SHIRE OF BUSSELTON

COASTAL EROSION STUDY

Assessment of Climate Change Impacts

August 2011

Final Report

96-00-01

Damara WA Pty Ltd

Table of Contents

List of Figures

List of Tables

1. Introduction

The Geographe Bay shoreline has previously been identified as at significant risk of adverse impacts resulting from climate change due to its low topography and the proximity of existing development to the coast [1&2]. The Shire of Busselton has recognised that this issue will requires consideration above and beyond the existing management, and has commissioned Damara WA to undertake an erosion study for the Geographe Bay coast. The study considers the possible implications of climate change, and evaluates future coastal management needs for the Shire.

This study has been developed to consider behaviour over the next 100 years, and in this manner differs from the coastal management strategy that is presently applied to the Geographe Bay coastline[3]. Specifically, the existing strategy involves the adoption of a ‘defendable line’, which is expected to be feasible over the next 50 years through the maintenance and further development of coastal protection structures between Quindalup and Wonnerup. There are presently more than 50 such structures, of which more than 75% are owned by the Shire of Busselton[4].

It is relevant to note that in the short-term, this study does not necessarily invalidate the existing coastal management strategy, which is relevant to present day structures and currently developed lots for several decades at least. However, in the longer-term, continued adaptation of the coastal protection system is expected to become increasingly expensive and more difficult to manage. By assessing over a longer-time frame, this study provides a suitable framework for planning of future land management along the Dunsborough to Wonnerup coast.

2. Planning Framework

2.1. WESTERN AUSTRALIAN POLICY

The Western Australian Government's policies for coastal management are outlined in the Coastal Zone Management Policy for Western Australia[5]. This document identifies the desire to minimise the use of coastal protection structures, and advocates use of development setbacks to resist coastal erosion. The policy was later followed by the Coastal Planning Policy SPP No. 2.6[6], which provides recommendations for selecting development setbacks, including allowances for erosive physical processes and other coastal management considerations. The policy includes a recommended schedule for the calculation of a physical coastal processes allowance based on:

HSD – horizontal setback datum, defined according to the limit of active coastal processes, which for a sandy shore is taken to be the limit of permanent vegetation or the base of an erosion scarp.

S1 – allowance for acute erosion, typically based upon modelling of a severe storm sequence.

S2 – allowance for progressive erosion, normally based upon interpretation of historic trends

S3 – allowance for erosion associated with projected climate change, including sea level rise. An allowance of 38m horizontal setback is usually applied to sandy coasts for this component.

The physical coastal process allowance represents the absolute minimum distance required for setback from the coast. SPP 2.6 outlines a range of other factors that should be considered when defining a coastal setback, including stability of geomorphic features. The recommended time frame of SPP 2.6 is a 100-year planning horizon, which is a critical component of the policy as it provides an extended period of time over which to identify changing climate and respond.

A median climate change scenario was previously applied to the Busselton coastline, with an allowance of 0.15m for a 50-year planning period and 0.38m for a 100-year planning period[3]. Following review of current adaptation policy, the Western Australian Planning Commission have adopted a more conservative allowance for sea level rise applied to setback assessment, with 0.9m allowance over a 100-year planning period[7].

2.2. PREVIOUS POLICY APPLICATION TO BUSSELTON

The Geographe Bay shoreline has an extensive amount of existing development close to the coast, and therefore, for practical purposes, was effectively considered a variation to the general case under SPP 2.6 for development of the Erosion Management Strategy[3]. Consequently, the setback calculation method of SPP 2.6 was not applied directly.

Setbacks calculated for the previous strategy are based upon 50-year and 100-year planning horizons. These give recommended setbacks of 50m and 83m for undeveloped sites on sandy shores. However, the majority of the foreshore is developed and defended by engineering works. As a result, sections of leasehold and freehold boundaries lie within 50m of the HSD. The strategy required that the existing coastal protection structures are maintained or upgraded as required.

2.3. IMPLICATIONS OF VARIATION TO THE GENERAL CASE

The Erosion Management Strategy identified within the Andrew report presents a variation to the “general case” presented in the WAPC Coastal Planning Policy[6]. Specifically, the strategy uses coastal protection structures as a significant measure for the protection of residential developments. In contrast, the general case suggests that development setbacks are used as the primary measure of protection.

The major implication of adopting the Erosion Management Strategy is the need to maintain and progressively enhance coastal protection structures between Quindalup and Wonnerup, so as to defend of the development line. The cost of ongoing maintenance and enhancement has not been identified, but is considered likely to increased under climate change scenarios.

The strategy requires careful consideration with regards to establishing land ownership, as the expected time frames for freehold or typical 99-year crown lease conflict with the 50-year erosion study time scale.

Use of structures as an integral part of coastal defence provides a change in the risk profile associated with extreme events. Care should be taken to consider the possibility of failure thresholds being reached, including the effects of structure degradation [8]. Similar thresholds may occur for parts of natural coasts such as a barrier dune breaching through overwash or an estuarine shoal being cut through during a flood event.

2.4. SETBACK POLICY DEVELOPMENT

SPP 2.6 is presently under review by the Western Australian Planning Commission. The Department of Planning have indicated that the revision is likely to include requirement to consider both erosion and inundation when assessing setbacks. Variations to the general case, including infill, will require assessment in terms of relative risk and identify potential and active risk mitigation options.

3. Scenario Definition

Analysis scenarios have been developed by the Shire of Busselton, in consultation with the Department of Transport[7]. Low, Medium and High scenarios of climate change are summarised by Table 3-1.

Table 3-1: Climate Change Scenarios

Scenario	Wave	Storm Wave	SLR	Extreme WL
Low		July 1996 storm	+0.4m	+0.4m
Medium	+10%	July 1996 +10%	+0.9m	Existing +0.9m + (η_{wave} x10%)
High	+10%	July 1996 +10%	+1.1m*	Existing +1.1m + (η_{wave} x10%)

* Sea level rise includes additional 0.2m allowance for glacial ice melt.

Significantly, a time scale of 100 years has been adopted for the definition of the climate change scenarios. Consequently, the projected mean sea level change (0.4 to 1.1m) is much greater than was applied to define the defendable line (0.15m), which was determined from the median projected sea level rise by 2050 (Figure 3-1). The Erosion Management Strategy[3] recommended review before 2020, pending an evaluation of the rate of sea level rise and corresponding coastal evolution.

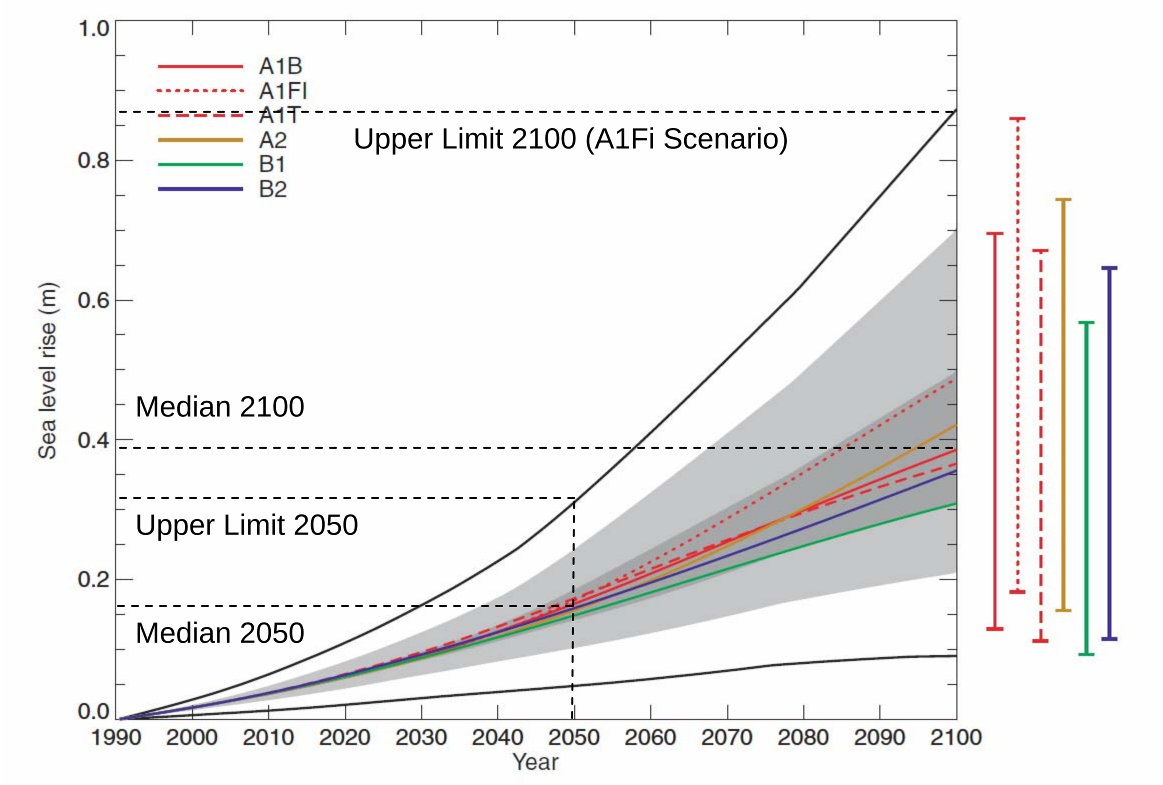


Figure 3-1: Time Series of Projected Sea Level Rise

Note: IPCC-TAR[9] has been used as subsequent reports do not show time series.
An alternative time series is available from www.cmar.csiro.au/sealevel/[10]

4. Metocean Conditions

4.1. SYNOPTICS

Busselton is located at approximately 34^{o}S and 115^{o}E in southwest Australia. The weather for this region is dominated by the extra-tropical high pressure ridge, but is also influenced by the mid-latitude low pressure trough. Under high pressure conditions, trade winds are most frequently mild and easterly. These are typically modulated by the daily seabreeze cycle, creating a bimodal pattern of easterlies in the morning and southwest winds in the afternoon (Figure 4-2). The strongest (storm) wind conditions are generally associated with the excursion of mid-latitude low pressure systems, which may bring strong westerly winds [11,12]. Latitudinal movement of the pressure bands provides an increased mid-latitude influence during winter months, with storm frequency, proximity and intensity increasing. Climate change projections for Australia and the south-west [13],[14] suggest a southward movement of the sub-tropical ridge, which is equivalent to increasingly “summer” conditions.

The nature of westerly storm events has been examined for southwest Australia [11,12]. These studies identified that mid-latitude storms can generate strong winds from the entire westerly half of the compass, and that the direction of storm winds (as perceived on land) rotates in an anticlockwise fashion as the storm passes. Some variation has been identified according to system passage, with cut-off lows capable of producing stronger northwest winds (Figure 4-1) whilst mid-latitude events typically produce strong westerlies and southwesters. Cut-off lows are responsible for a high proportion of extreme surges [15].

