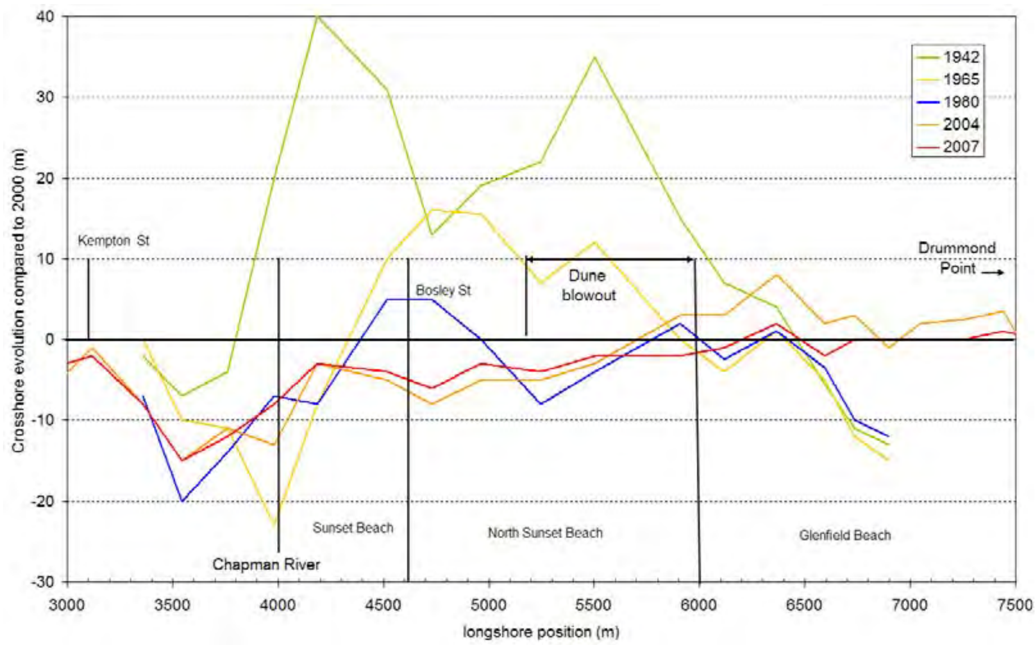

Figure 2-6 Shoreline evolution compared to the shoreline position from 2000 for the northern part of Champion Bay

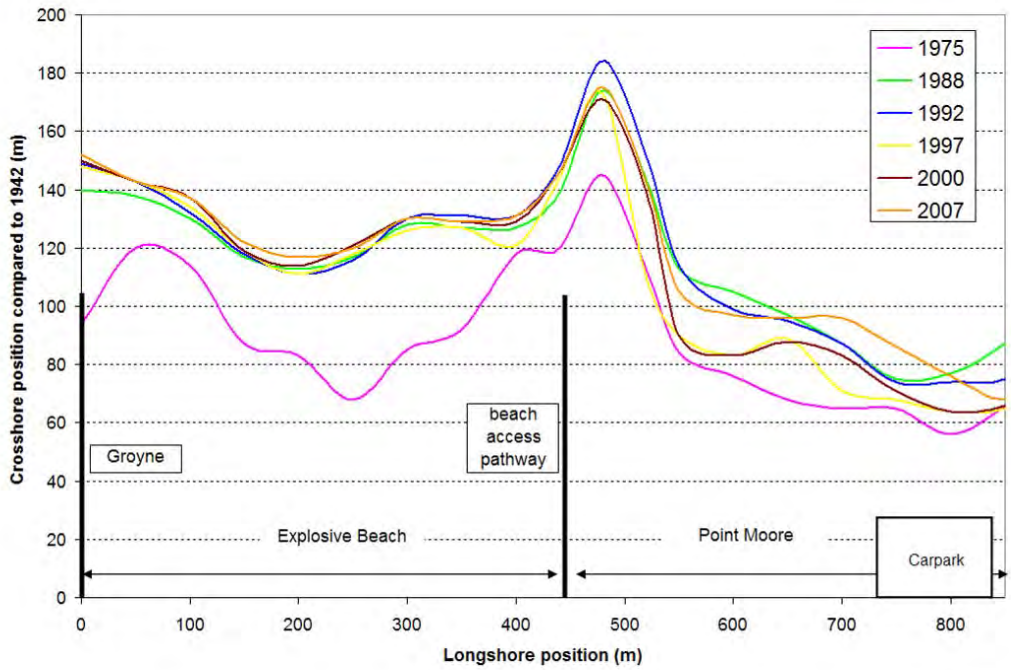

Figure 2-7 Shoreline evolution compared to the shoreline position from 1942 in Point Moore and Explosive Beach

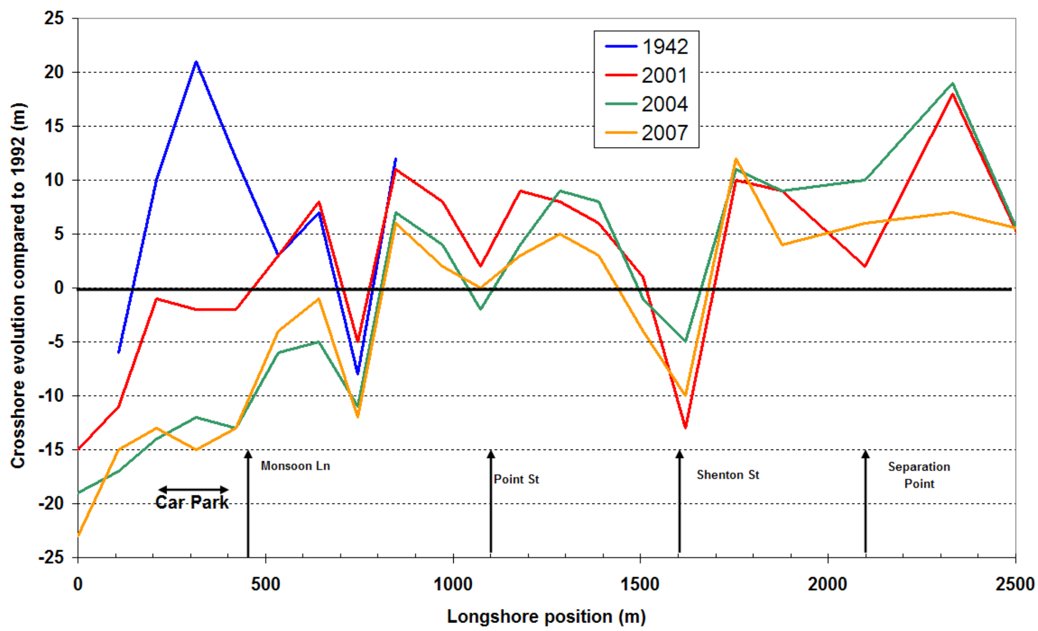

Figure 2-8 Shoreline evolution compared to the shoreline position from 1992 in Grey's Beach

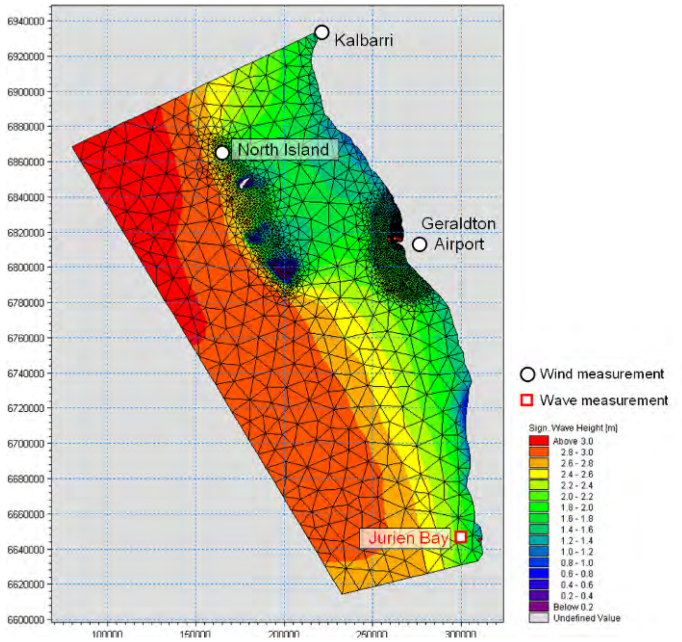

Figure 2-9 Wave Model domain and bathymetry

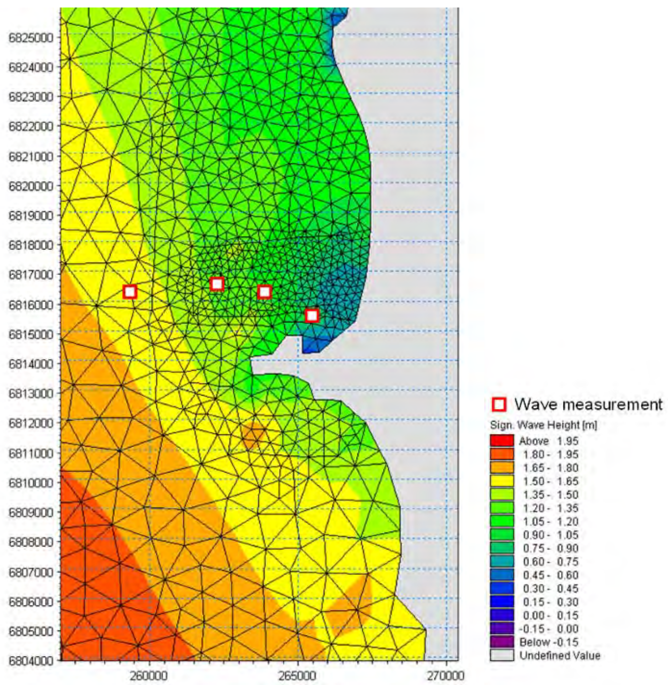

Figure 2-10 Wave Model domain and bathymetry: Geraldton area

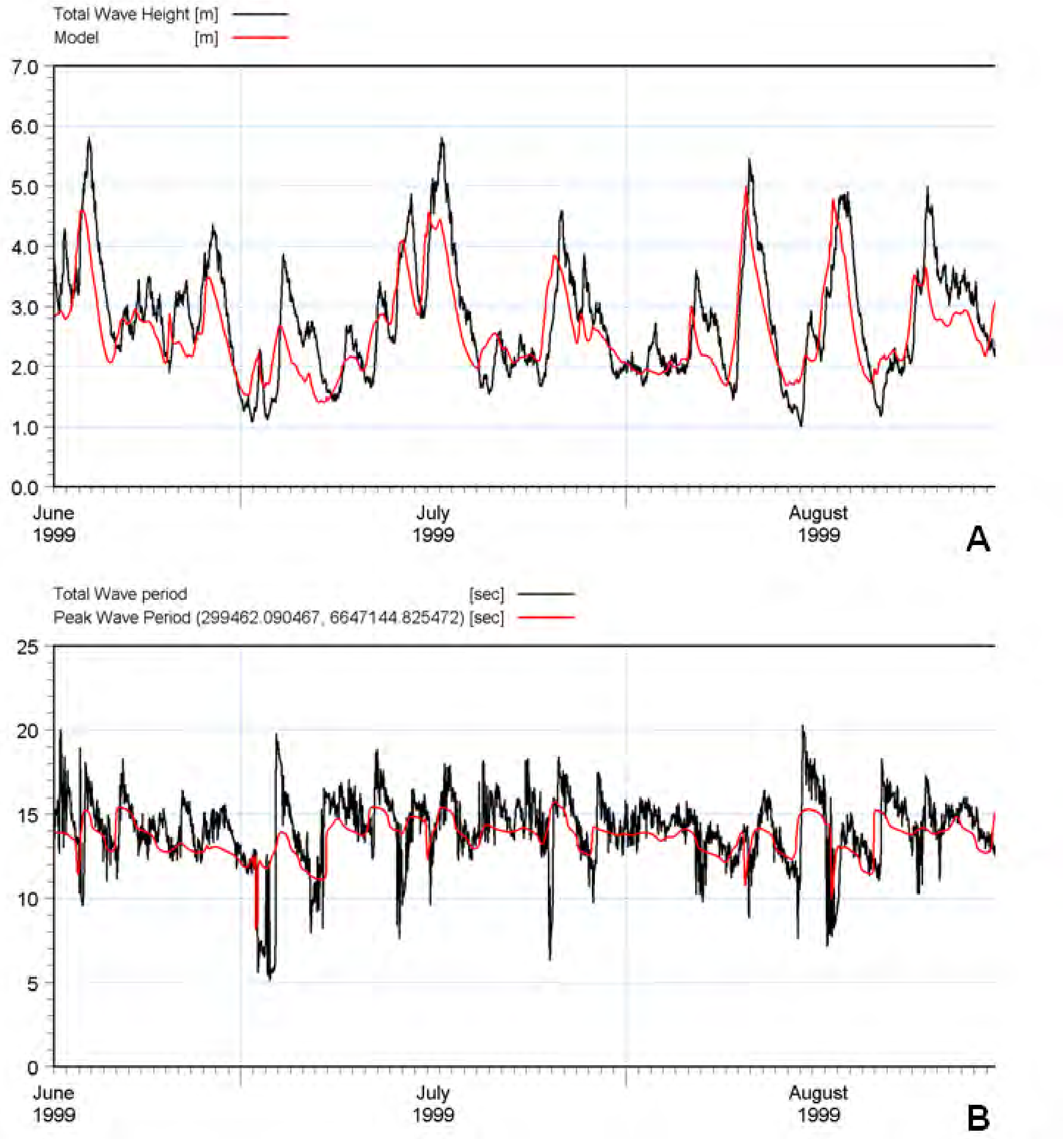

Figure 2-11 Time series of significant wave height (A) and wave period (B) in Jurien Bay; comparison of wave measurement (black lines) and model results (red lines)

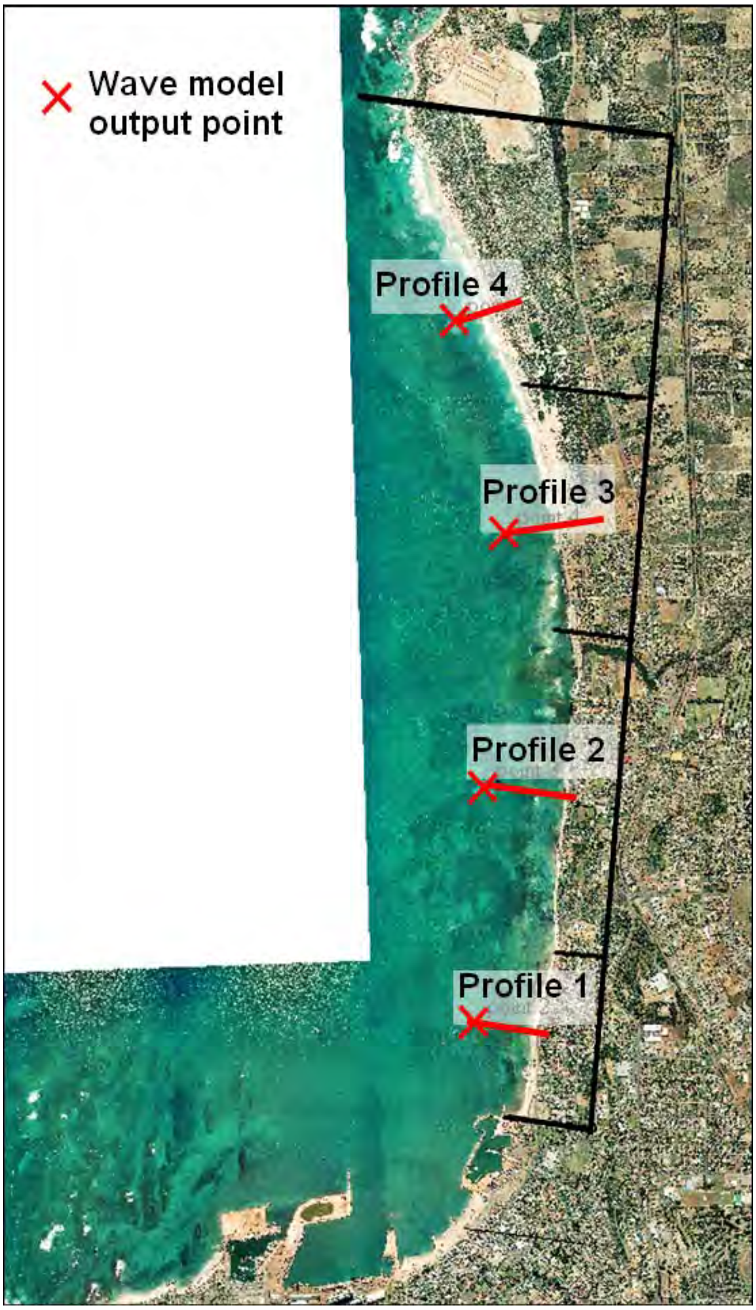

Figure 2-12 Model domain showing the wave modelling output points (red crosses), the four crosshore profiles (red lines) and the LITPACK reference line (black lines)

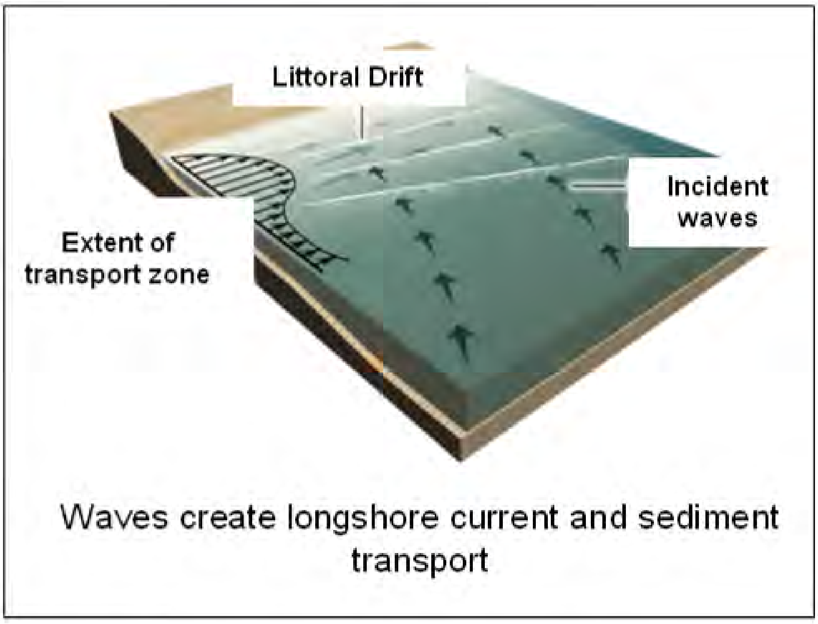

Figure 2-13 Longshore sediment transport direction depending on incident wave direction