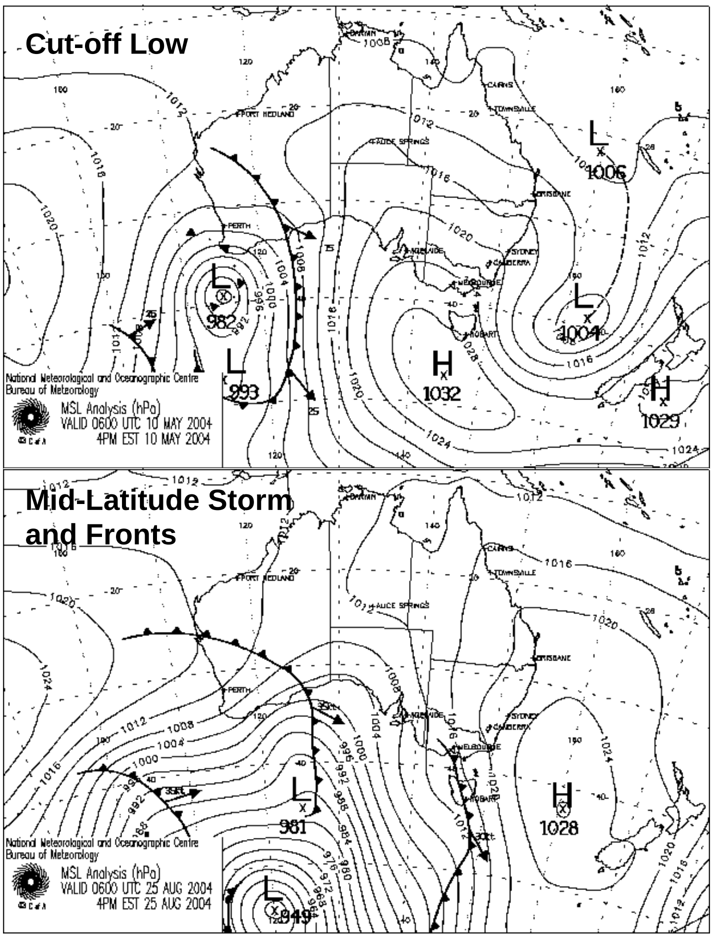


Figure 4-1: Example Storm Events

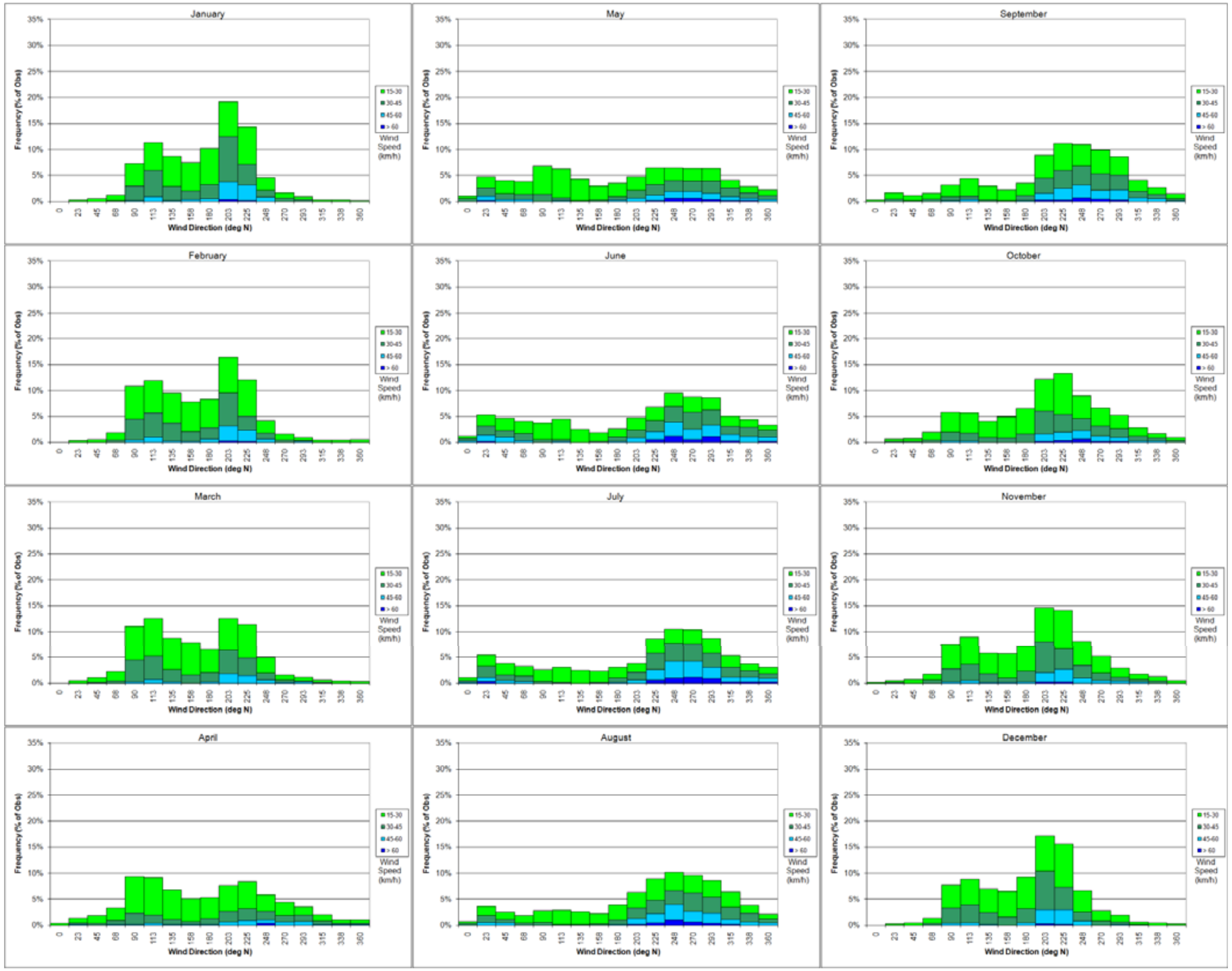


Figure 4-2: Monthly Wind Distributions (Busselton Aero)

Note dominance of easterly and southwest winds in summer, which changes to northeast and westerly winds in winter.

4.2. WAVES

The regional offshore wave climate is measured through a permanent network of waverider buoys deployed and maintained by the Department of Transport. These are supported by a series of temporary nearshore deployments of acoustic wave and current (AWAC) meters. The Cape Naturaliste waverider provides offshore (48m depth) measurements since May 1999, with an inshore (13m depth) instrument deployed off Busselton from November 2006 as a long-term deployment to inform the management of Busselton beaches and coastal facilities.

Time series of the wave measurements are shown in Figure 4-3, noting that the AWAC data shown contains excess scatter and requires re-processing. Records from instruments show a strongly seasonal pattern, with more energetic waves during the winter period. However, there is a significant reduction in scale from offshore to inshore (Figure 4-4). Second, although there is a general relationship between the two data sets, the relative magnitude of individual storm events is not maintained. This is explained by the relative protection the Busselton site receives from its position in Geographe Bay, which reduces the influence of westerly and southwester storm events.

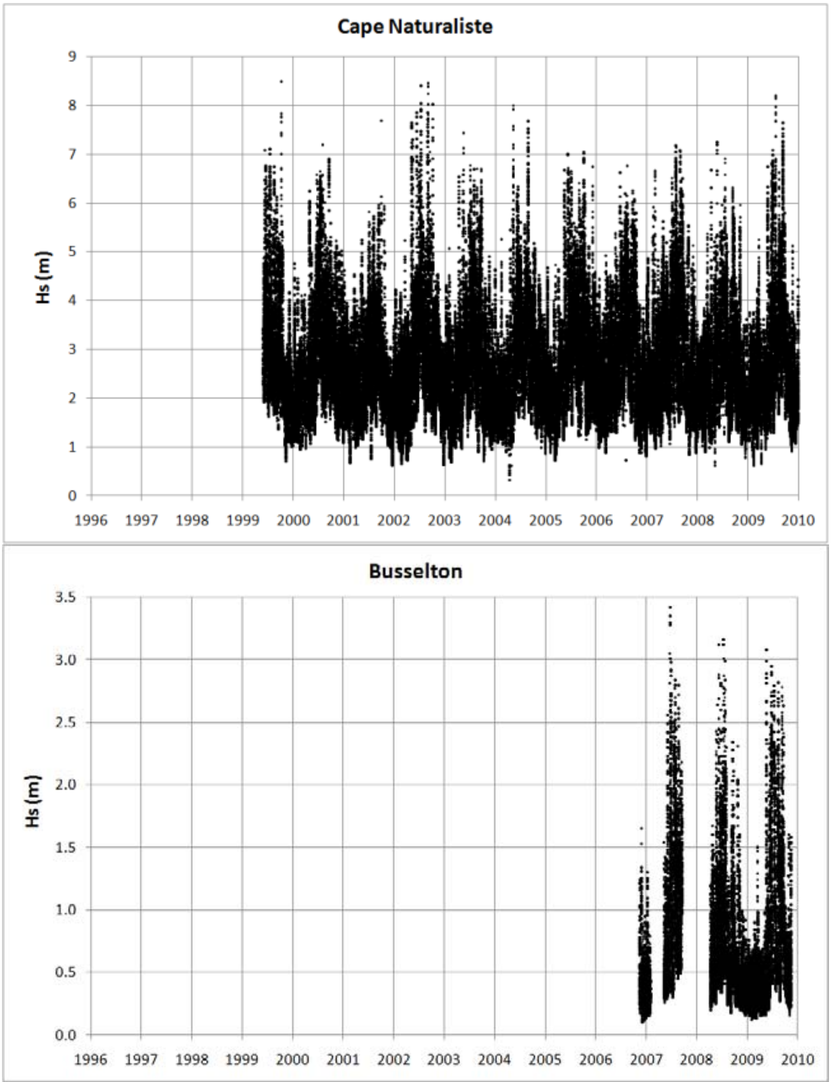


Figure 4-3: Wave Height Time Series

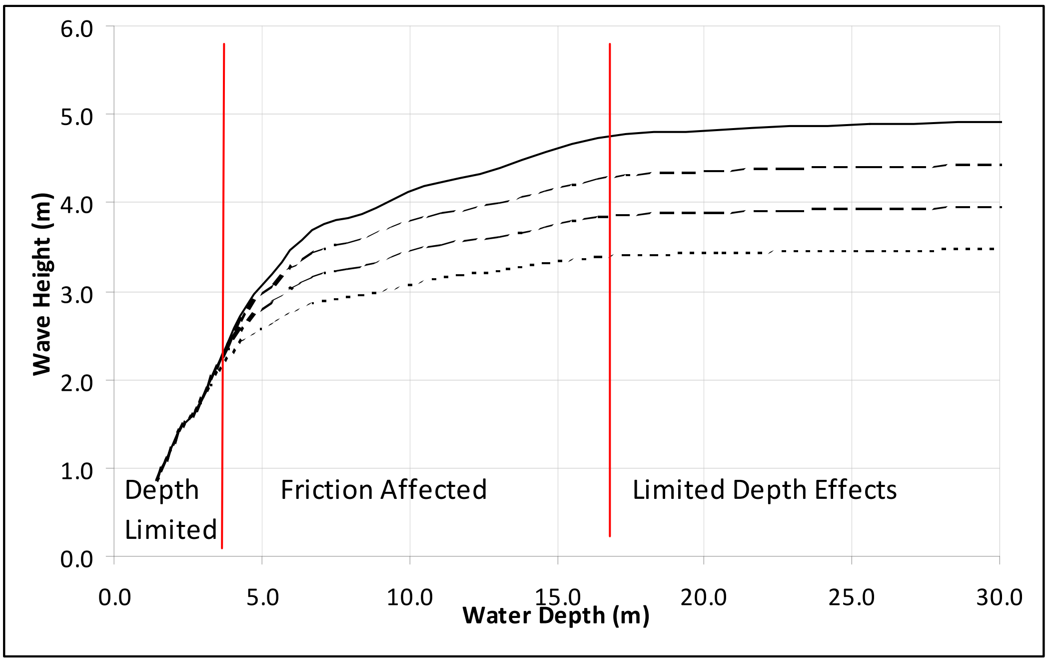


Figure 4-4: Modelled Nearshore Wave Decay

Analysis of the highest wave events occurring within the Busselton wave record shows a dominance of northerly and northwesterly storms (Table 4-1). This is a strong contrast to the highest wave events measured by the Cape Naturaliste waverider buoy, which are predominantly west to southwest storms (Table 4-2).