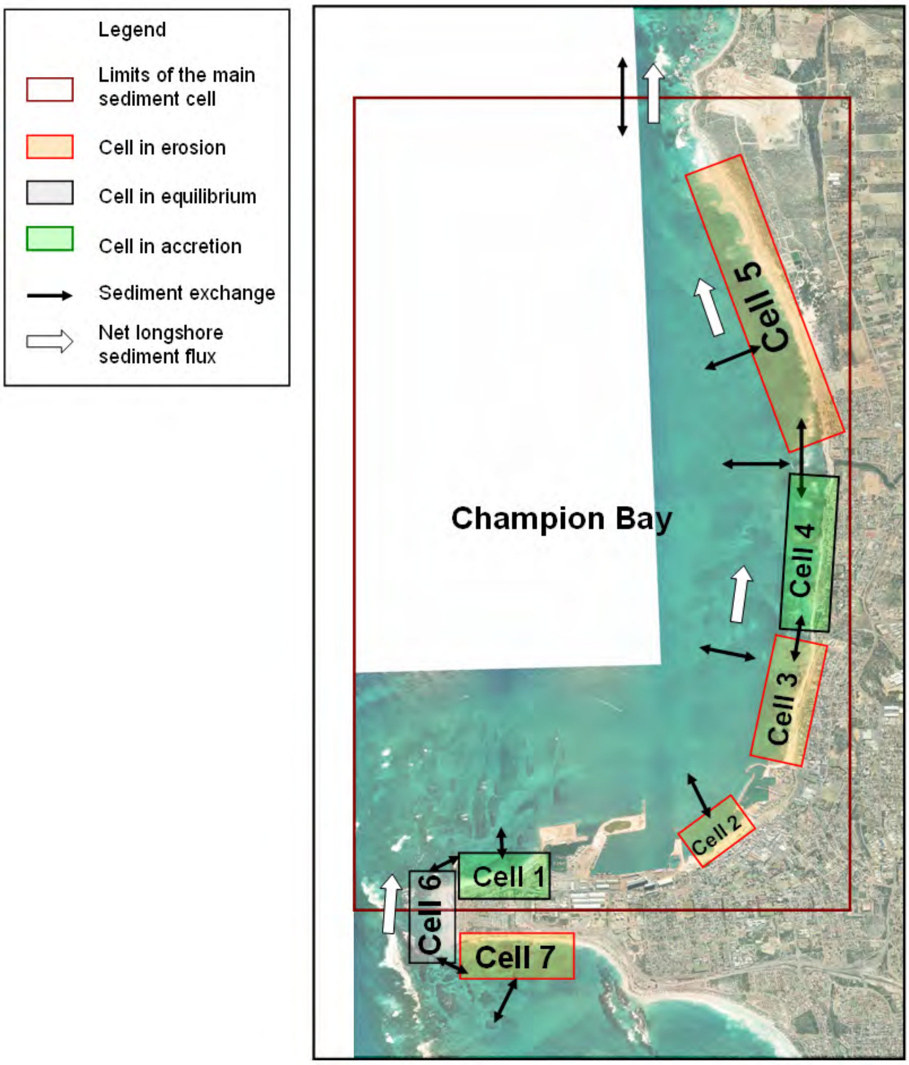

Figure 2-14 Sediment transport dynamics along the study area

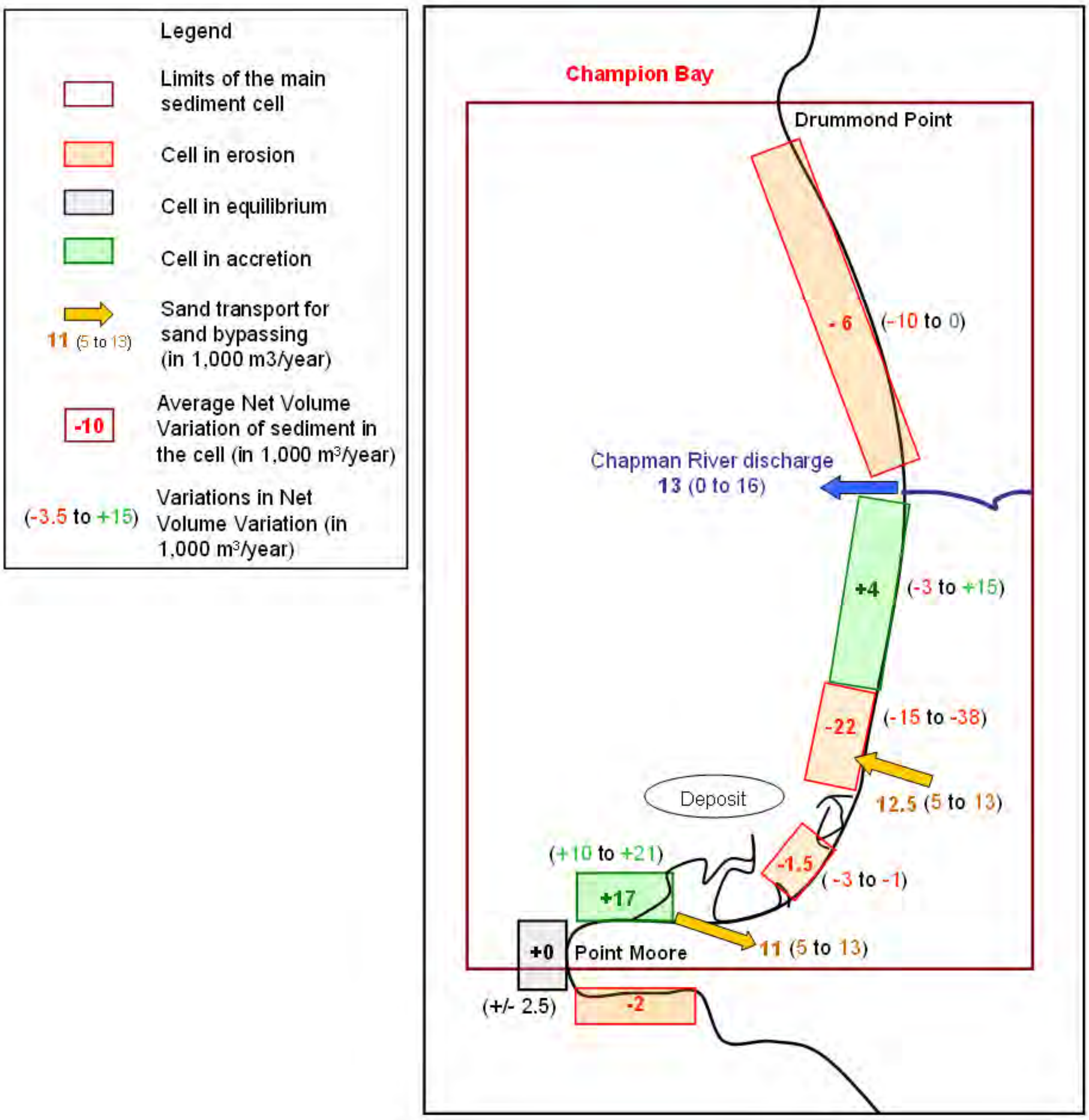

Figure 2-15 Estimated sediment budgets along the study area

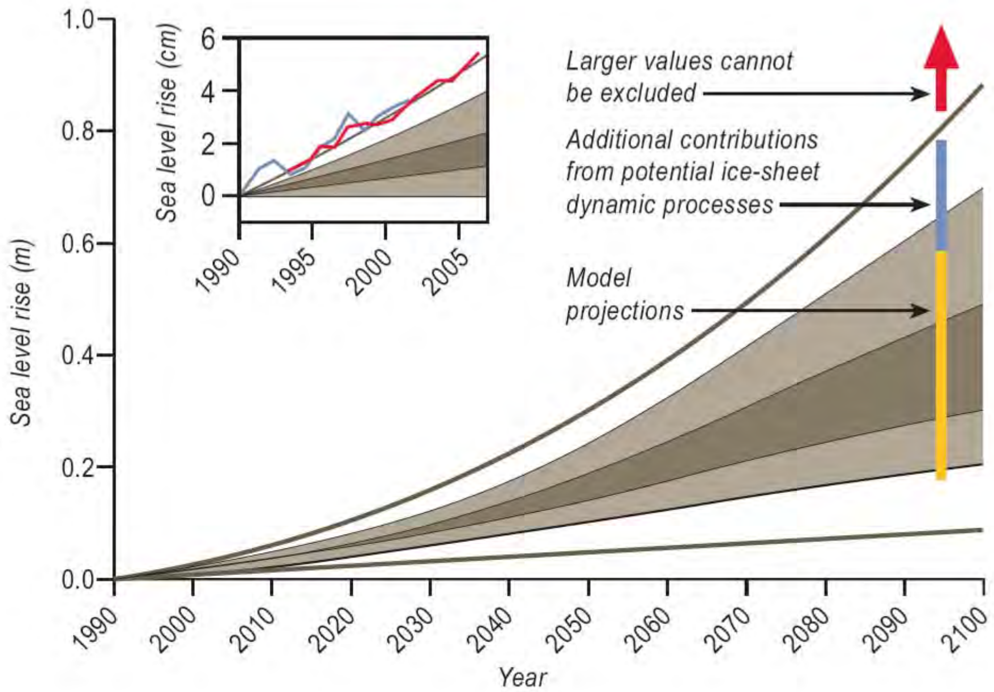

Figure 3-1 Projected Sea Level Rise for 2100 (Source ACE CRC 2008)