Table 4-1: Highest Wave Events at Busselton (2007-2009)

Rank	Date	Hs (m)	Tp (s)	Direction	Event	Synoptic
1	22/06/2007	3.42	10	353	CO	N
2	11/07/2008	3.16	8.1	335	ETL	N
3	9/06/2008	3.12	7.9	348	CO	NNW
4	21/05/2009	3.08	8.5	332	CO	NW
5	15/07/2008	3.01	8	337	ML	NW
6	23/07/2008	2.99	8.5	333	ML	NW
7	1/07/2007	2.98	9.3	332	ML	NW
8	28/06/2009	2.95	10.7	316	ML	NW
9	30/06/2007	2.92	8.6	336	ML	NW
10	30/07/2007	2.84	9.4	324	ML	NW

CO = cut-off low, ETL = extra-tropical low, ML = mid-latitude depression

Table 4-2: Highest Wave Events at Cape Naturaliste (2000-2009)

Rank	Date	Hs (m)	Tp (s)	Event Type	Synoptic
1	2/09/2002	8.46	16	ML	SW
2	12/07/2002	8.4	12.5	ML	WSW
3	20/07/2009	8.2	16.67	CO	SW
4	6/10/2002	8.03	14.55	CO	WSW
5	10/05/2004	8	16.33	CO	SW
6	14/06/2002	7.85	15.09	ML	SW
7	29/09/2001	7.69	13.11	CO	SW
8	25/08/2004	7.68	17.02	ML	SW
9	7/05/2002	7.64	15.69	ML	W
10	10/09/2009	7.64	12.5	ML	WSW

In addition being sheltered from the prevailing southwest to westerly waves, depth effects (refraction) as waves approach the inshore site narrow the range of potential wave directions (Figure 4-5). This effect is significant for alongshore sediment transport.

Further analyses of observed wave conditions at Cape Naturaliste, Bunbury and Busselton are included in Appendix 0. These highlight that high wave events at Busselton generally occur earlier in winter months than the peaks at Bunbury or Cape Naturaliste; and that locally generated waves have greater influence at Busselton than at the other two locations.

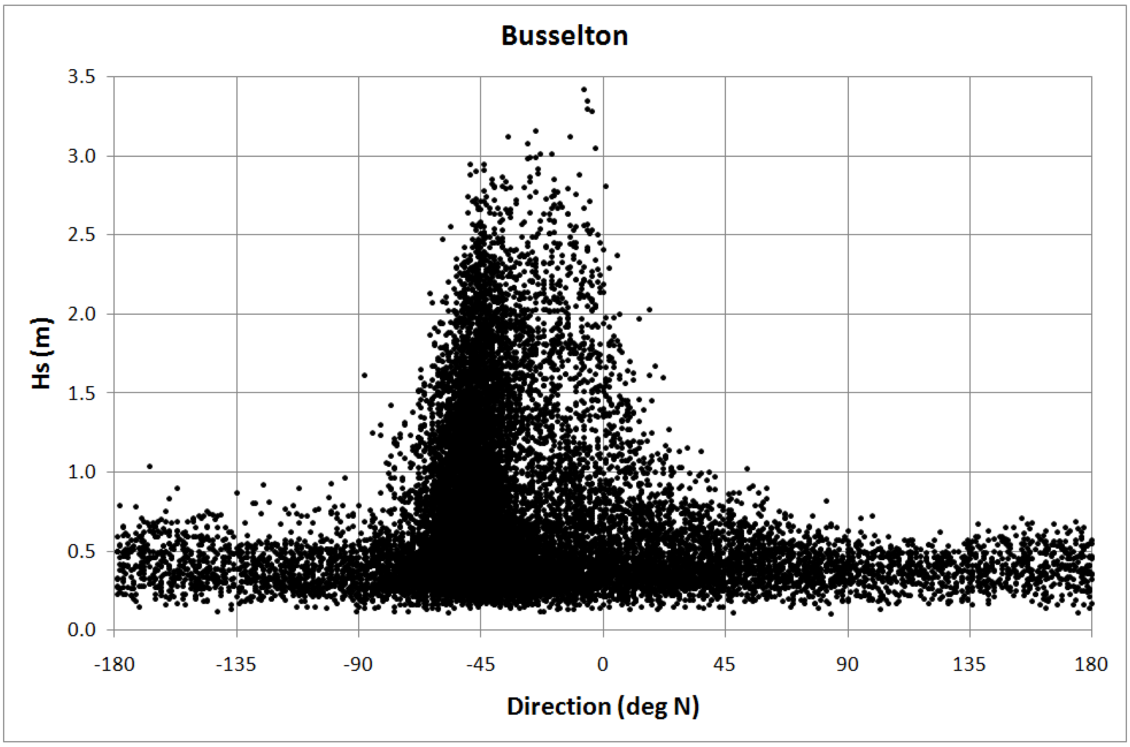


Figure 4-5: Busselton AWAC Directional Wave Observations

Generalisation to the wider area of the Geographe Bay must consider that the shelter varies along the coast (Table 4-3). The bay structure provides considerable protection from common wave events, including background swell and southwest storms. However, it provides limited protection against the more unusual events including tropical cyclones and northwest storms. The bay structure is crucial for the relative importance of different wave directions, and therefore magnifies the influence of different weather event types.

Table 4-3: Wave Event Types

Wave Direction	Event Types	Event Frequency	Comment
Southwest	Prevailing Swell	Common	Significant shelter from Cape Naturaliste
	Southwest Storm	Common	Wave climate determined by fetch, largely sheltered west of Wonnerup
West	Westerly Storm	Common	Partial shelter from Cape Naturaliste, mainly west of Siesta Park
Northwest	Northwest Storm / Tropical Cyclone	Moderate / Rare	Largely unprotected east of Quindalup
North	Tropical Cyclone	Rare	Largely unprotected, but fetch limited by refraction
Northeast	High Pressure System	Moderate	Wave climate determined by fetch, largely sheltered east of Busselton
East	Land Breezes	Common	Wave climate determined by fetch, largely sheltered east of Siesta Park

4.3. WATER LEVELS

Water levels in the Busselton region are measured through a tide gauge located within Port Geographe, which is maintained by the Department of Transport. Busselton experiences microtidal conditions, with an average daily range of approximately 0.60m and a lowest to highest astronomic range of 1.20m (Table 4-4) [16]. The water level is strongly influenced by non-tidal forcing, such that the total water level range from 2002 to 2008 was 2.32m, which is almost twice the astronomic tidal range (Figure 4-6). Nearly 0.3m of the water level range is determined by a seasonal sea level cycle. Busselton is predominantly diurnal, experiencing a single tidal cycle on most days. In addition to monthly spring-neap cycles, there is a bi-annual tidal cycle, with peaks occurring in June and December (solstices). The seasonal mean sea level cycle peaks in May-June and is lowest in October-November, which approximately corresponds with winter westerly wind events and summer easterly winds respectively (Figure 4-7).

Table 4-4: Busselton Tidal Planes

Tidal Level		Water Level (m LAT)
Highest Astronomical Tide	HAT	1.2
Mean Higher High Water	MHHW	0.8
Mean Lower High Water	MLHW	0.6
Mean Sea Level	MSL	0.6
Mean Higher Low Water	MHLW	0.6
Mean Lower Low Water	MLLW	0.3
Lowest Astronomical Tide	LAT	0.0

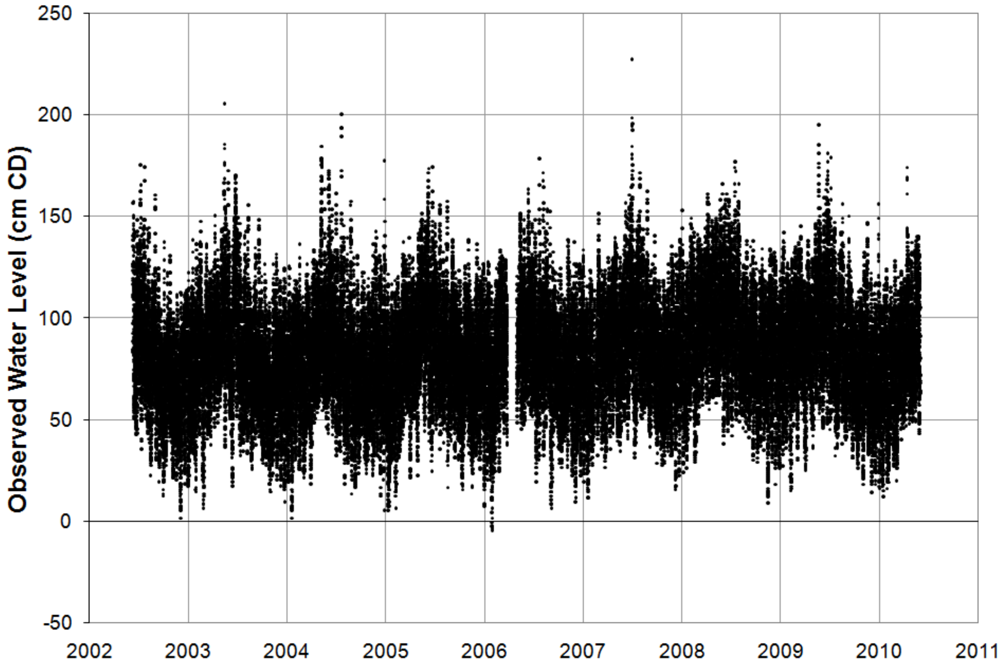


Figure 4-6: Busselton Observed Water Levels, 2002-2008

Time series decomposition of the observed Busselton water level has been applied to identify the relative contributions of tide, surge and mean sea level. The concave shape of Geographe Bay amplifies surges reaching the Busselton region, particularly for storm systems travelling southwards. This is enhanced through the clockwise propagation of the surge signal and an eastward propagation of both tides and storm systems. Extreme water levels were experienced during TC Alby (April 1978), following the Sumatra tsunami (December 2004) and during July 2007.