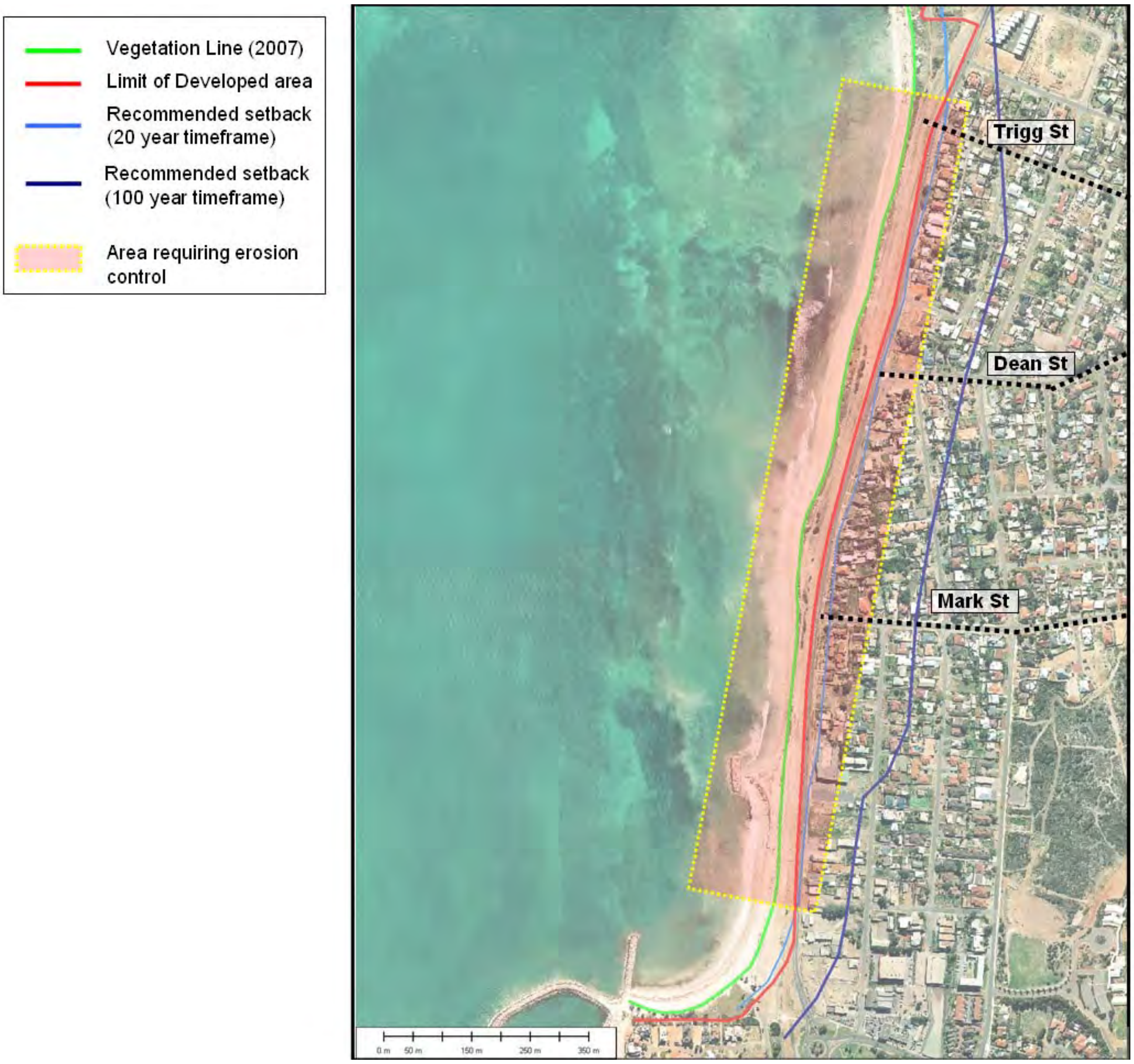

Figure 3-2 Coastal setback analysis: Northern Beaches

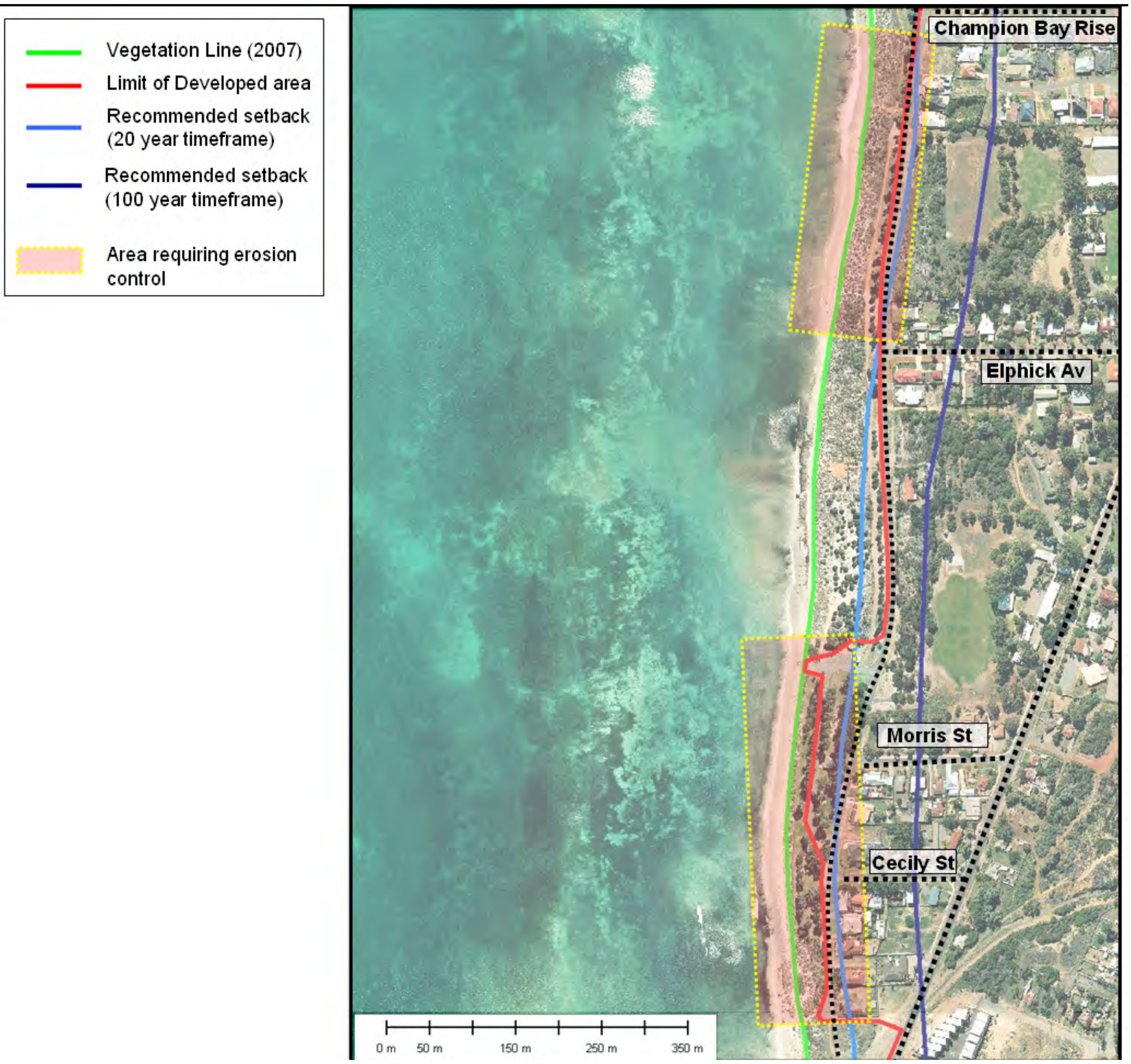

Figure 3-3 Coastal setback analysis: Northern beaches

Figure 3-4 Coastal setback analysis: South of Chapman River

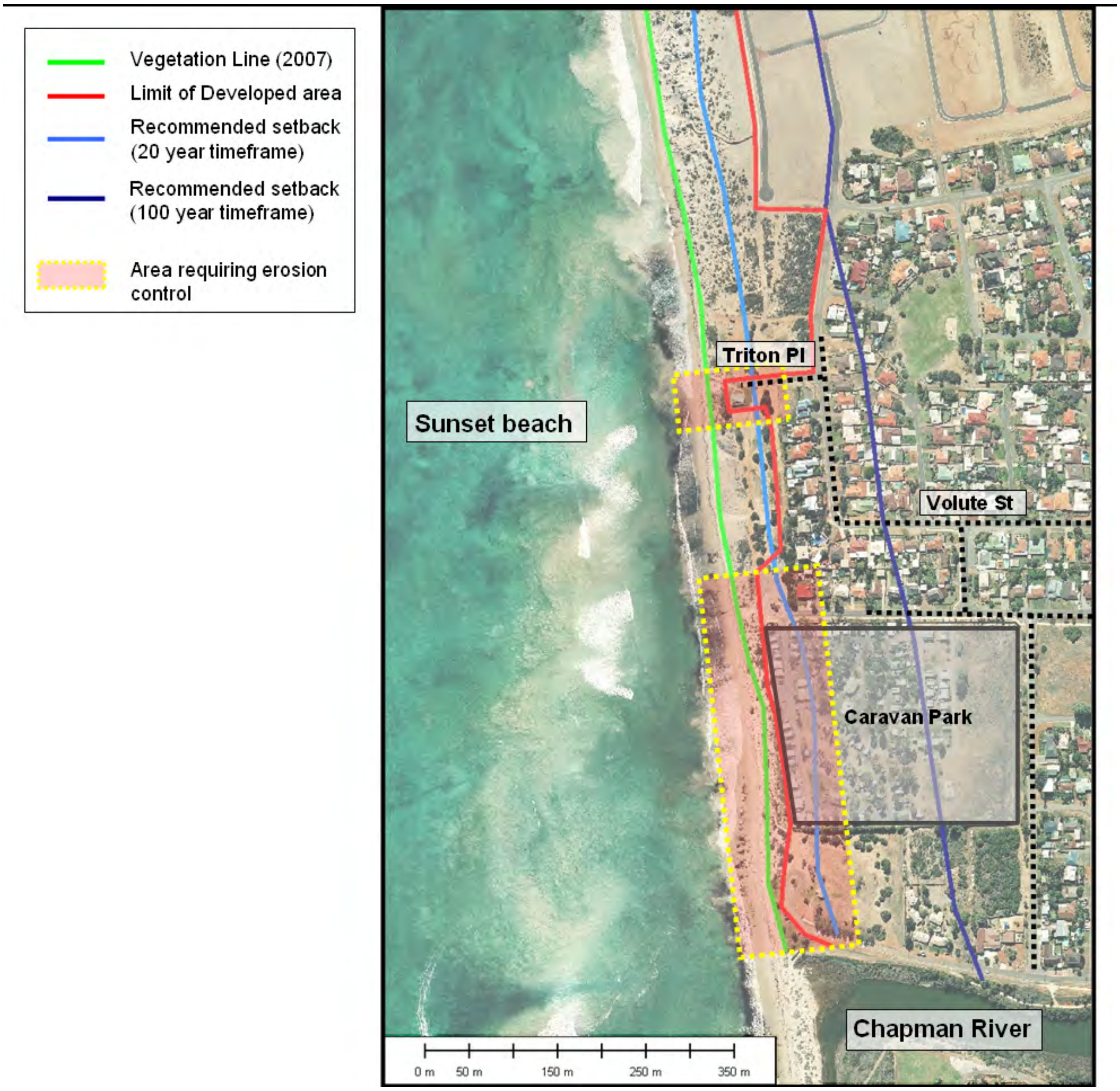

Figure 3-5 Coastal setback analysis: Sunset Beach

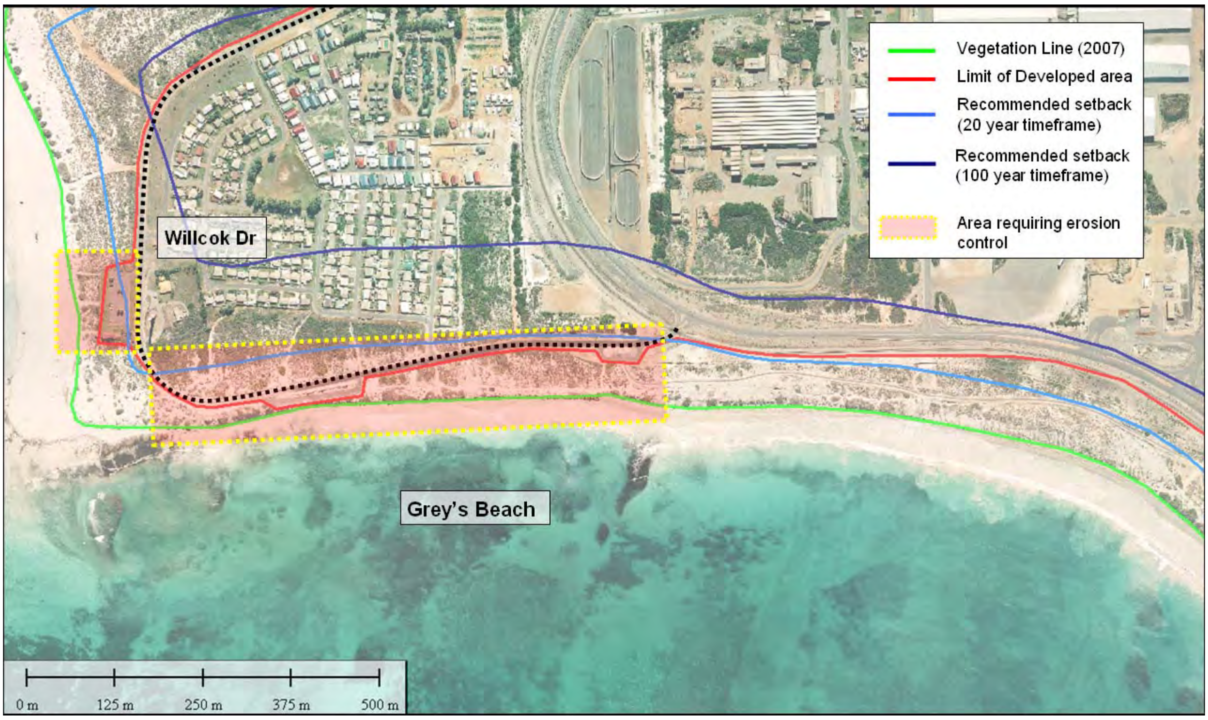

Figure 3-6 Coastal setback analysis: Grey's Beach

Figure 3-7 Coastal Protection Options

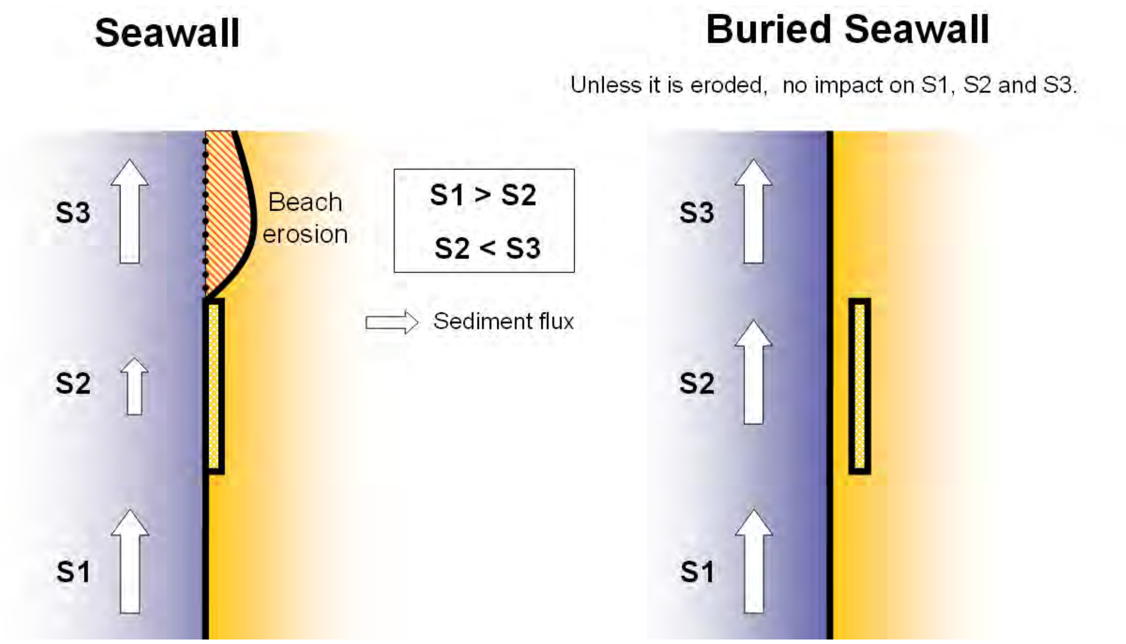

Figure 3-7a Schematic view of the effects of seawall on shoreline evolution

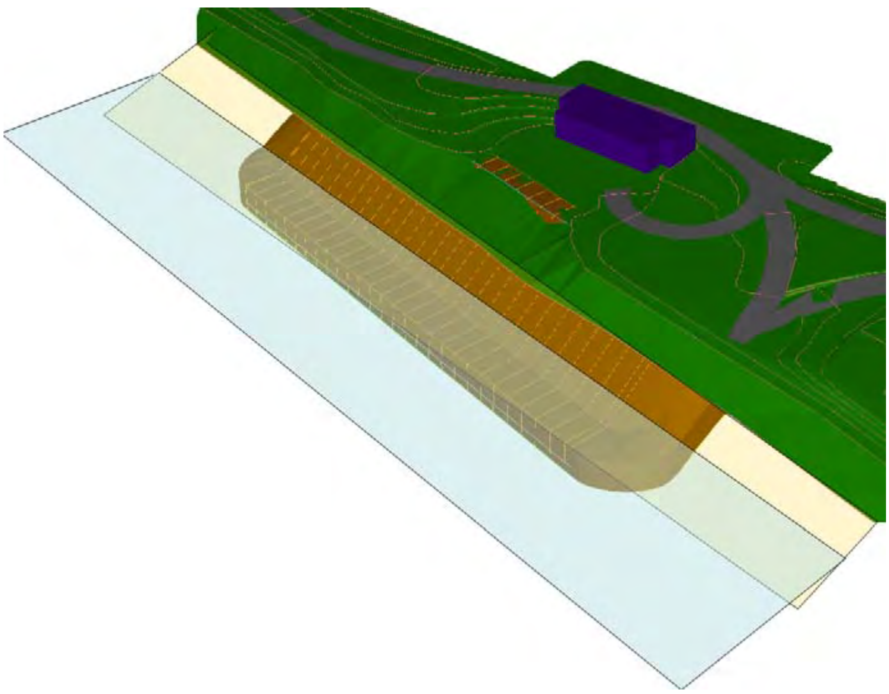

Figure 3-7b Buried Seawall Concept

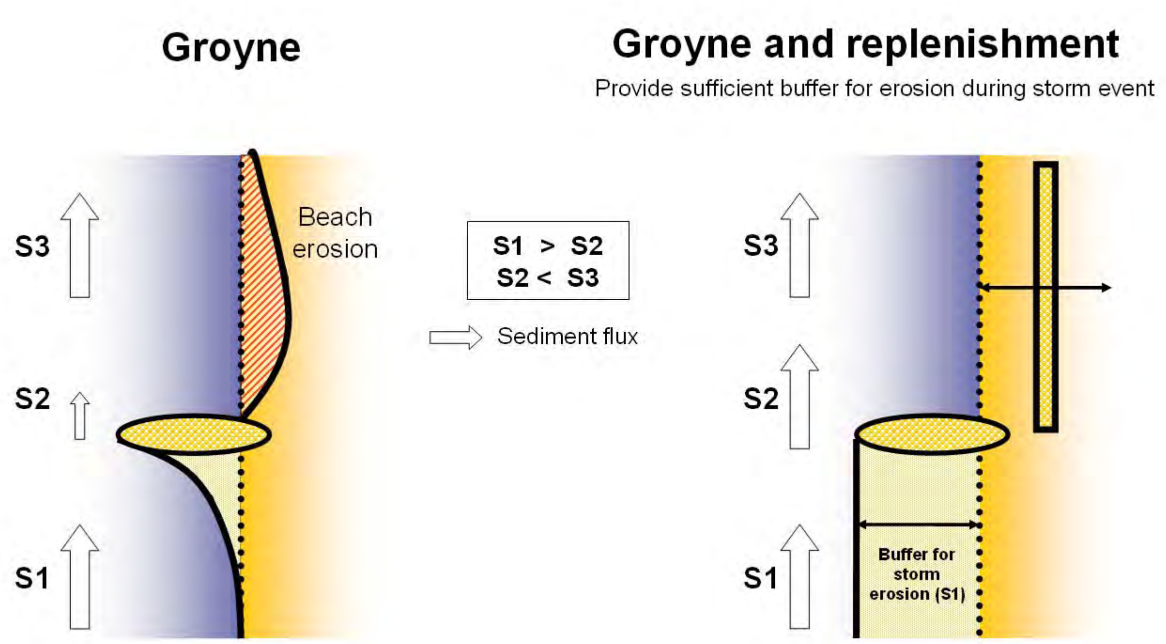

Figure 3-8a Schematic view of the effects of groynes on shoreline evolution

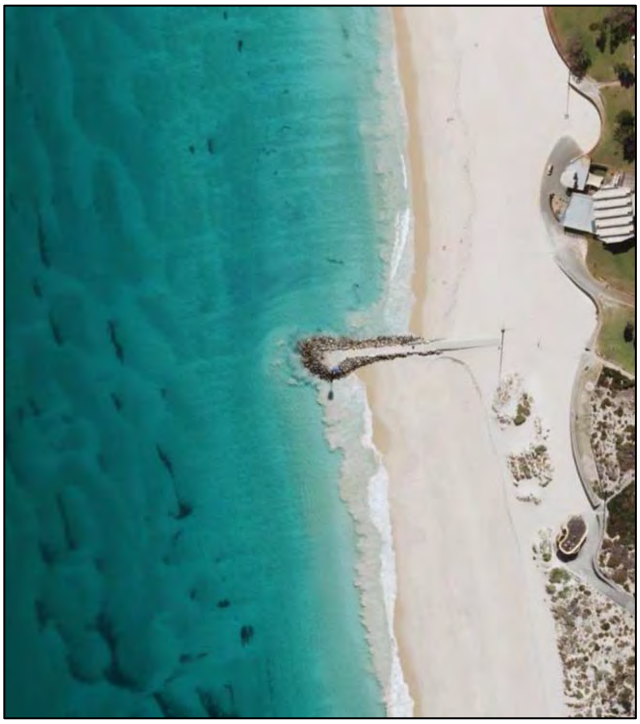

Figure 3-8b Example of the use of groyne to create a buffer against storm erosion

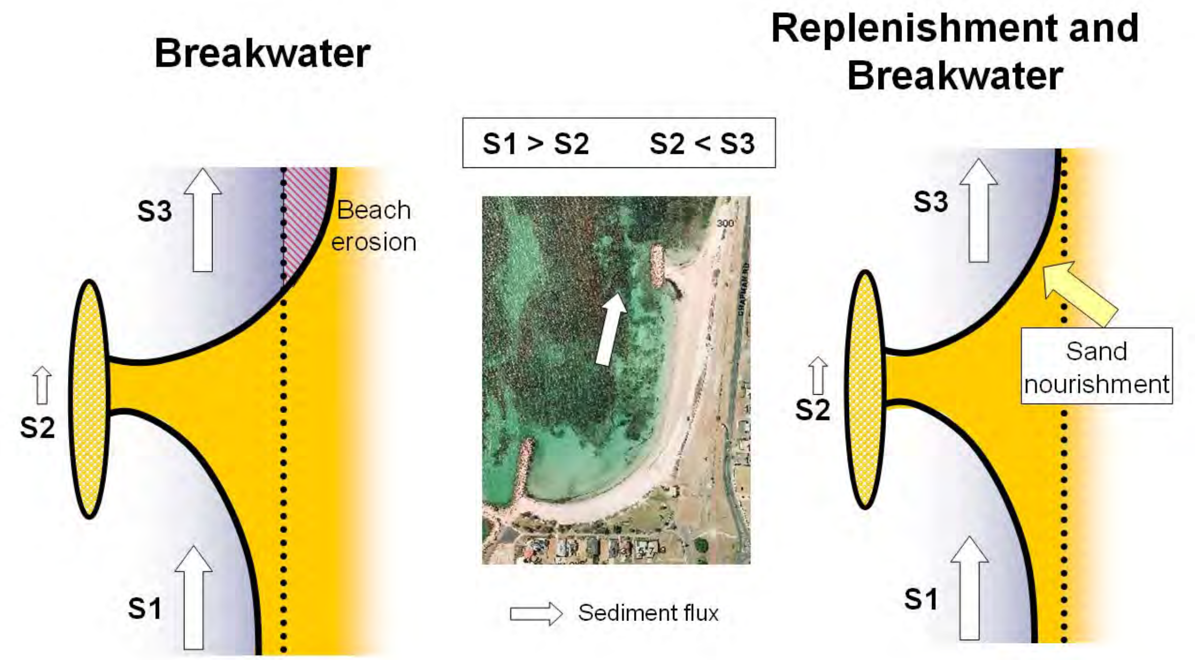

Figure 3-9 Schematic view of the effects of breakwater on shoreline evolution