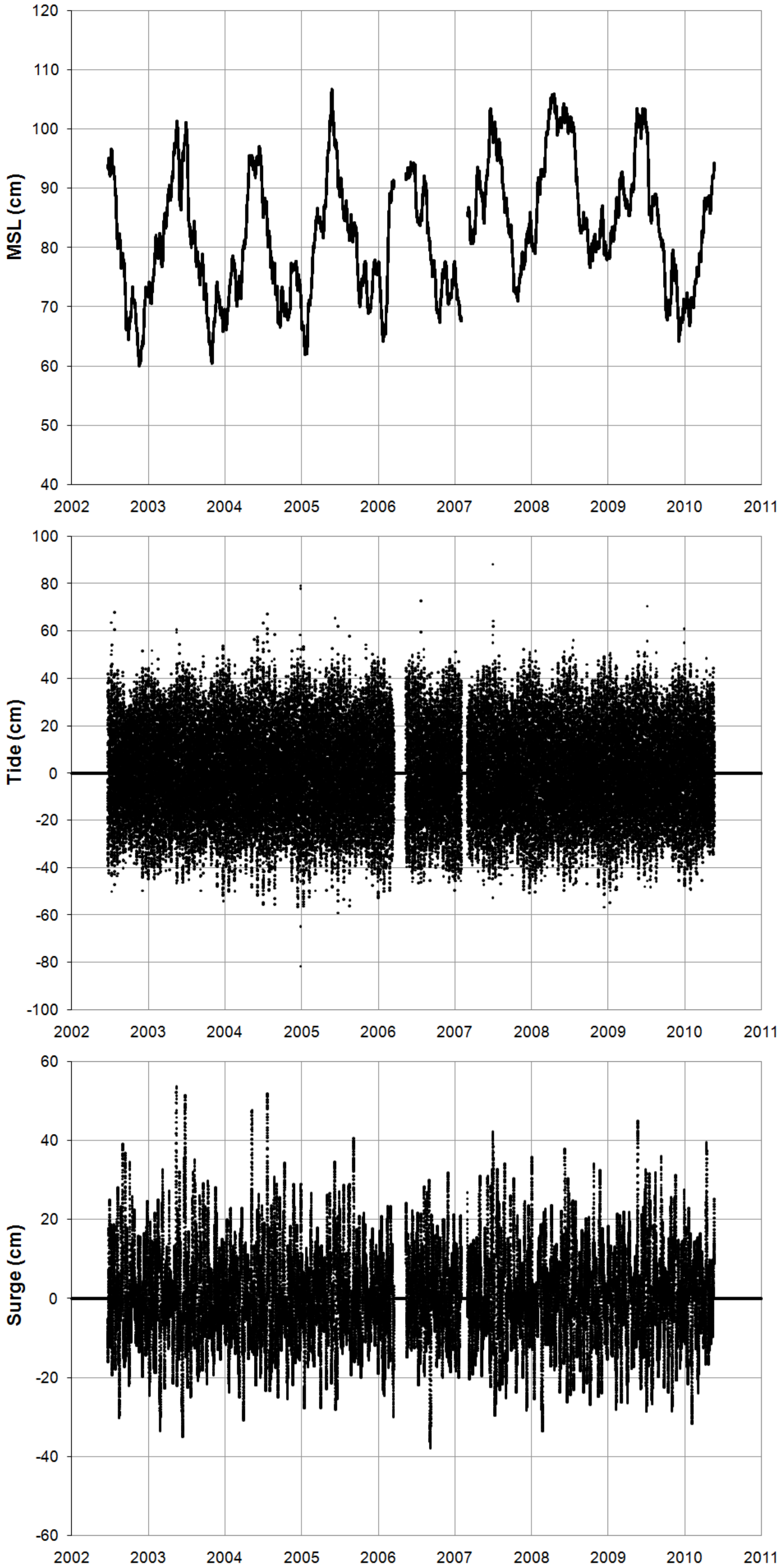


Figure 4-7: Busselton Water Level Decomposition

5. Geomorphic Assessment

5.1. GEOLOGY, COASTAL ORIGINS & SEDIMENT CHARACTER

South Western Australia extends across three principal geological regions. The western portion is the Leeuwin-Naturaliste Ridge, a pre-Cambrian granite mass overlain with Pleistocene Tamala limestones. The central region, including Geographe Bay, is located on the shallow Swan Coastal Plain, which is comprised of reworked mobile Holocene sediments overlying Tamala limestones and clays. Further to the east, the Yilgarn Block granites form the Darling Scarp and are overlain by geologically aged sediments.

Geographe Bay has a predominantly sandy coast, comprised of a thin offshore sand sheet and a series of parallel beach ridges belonging to the Quindalup Dune system. The coastal sediments are geologically recent, mainly deposited along the Geographe Bay foreshore during the last 5,000 years [17&18]. They form a thin veneer overlaying a range of older Pleistocene units including Busselton Limestone and/or Geographe Clay. Geomorphic classification distinguished the Holocene sediments into the units '*Beach Ridge Wedge*' and '*Sand Sheet*'. The modern coastal structure is considered to be the result of gradually declining sea levels from a highstand approximately 5,000 years before present. Geologic profiles from Quindalup (Figure 5-1) and East Busselton (Figure 5-2) suggest the thin nature of the Sand Sheet formation.

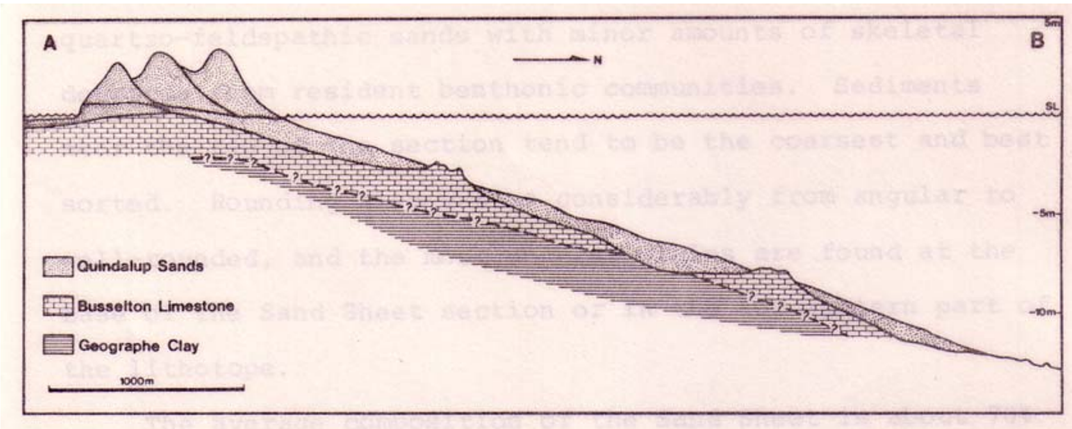


Figure 5-1: Quindalup Geological Profile
From Searle & Logan [17]. Vertically exaggerated.

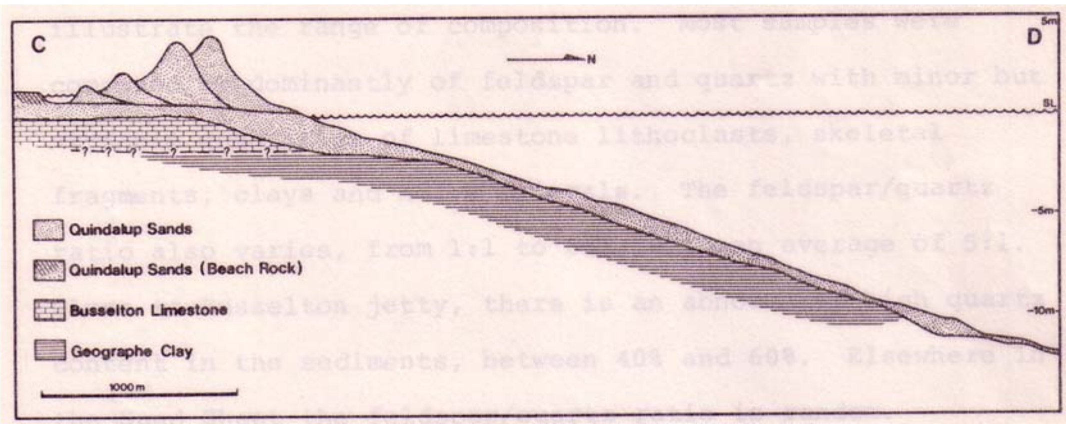


Figure 5-2: East Busselton Geological Profile
From Searle & Logan [17]. Vertically exaggerated.

The Beach Ridge Wedge unit '*consists of beach, beach ridge and minor lagoonal sediments that extend along the shores of Geographe Bay in a belt averaging 500m in width. The unit has an overall configuration of a wedge (after Hagan & Logan 1974), thinnest inland and reaching 5m in thickness at the seaward margin before tapering down to intergrade with the Sand Sheet*' [17]

The Sand Sheet is a '*blanket like sediment body extending from low water level where it is intergradational with beach deposits, to about the 14m isobath where it thins out exposing the unconformity surface covered by a veneer of skeletal encrustations. The Sand Sheet has a maximum thickness of 1 m, There is a general trend for thicker sections nearshore thinning seaward*' [17]

Pleistocene Units include Dunsborough Green Sand, Geographe Clay and Busselton Limestone. The limestone forms an intermittent cover on the Geographe Clay, and are exposed in offshore and onshore locations where the Holocene Sands thin. Sediment sampling undertaken along the Geographe Bay coast identified the presence of limestone sediments near to locations where exposed limestone occurs [19]. Semi-consolidated and often sandy clays of variable colour and composition underlie the Busselton limestone throughout Geographe Bay. These Pleistocene units can be exposed at the landward margin of the Beach Ridge Wedge at elevation of about RL 1.3m AHD.

Analysis of the Holocene sediments concluded that they were derived mainly from:

- The Pleistocene sediments
- Gneiss from the adjacent Leeuwin-Naturaliste Block
- Carbonate producing benthic communities (seagrasses)
- Relict shelf sediments

It was noted that a slow supply of sediment from all these sources is still being added to the sand veneer.

Overall the sedimentary units for southern Geographe Bay resemble a receding dune barrier in which the dune ridge may roll landward under rising sea level [20]. Retreat of the shoreline apparently slowed as sea level peaked some 6,000 years before present and the modern beach ridge developed as an aggradation feature under a slightly falling sea level. Deposition occurred in several phases of dune building, which suggests a pulsing supply of sediments to the shore, or intermittent severe erosion events.

5.2. LIDAR DATA

The seabed structure of Geographe Bay has recently been captured through a LIDAR aerial survey from Cape Naturaliste to Mandurah by the Department of Planning. This data set significantly enhances the capacity to identify active sediment transport processes affecting Geographe Bay. Specifically, the ability to easily examine bathymetry at a range of scales allows better identification of feature characteristics and processes, as illustrated by the progression from Figure 5-3 through to Figure 5-4 and Figure 5-5.