Figure 4-1 Medium term shoreline evolution for the case "Do Nothing" or "Managed Recession" along the Northern Beaches

Figure 4-2 Medium term shoreline evolution for the case "Do Nothing" or "Managed Recession" along Sunset Beach

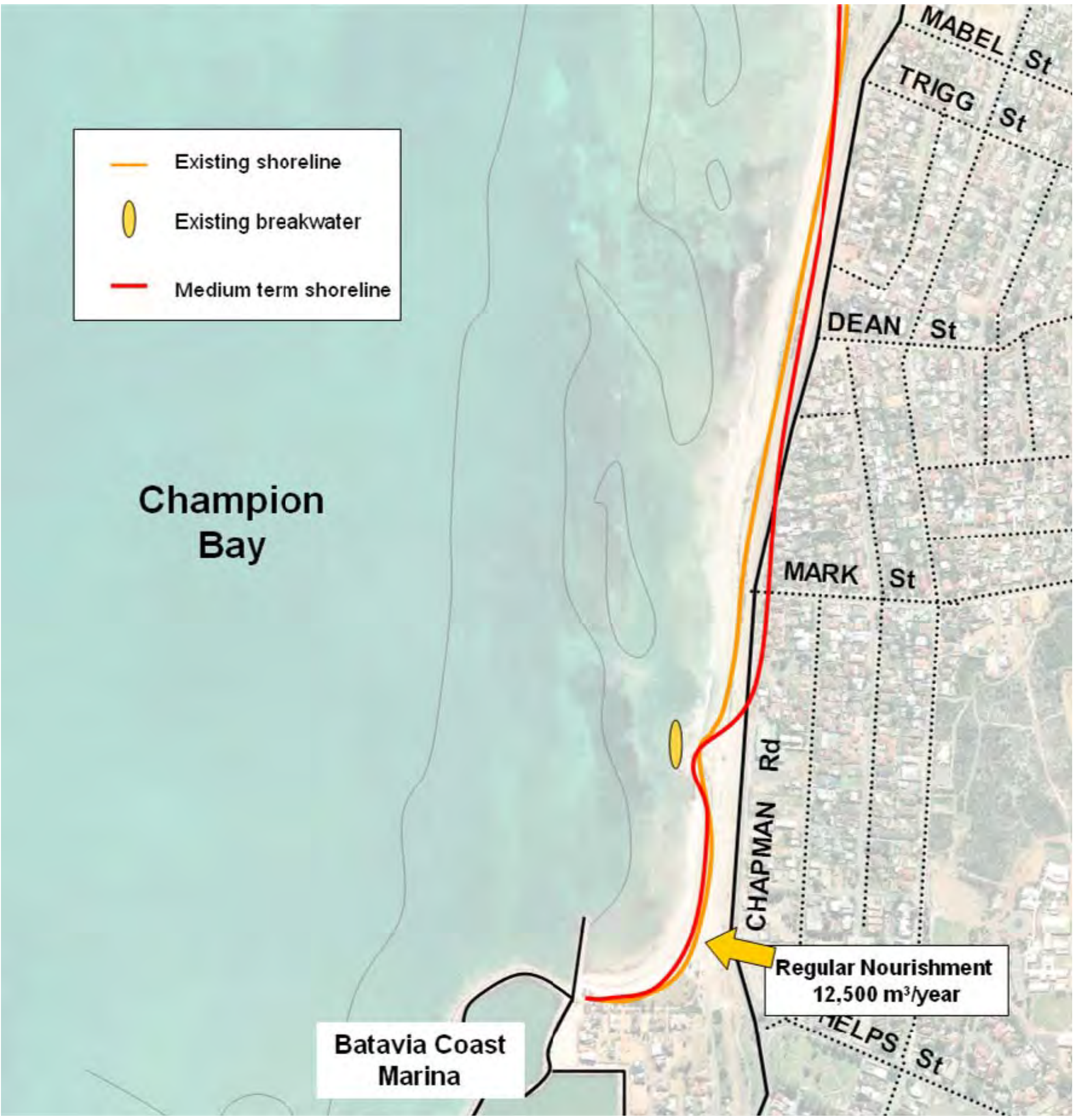

Figure 4-3 Medium term shoreline evolution for the present situation of the NSBP

Figure 4-4 Medium term shoreline evolution for the present situation of the NSBP and an additional nourishment north of the detached breakwater