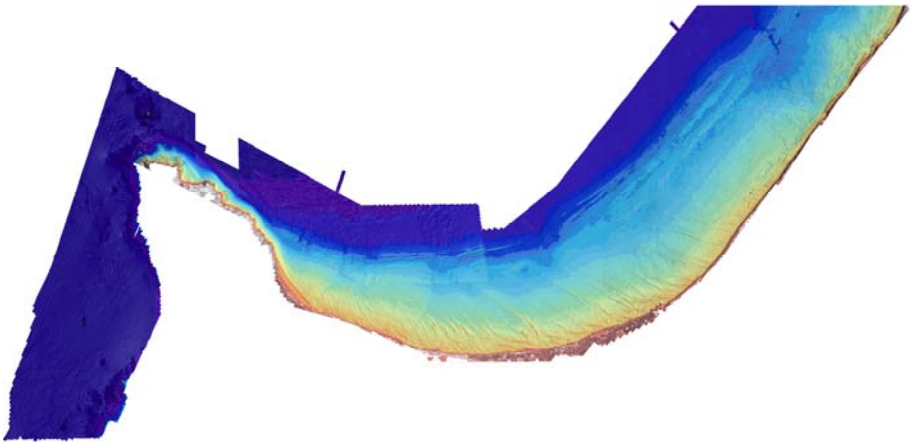


Figure 5-3: Geographe Bay Seabed Features, captured by LIDAR

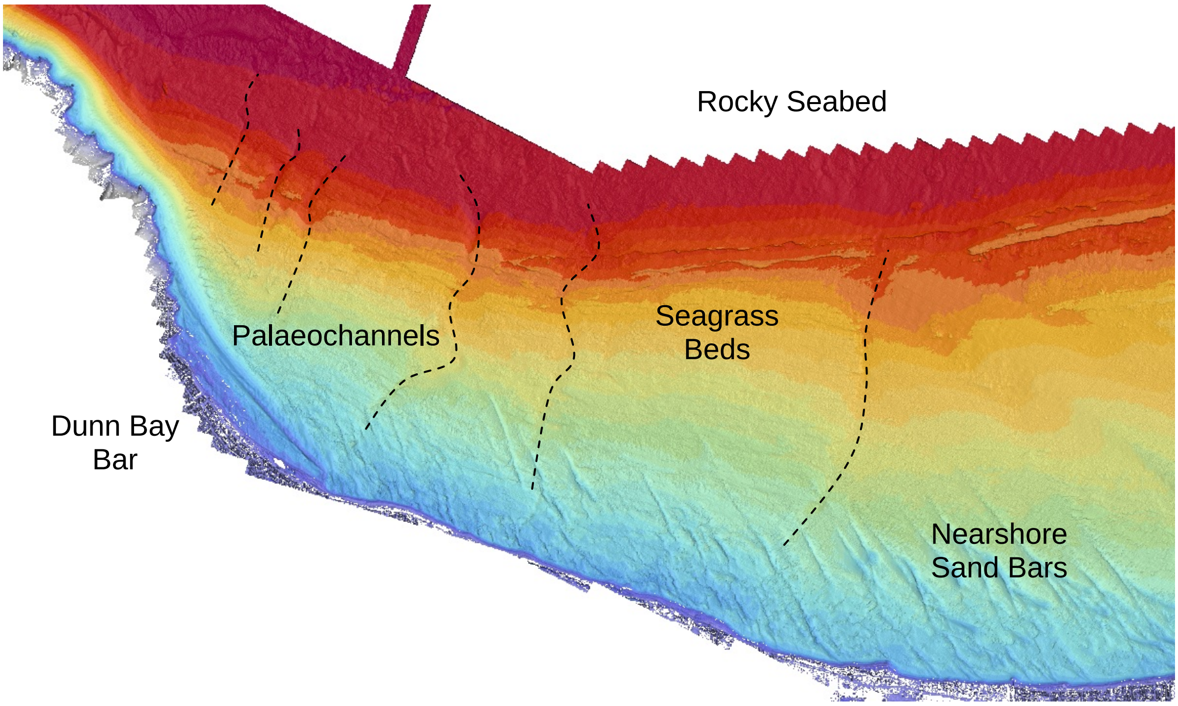


Figure 5-4: Quindalup Seabed Features, using mid-scale LIDAR imagery

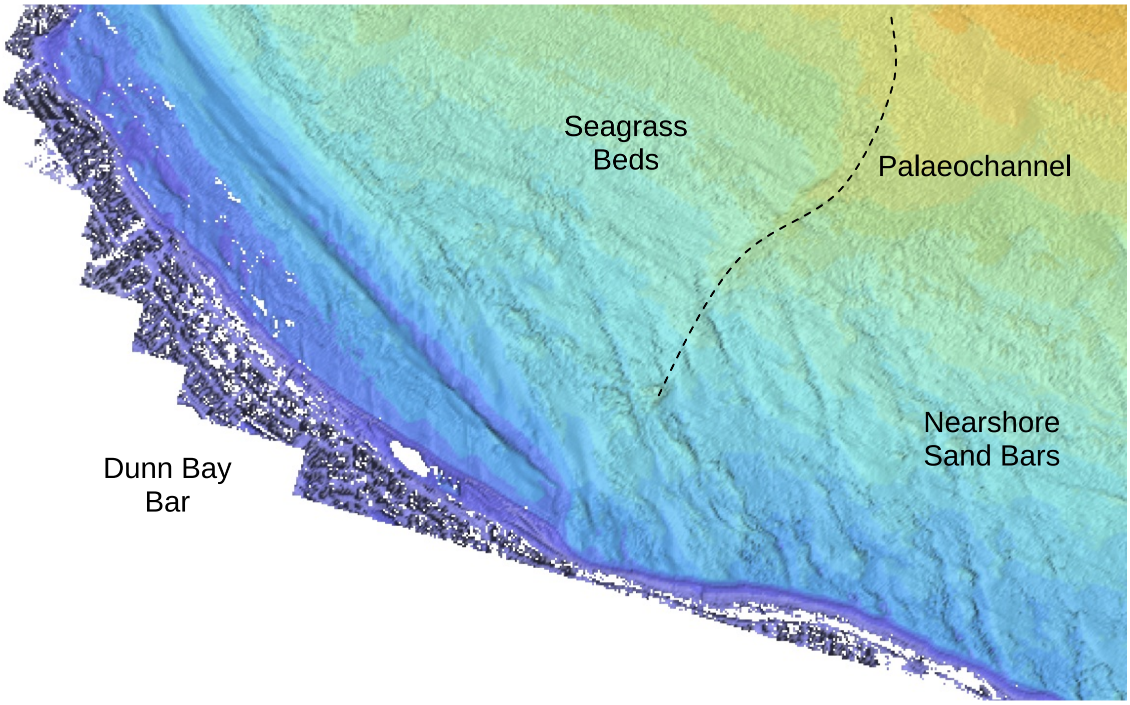


Figure 5-5: Dunn Bay Bar and Smaller Sand Bars, using fine-scale LIDAR imagery

The LIDAR data has been used to define cross-shore profiles at 1 km intervals along the Geographe Bay shoreline for use in storm erosion modelling. It has also been used to examine the structural characteristics of observed bed features in detail, which are mainly sandbars and drainage channels.

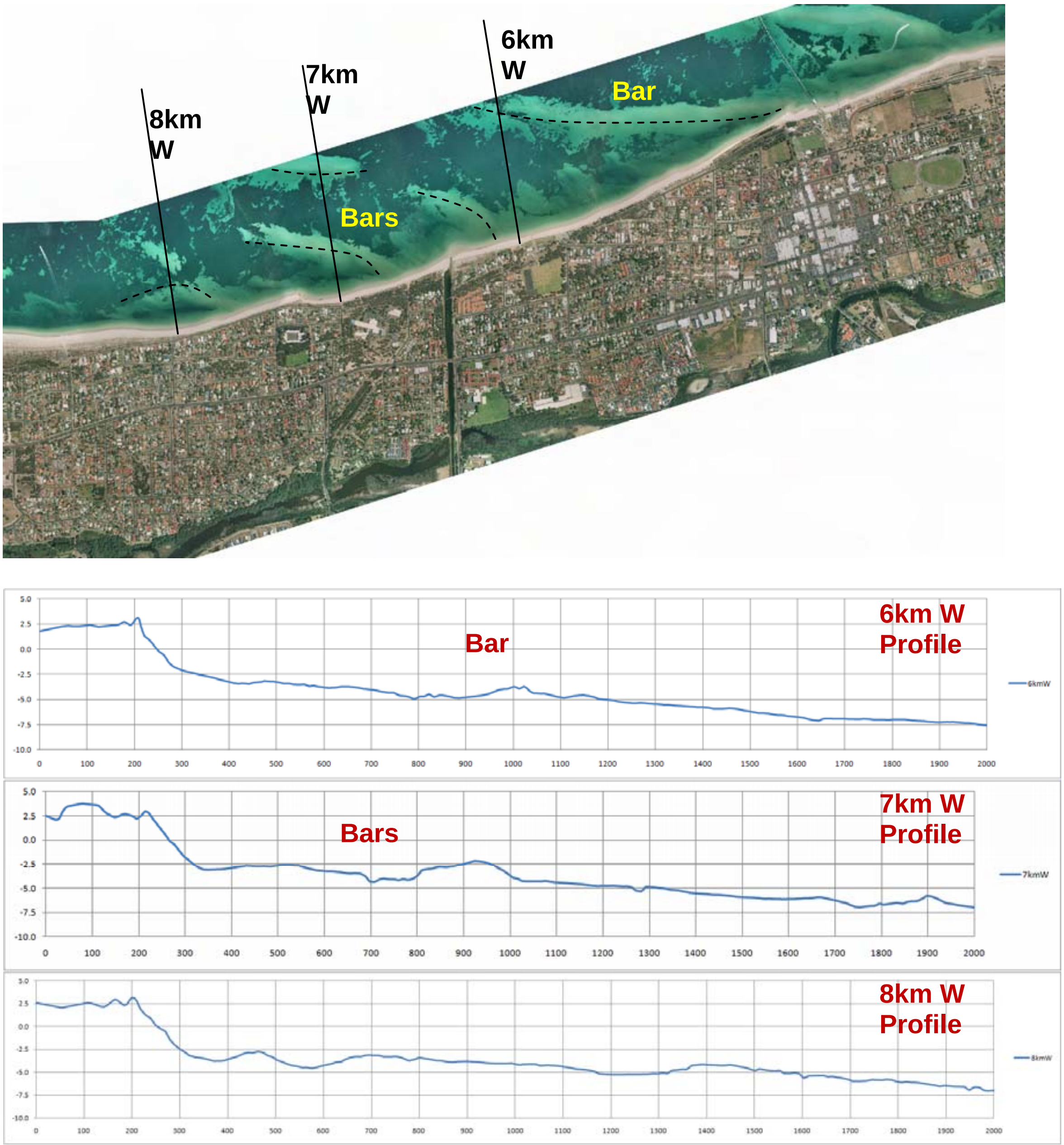


Figure 5-6: Illustration of Feature Capture with LIDAR profiles

A number of transverse furrows and associated linear sand bars are identifiable from the LIDAR data. The bar patterns are consistent with offshore and alongshore supply of sediment to the shore. The largest sand bar features are Dunn Bay bar (Quindalup), Abbey bar, Busselton Jetty bar and Wonnerup bar. Recent behaviour of three of these bars has been illustrated using aerial imagery from 2002, 2004 and 2007 (Section 5.3). Evidence to describe the evolution of Geographe Bay over geological time frames is available from sediment analyses [17,21&22]. These confirm that the shore of Geographe Bay has been progressively accreting for approximately two and a half thousand years, in response to gradually falling sea levels. Geomorphic evidence confirms this general behaviour, but has also identified occasional overwash events, although it is unclear whether these relate to barrier collapse or breach formation.

5.3. HISTORIC SHORELINE CHANGES

The general trend of accretion over the last two thousand years is anticipated to slow, and between 50 to 80 years from now (see Section 9.5), is likely to shift towards an erosive trend as sea level rise progresses. Despite this projected reversal, historic shoreline changes along the Busselton foreshore provides an important basis for assessing the coastal impacts of climate change. Whilst it is recognised that assuming ergodic behaviour is flawed (i.e. a future response based entirely on the historic pattern of change), an assessment of historic shoreline change provides the best opportunity to determine what is currently driving coastal change along the Busselton foreshore and how the shoreline may respond to changes in the magnitude or relative influence of these driving mechanisms.

A modern perspective is available from anecdotal and documented historic records [23]. The most reliable form of assessment is provided by aerial photographs, which have been obtained across Geographe Bay by the WA State Government since 1941, with increased frequency of assessment over recent years. Analysis of the vegetation line change between 1941 and 2008 has been undertaken, to identify regional patterns of accretion and erosion (Figure 5-7). It is evident from previous investigations and historic aerial photography that the Geographe Bay foreshore *as a whole* has been accreting over the last 70 years, with the Locke Estate area providing the marked exception, following installation of Siesta Park groyne.

It is recognised that the complete historical aerial photograph record provides significant additional information with respect to decadal-scale fluctuations in shoreline. Typically these variations represent the processes of storm erosion and recovery, which are characteristic of alongshore variations in the sediment transport rate associated with individual storm events (Section 7). Local exceptions to this generalisation include (i) response to installation of coastal structures; (ii) a significant period of shoreline movement after construction of the regional drainage network (imagery indicates sometime between 1941 and 1975); and (iii) fluctuations at the landward end of the large sandbar features of Geographe Bay.

Installations of coastal structures are responsible for the major coastal changes identified within the aerial imagery record. The magnitude of impact and the time scale required before the coast approaches a semblance of stability are strongly influenced by the length that the structure projects from the shore (Table 5-1). Longer structures have greater relative significance as they are expected to influence coastal behaviour for a much longer period than other structures.

Table 5-1: Influence of Structure Length on Adjustment Time Scale

* Adjustment Time Scale has been estimated using a 6^{o} capture angle. This angle varies at structures around Geographe Bay, from 1^{o} to 30^{o}, which gives an additional factor of 5.

Structure Length	Capture Capacity	Adjustment Time Scale*	Examples of given length*
20m	13,000 m^3	< 1 year	
30m	29,250 m^3	1-2 years	Abbey Boat Ramp
50m	81,250 m^3	2-4 years	
75m	182,813 m^3	4-9 years	Norman Road
100m	325,000 m^3	8-16 years	
155m	780,813 m^3	20-40 years	Siesta Park
183m	1,088,393 m^3	25-50 years	Port Geographe

* There is a program for bypassing at Port Geographe, to sustain navigation.

Between the aerial imagery of 1941 and 1975, a significant change to the drainage network is apparent, due to construction of the regional drainage network. This period is also associated with large areas of accretion, particularly in the vicinities of Dunsborough-Quindalup, Merribrook and Abbey. Calculation of total accretion rates from 1941 to 1975 and 1975 to 2008 suggests that the net change is commensurate with trapping at Guerin Street Groyne or Port Geographe. It is inferred that whilst modification of the drainage network released a large quantity of sediment through disruption of ebb-tide deltas, this material was later captured through formation of new sedimentary features at the trained drainage outlets. This process, where the ebb-tide deltas switch between acting as sinks and sources is active over sub-decadal time scales, and may help to cause significant but short-term variation of shoreline position (Section 5.4.2).

Sandbars along Geographe Bay coast occur with a range of sizes, but generally similar structure (Figure 5-4 and Figure 5-5). For most bars, the direction is approximately in line with the diffracted prevailing swell, until near shore, where alongshore tidal and wave driven currents cause the bar to bend towards shore parallel. The largest sandbar at Dunn Bay is a relative exception to this configuration, with the body of the sandbar cutting across the direction of swell. Dynamics of the largest sand bars have previously been examined, identifying their capacity to generate large onshore sand feeds through wave action, resulting in lobes of sediment at the coast nearest their tip. Due to its orientation and relatively shallow crest, Dunn Bay bar supplies a relatively higher rate of sediment than the other bars. LIDAR data examined as part of this study has indicated that the smaller bar systems are more variable in structure, and may have side slopes skewed in either direction.

The larger sandbars have historically migrated eastwards, shifting the lobe of coastal accumulation with them, which causes rapid local erosion or accretion on the west or east side respectively. The patterns of change adjacent to sandbars are relatively gradual, with only minor episodes of accretion or movement apparent when considering sequences of recent aerial imagery. Dunn Bay bar shows dramatic shoreline accretion between 2002 and 2004 (Figure 5-8). Negligible changes are evident at Busselton Jetty bar (Figure 5-9) and Wonnerup bar (Figure 5-10).

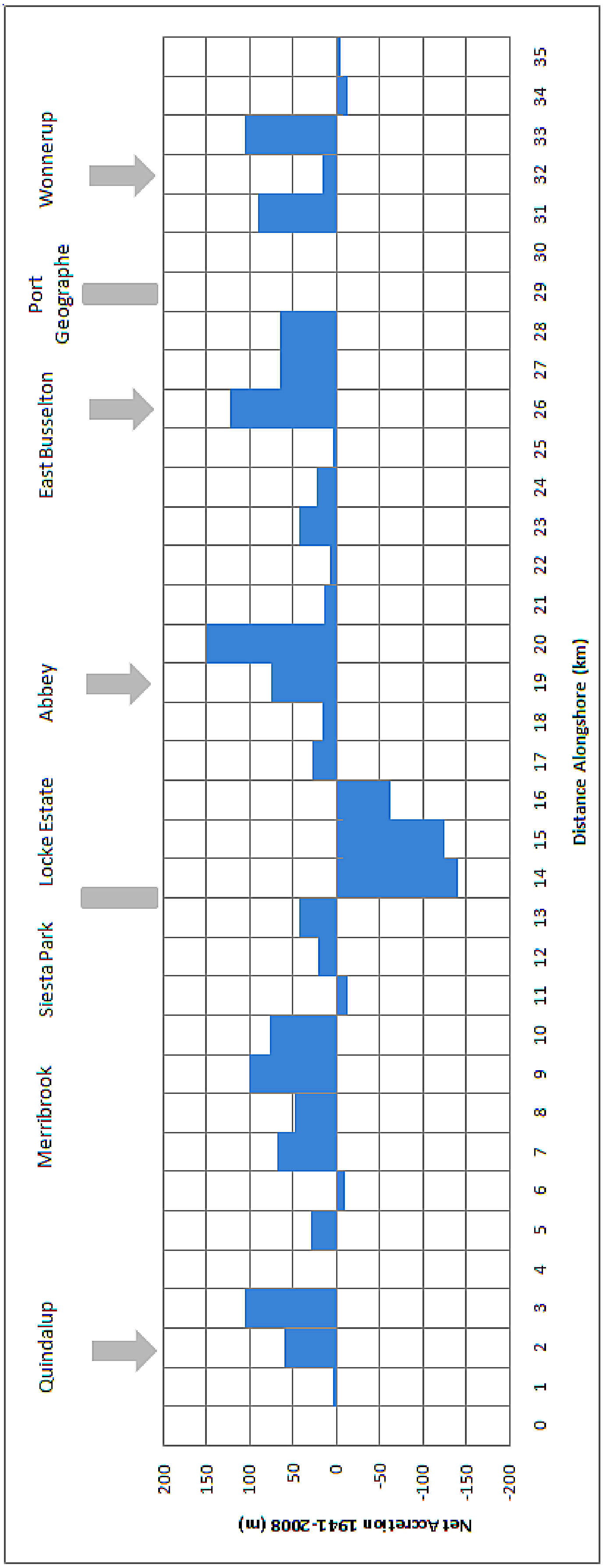
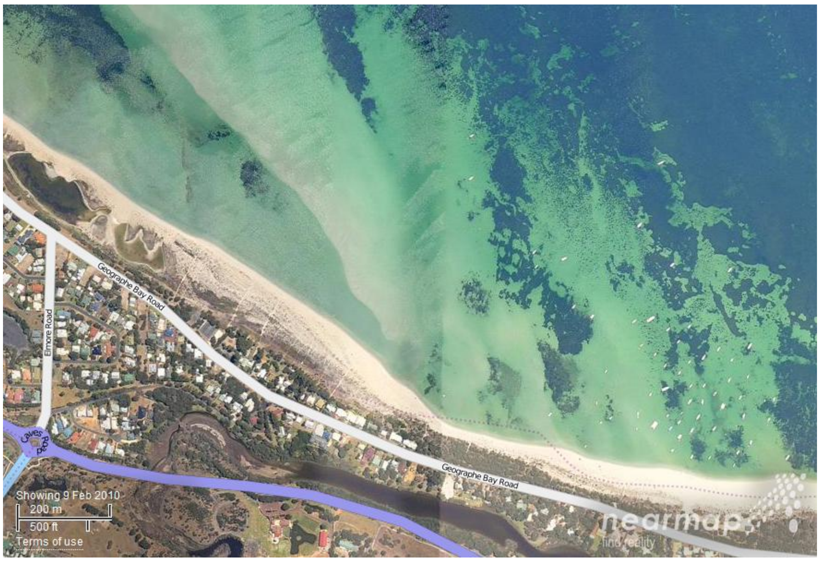


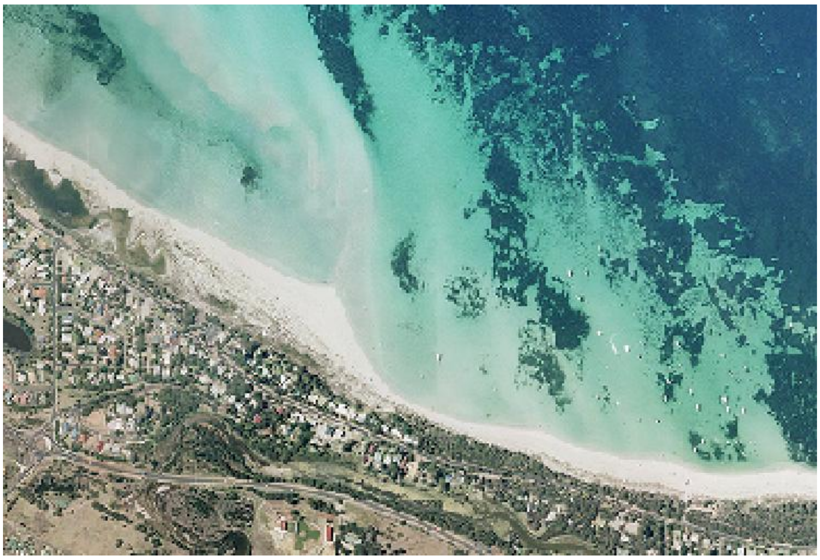
Figure 5-7: Shoreline Change from 1941 to 2008

5.3.1. Dunn Bay Bar



2002

2004



2007

Figure 5-8: Dunn Bay Bar Recent Nearshore Evolution

5.3.2. Busselton Jetty Bar

2002

2004

2007

Figure 5-9: Busselton Jetty Sand Bar

5.3.3. Wonnerup Bar

2004

2007

Figure 5-10: Recent Change at Wonnerup Sand Bar

5.4. ACTIVE PROCESSES

The active geomorphic processes provide an indication of how the Geographe Bay coastline is most likely to respond to change. These processes have been separated according to process scale, as this provides an indication of the management actions that may be required.

5.4.1. Large-scale Processes

Large-scale processes are considered those that affect the whole of Geographe Bay coast, and have been occurring over time scales longer than decades. The prevailing large-scale process occurring along Geographe Bay is accretion which has been occurring for a several thousand years, albeit slowly. Distribution of the accreting sediment is provided by net eastward alongshore transport, with flux increasing to the east. The behaviour is described as '*a net eastward littoral sand drift in response to a dominant swell wave forcing which is reversed on only a few occasions in most years by wind waves associated with winter gales. These normal winter storms, varying between 5 and 15 per year, mainly move sand immediately offshore from whence it is returned by the swell waves.* ' [3]

Historical aerial photographs show that the average accretion distance has been approximately 28m, which equates to roughly 100,000 m^3 p.a. over 35 km of coast. The volume has been converted to an equivalent horizontal distance by dividing by 6.5m, which is determined from the average dune crest height (2.5 m AHD) to the typical change in beach grade (-4.0 m AHD). Accretion is spatially distributed, occurring onshore from large sandbars and updrift from large coastal control structures at Siesta Park, Port Geographe and the ebb-delta at Toby's Inlet. Long-term erosion has mainly occurred downdrift of the two structures, with erosion at other locations typically being short-term storm responses, although it has prompted permanent installation of control structures [3].

Erosion due to sea level rise is a large-scale process that is anticipated to have future impact. Whilst the historic mean sea level change has been comparatively small, with 0.15m observed mean sea level rise over the 20th Century, the fluctuations of mean sea level associated with decadal scale climate variations can be used as a simplified indicator of shoreline response to mean sea level processes [24]. From 1993 to 2000, mean annual sea level rose approximately 0.2m, but only produced minor general erosion, with 0.5m average from Dunsborough to Wonnerup. The implied sediment deficit (balanced against supply) is in the order of 800,000m^3, which gives a ratio of 20:1 shoreline change to sea level rise. This approximately corresponds to a geometric response [25], which is significantly less than that suggested by Bruun, in the range of 50-100 (typically less for low energy coasts).

The discrepancy between observed response to a decadal sea level change and the Bruun ratio can partly be explained in terms of time scales for response, but is more significantly affected by the local morphology, compared with the littoral shore morphology relevant to the Bruun ratio derivation [26]. The morphology of Busselton shoreline is a transgressive barrier system overlying a shallow rock base, where under rising sea level conditions, the relatively small quantity of mobile sediment overlying rock is pushed upward and backward, forming a new barrier system (beach and dune sequence).

Shoreline dynamics for a shallow-based barrier are fundamentally different to the processes used to derive the Bruun ratio (Figure 5-11) making it invalid to apply to Busselton coastline. Instead of relative translation of the littoral zone, the rate of retreat balances against the volume of material required to maintain an adequate buffer against wave action. As an upper limit, the ratio can be estimated as the existing height of the barrier relative to the average distance associated with overwash events.