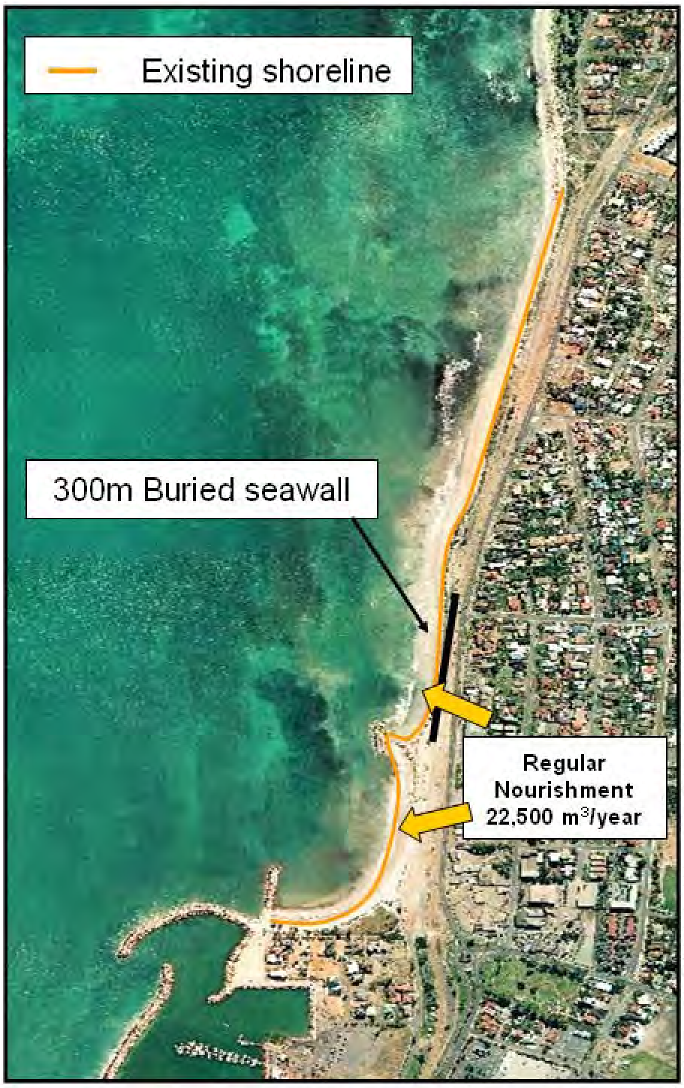

Figure 4-5 Possible coastal protection north of the breakwater (300m buried seawall)

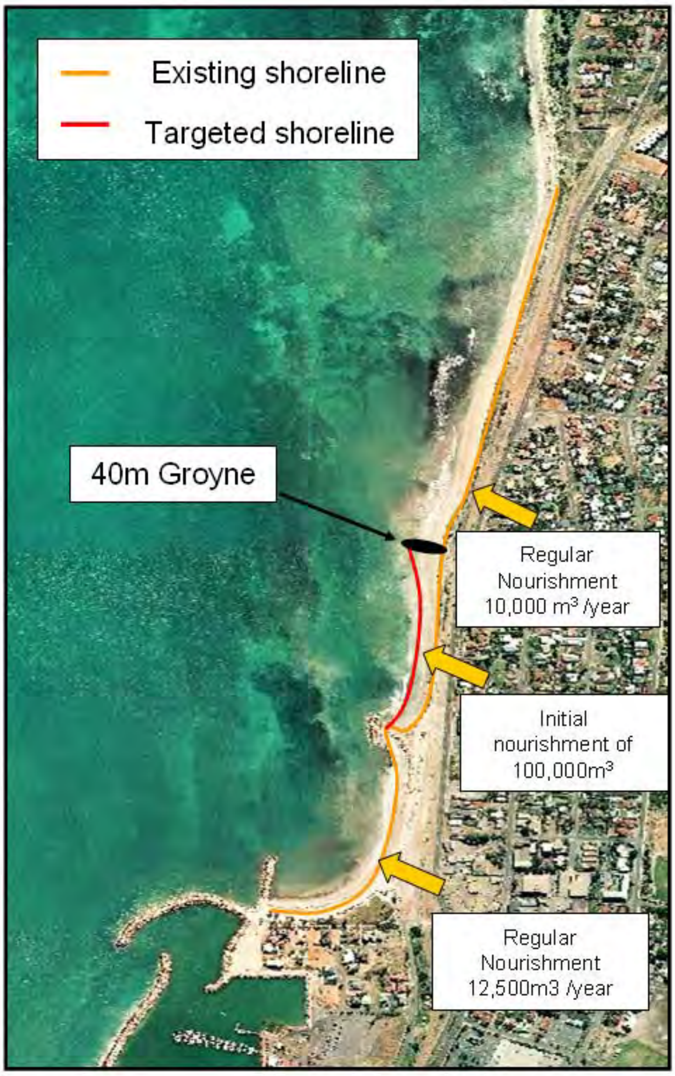

Figure 4-6 Possible coastal protection north of the breakwater (40m groyne)

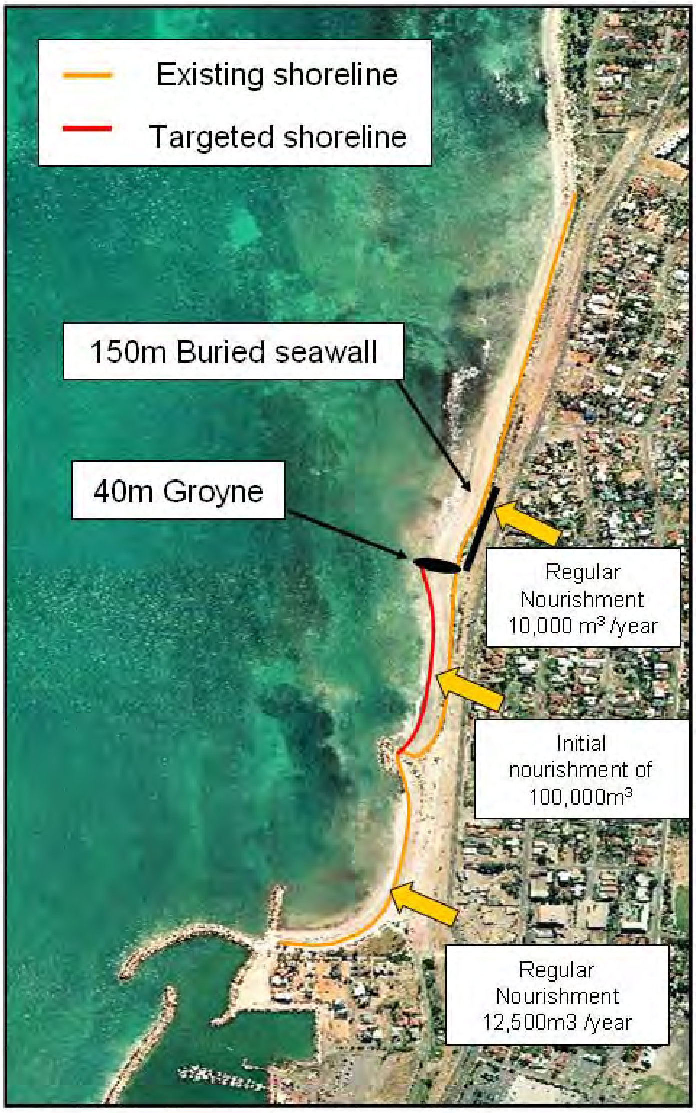

Figure 4-7 Possible coastal protection north of the breakwater (40m groyne and 150m buried seawall)