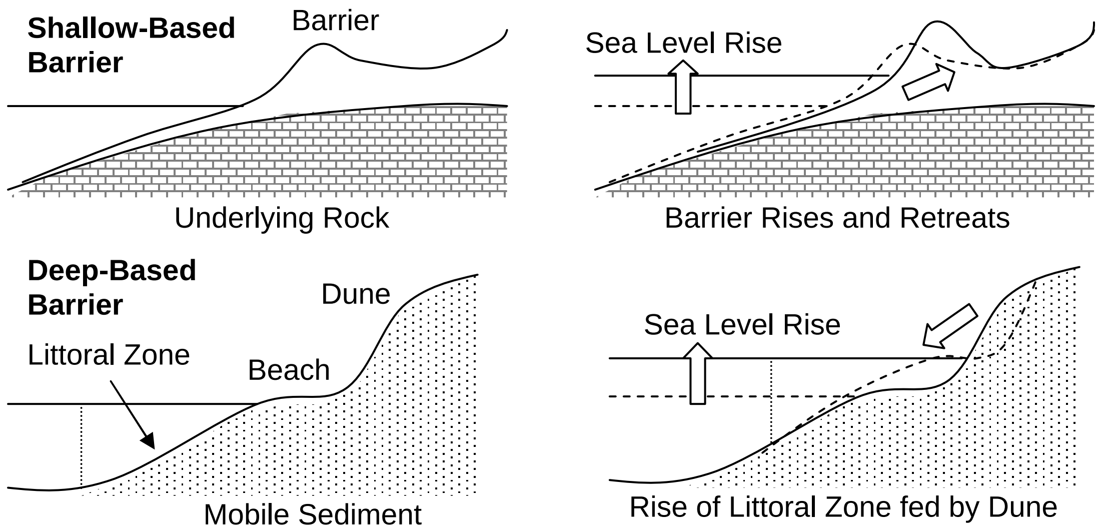


Figure 5-11: Conceptual Models of Response to Sea Level Rise

The effective distance of overwash is affected by the relative severity of storm events and the existing state of the barrier system. Response to sea level rise is a time dependent process:

- For sea level rise under sustained moderate energy conditions, with an active supply of material, the frontal dune may grow as a relatively narrow barrier. Under these circumstances, the ratio may be approximated by the barrier width to the barrier height, typically in the range of 10:1 to 30:1;
- For sea level rise with occasional extreme events, the barrier system may undergo episodes of collapse and retreat. Under these circumstances, the ratio of retreat to SLR may be approximated by the overwash length to the barrier height. The existing distance from the dune crest to low points behind the dunes is highly variable along the Busselton shore from 50m to almost 1km. This implies a potential ratio of retreat to SLR from 10:1 to 500:1.

This variability of response to the severity of events explains the relatively minor observed change in response to the sea level perturbation between 1993 and 2000. Although enhanced dune building is likely to have occurred, only a 0.2m rise is unlikely to have caused significant overwash.

5.4.2. Moderate-scale Processes

Moderate-scale processes are considered those which affect sections of the coast larger than several kilometres, and cause progressive change over time scales from years to a decade. There are three major moderate-scale processes, being the onshore sand feeds, artificial interruption of alongshore transport and natural alongshore variation of sediment transport rates.

Onshore sand feeds have been assessed using the long-term shoreline movement record to refine the regional sediment budget (Section 6). These are apparently the major source of the accretion occurring along Geographe Bay. Supply may vary from year to year, but over decadal time scales appears to have remained relatively consistent.

The two major barriers at Siesta Park and Port Geographe provide significant coastal realignment and a major differential of alongshore sediment transport. As a result, limited natural bypassing occurs, producing ongoing downdrift erosion and updrift accretion. This effect is partially offset at Port Geographe through sand bypassing activities, although these have not been regular since construction of the breakwaters, and have caused downdrift erosion at Wonnerup.

Ebb-tide deltas at drainage outlets are capable of holding sediment due to their disruption of alongshore flows. The two largest examples are at Toby's Inlet and the delta at the Vasse-Wonnerup entrance. Under the majority of conditions these features are fully saturated and experience complete bypassing. However, changes in the availability of sediment can occur for a number of years after extreme flooding when the delta subsequently acts as a sediment sink, or if the tidal prism is reduced when the delta subsequently acts as a sediment source. Over decadal or longer time scales, these processes are approximately in balance. Smaller drainage channels also have the capacity to switch from source to sink, as suggested by the aerial photograph interpretation, but generally respond seasonally.

The natural alongshore variation of sediment transport is developed through the differing degrees of shelter provided by Cape Naturaliste to waves generated from different directions, and the relative resistance to transport provided by the coastal orientation. This allows transport to vary locally according to the relative incidence and intensity of different storm events. For example, a westerly storm is mainly active from Siesta Park to East Busselton, and may cause erosion at Locke Estate, accretion at Busselton and limited effects outside this area. Over several years, inter-annual variability of storm events allows these variations to produce local zones of erosion or accretion, which in many cases have been responded to by the installation of coastal protection structures.

The process of alongshore variation of sediment transport is discussed in greater detail in Section 7.

5.4.3. Small-scale Processes

Small-scale processes are considered those which affect sections of the coast smaller than several kilometres, and cause progressive change for less than a year, or changes that are reversed within several years.

The most significant small-scale process is storm erosion, which causes sand to be dragged offshore under energetic wave conditions. Under mild conditions, wave action pushes the material back towards shore. This process is not wholly reversible, as the zones of erosion (beach scarp) and accumulation (offshore storm bar) during a storm may be outside the influence of moderate conditions, and the resulting features may last for a number of years.

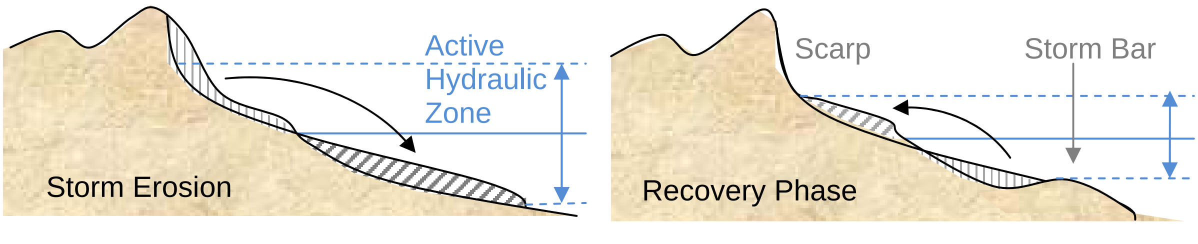


Figure 5-12: Cross-shore Storm Erosion and Recovery

A second small-scale process that is relevant to the calculation of setbacks is the downdrift erosion associated with alongshore control features, which may be natural or artificial. Here features act to hold a fixed position, which retains sediment on the updrift side during an alongshore transport event, producing downdrift erosion until the feature is saturated and sand is bypassed (Figure 5-13).

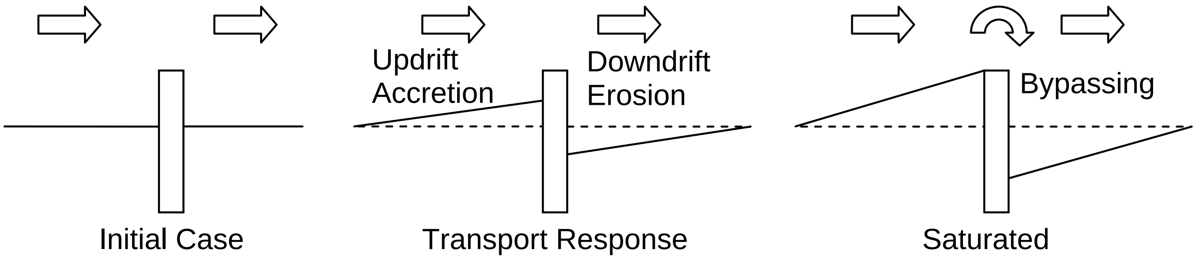


Figure 5-13: Coastal Response at Alongshore Control Feature

The effect of downdrift erosion is affected by the relative storage of the structure (Table 5-1) and its capacity to bypass material. In general, a longer structure stores more sediment, causes retarded bypassing and hence exacerbates downdrift problems. This is highlighted at Siesta Park and Port Geographe, in comparison with the performance of small timber groynes on the Quindalup and Busselton foreshores.

The systematic interaction of coastal structures requires consideration (Figure 5-14). During a storm event, cross-shore erosion moves sand offshore, which is gradually returned through wave action. However, the longshore transport is still active, which will start to fill in at the most updrift structure. There is a lag at adjacent locations until bypassing starts to occur or the offshore material returns shoreward. The barrier to alongshore supply causes erosion to occur on the downdrift end of the structures, until each of the cells formed between structures have been filled.

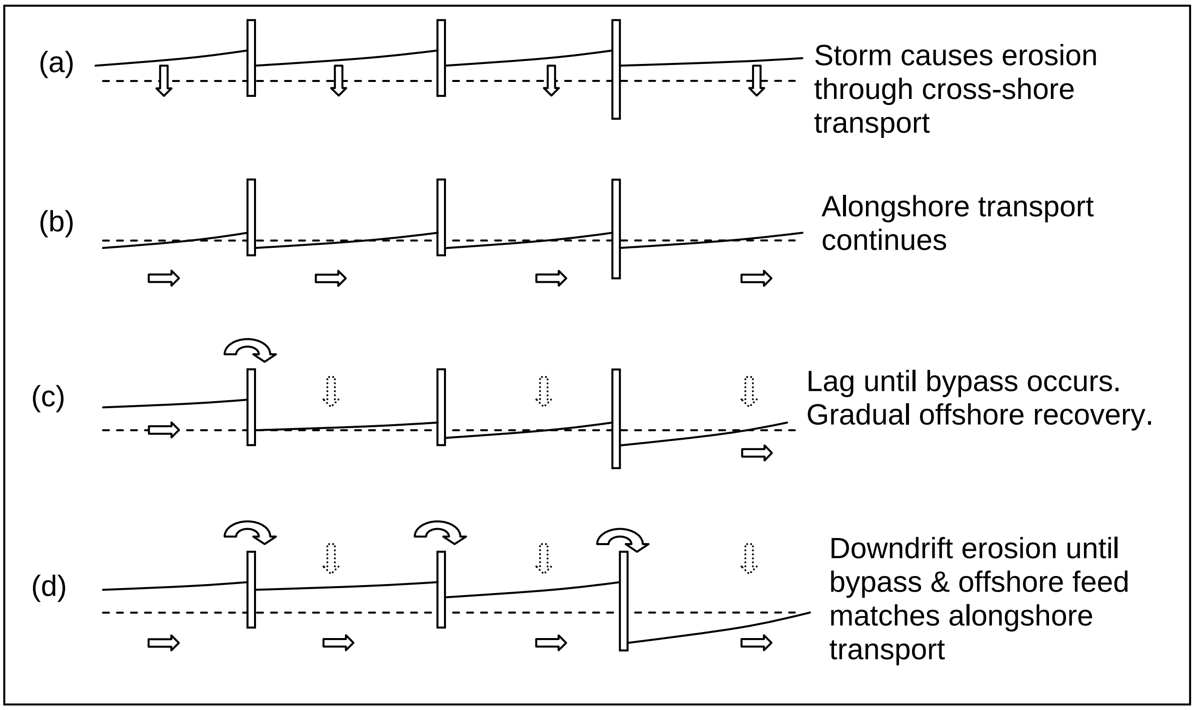


Figure 5-14: Downdrift Erosion Enhanced by Cumulative Structures

6. Sediment Budget

A sediment budget provides a means of looking at larger-scale processes and management requirements for the coast. It does not capture local processes or those occurring over decadal or shorter time scales.

A preliminary sediment budget was previously prepared by Oceanica and MP Rogers & Associates [27]. Whilst the preliminary nature of this budget was noted, it did not quantify the input of the sand bars to onshore sand feed, and therefore failed to suggest the large quantity of accretion that has occurred over the long term along the Geographe Bay coast. A revised sediment budget has been developed from the shoreline movement plans over the period 1941 to 2008. This budget is qualitative in nature, and whilst it includes information additional to that previously reported, it remains preliminary in nature. It is relatively consistent with the previously reported budget.