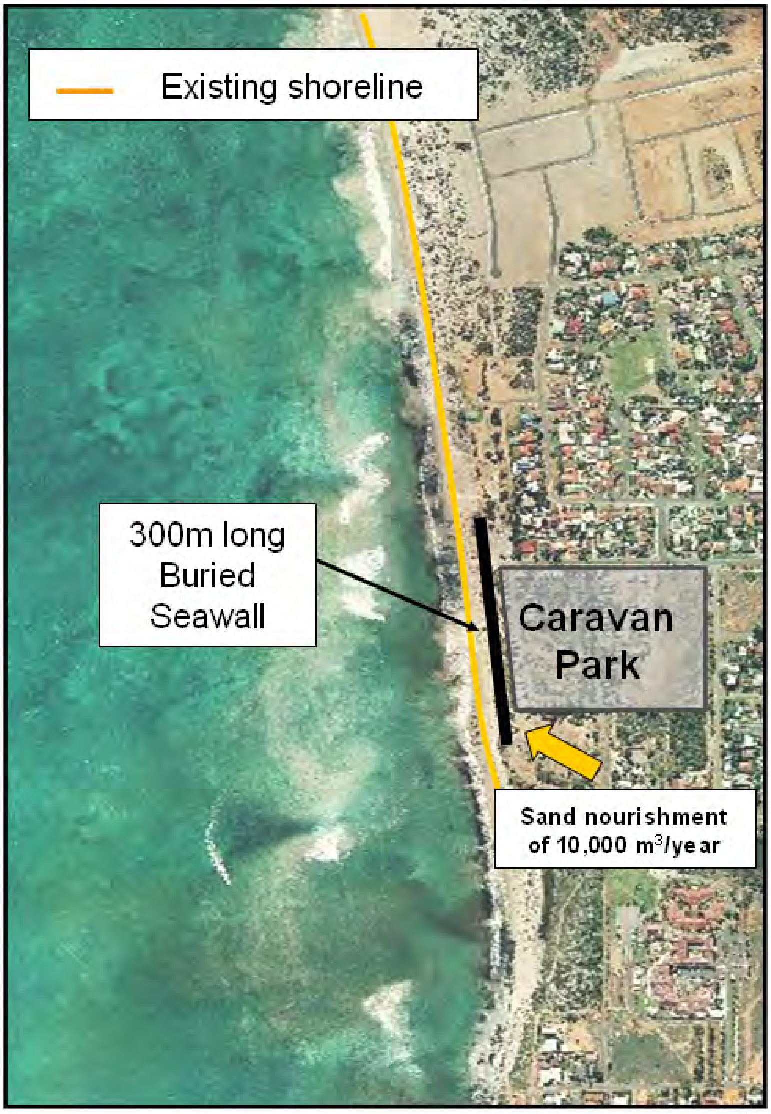

Figure 4-8 Possible coastal protection option at Sunset Beach

Figure 4-9 Possible coastal protection south of the Chapman river

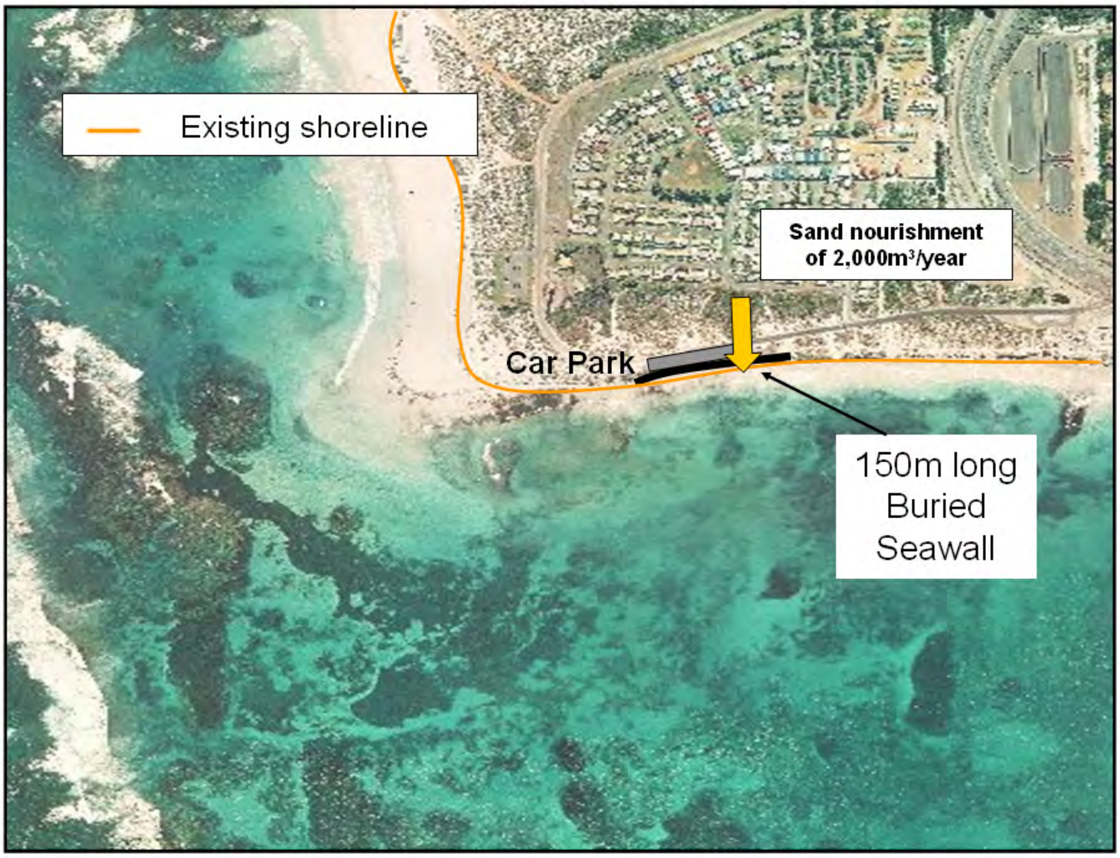

Figure 4-10 Possible protection at Grey's beach

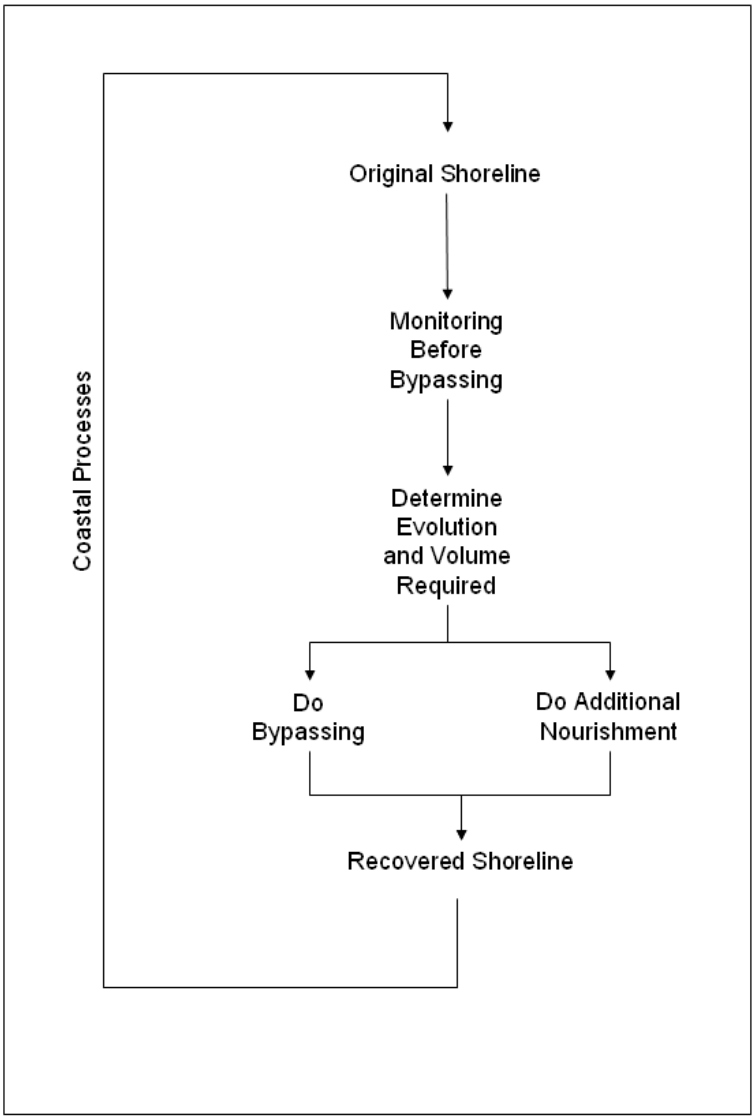

Figure 5-1 Annual Coastal Management Programme

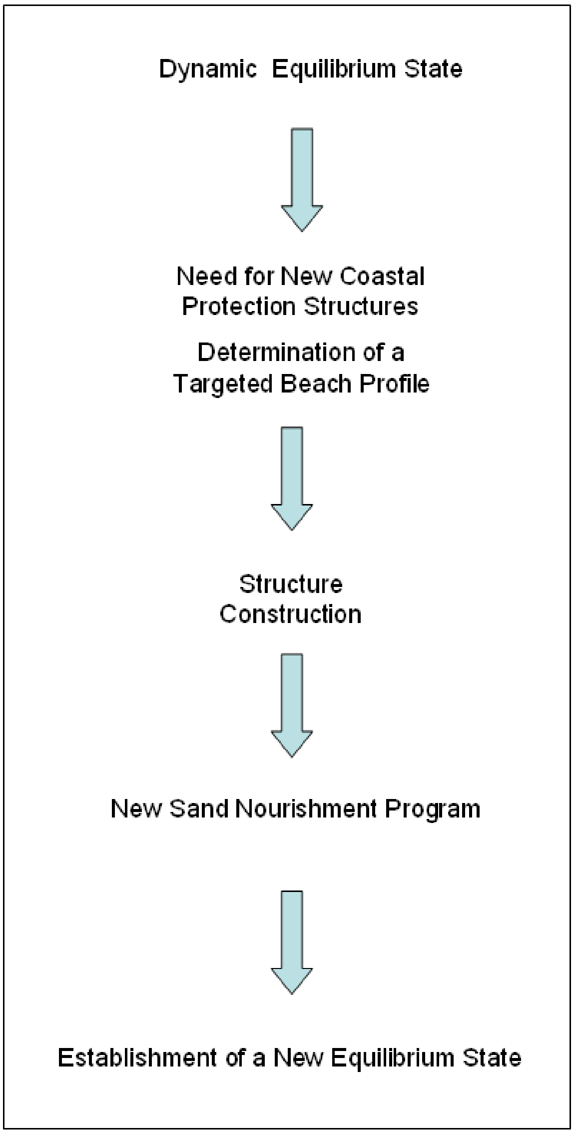

Figure 5-2 Process to Implement Medium Term Coastal Management Programme