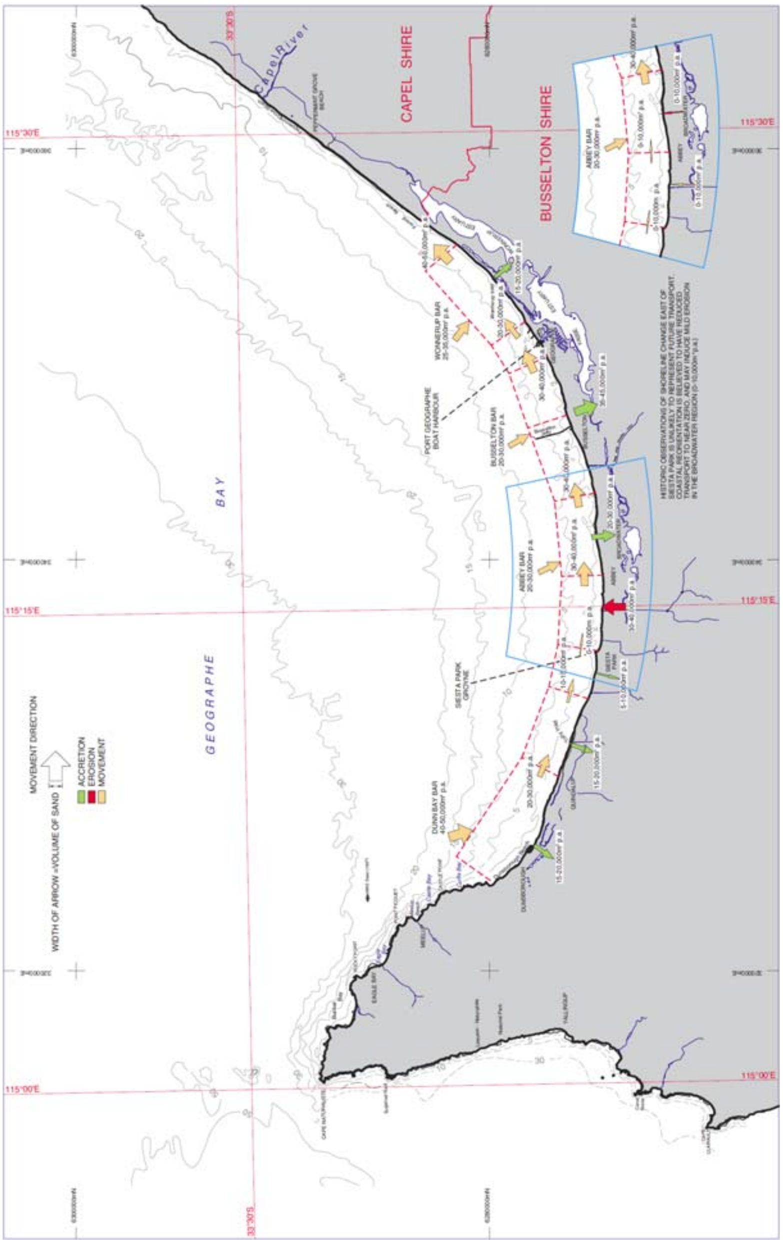


Figure 6-1: Preliminary Sediment Budget

Adapted from Oceanica [27]

Interpretation of how the historic sediment budget may apply to future conditions requires care. Most particularly, reorientation of the coast due to coastal protection structures may significantly reduce the alongshore sediment transport. Downdrift of the structure, the absence of supply will affect the coast, generally causing erosion, such as has occurred in the Locke Estate area due to installation of Siesta Park groyne. As a result of this erosion, the downdrift coast will also change orientation, reducing the alongshore sediment supply further downdrift.

Table 6-1: Alternative Sediment Budget Derived from Aerial Imagery

Location	Sand Feed	Change	Transport
Dunsborough-Quindalup	Dunn Bay Bar 40-50,000 m^3 p.a.	Accretion 15-20,000 m^3 p.a.	Eastwards 20-30,000 m^3 p.a.
Toby's Inlet-Merribrook		Accretion 15-20,000 m^3 p.a.	Eastwards 10-15,000 m^3 p.a.
Siesta Park West of Groyne		Accretion 5-10,000 m^3 p.a.	Bypass Eastwards 0-10,000 m^3 p.a.
Locke Estate *		Erosion 30-40,000 m^3 p.a.	Eastwards * 30-40,000 m^3 p.a.
Abbey *	Abbey Bar 20-30,000 m^3 p.a.	Accretion * 20-30,000 m^3 p.a.	Eastwards 30-40,000 m^3 p.a.
Busselton-East Busselton	Busselton Bar 20-30,000 m^3 p.a.	Accretion 35-45,000 m^3 p.a.	Eastwards 30-40,000 m^3 p.a.
Port Geographe			Bypass Eastwards 20-30,000 m^3 p.a.**
Wonnerup	Wonnerup Bar 25-35,000 m^3 p.a.	Accretion 15-20,000 m^3 p.a.	Eastwards 40-50,000 m^3 p.a.

* Historic observations of shoreline change at Locke Estate are unlikely to provide an adequate representation of future transport. Reorientation of the shoreline at a local scale is expected to have reduced the alongshore transport rate transported eastward. This is anticipated to significantly change conditions at Abbey, potentially causing 0-10,000 m^3 p.a. erosion.
** Bypassing rates at Port Geographe include historical behaviour without structures, and periods where limited mechanical bypassing has occurred.

The rate of sand feed from offshore sandbars has been estimated to provide a material balance near Siesta Park and be the only source of accretion at Abbey over the long-term. These assumptions have not been verified, and therefore the rates of sand feed should be considered indicative only. Qualitative confirmation of the sand feed rates has been provided by measuring the change in shoreline angle updrift and downdrift of the sand feeds.

7. Alongshore Transport Variations

The Dunsborough to Busselton coast has historically experienced several occasions of intense local erosion, which have resulted in the construction of shore protection works. These are not explained by the net sediment budget, which indicates a general long-term pattern of accretion. Some explanation can be given in terms of the alongshore variation of sediment transport, which is determined by the degree of shelter from Cape Naturaliste, the nature of wave energy from different directions and the coastal orientation.

A simplified analysis of the wave directions has been used to evaluate patterns of behaviour along Geographe Bay. The influence of different wave directions upon sediment transport is illustrated schematically through a series of figures.

Northwest waves are expected to most strongly influence the Dunsborough-Quindalup region, producing eastwards sediment transport. The changing shore alignment reduces the capacity for transport across the Busselton region (Figure 7-1).

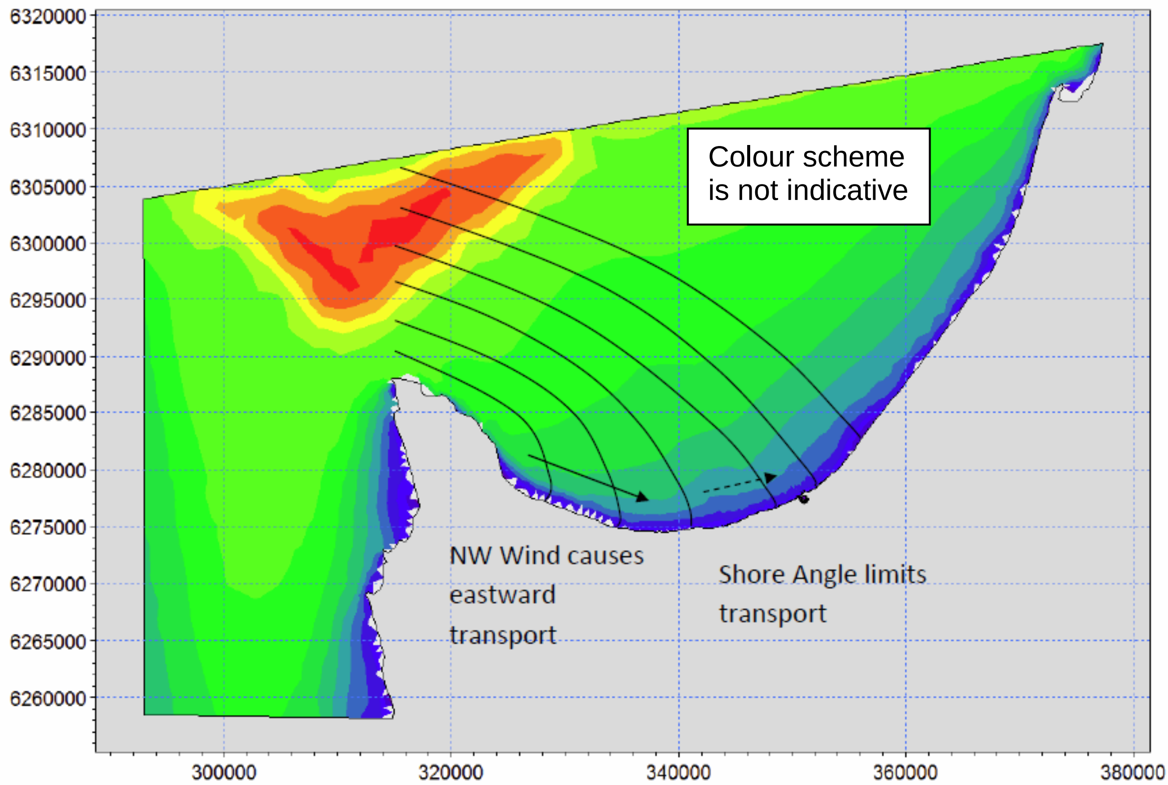


Figure 7-1: Schematic of Transport Due to Northwest Waves

Westerly waves are expected to be dominant for transport along the Busselton region, producing eastwards transport. The western part of the Bay is sheltered by Cape Naturaliste, and transport to the east is reduced by the changing shore alignment (Figure 7-2).

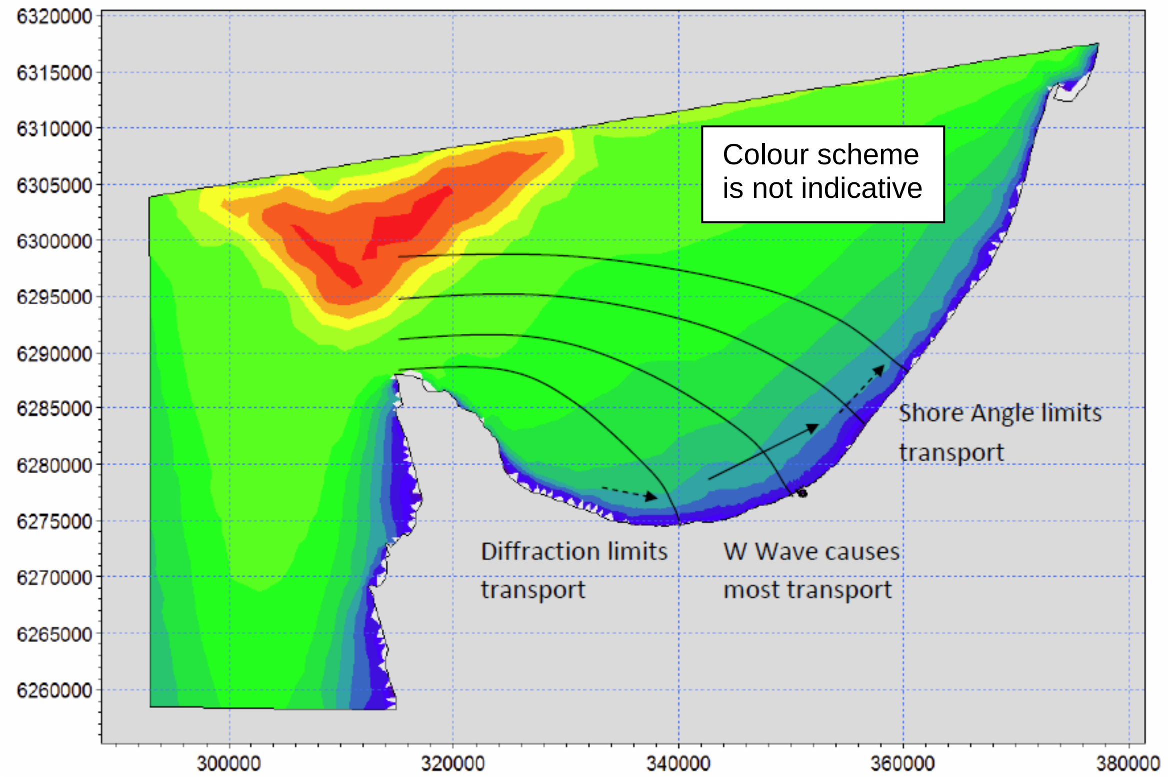


Figure 7-2: Schematic of Transport Due to Westerly Waves

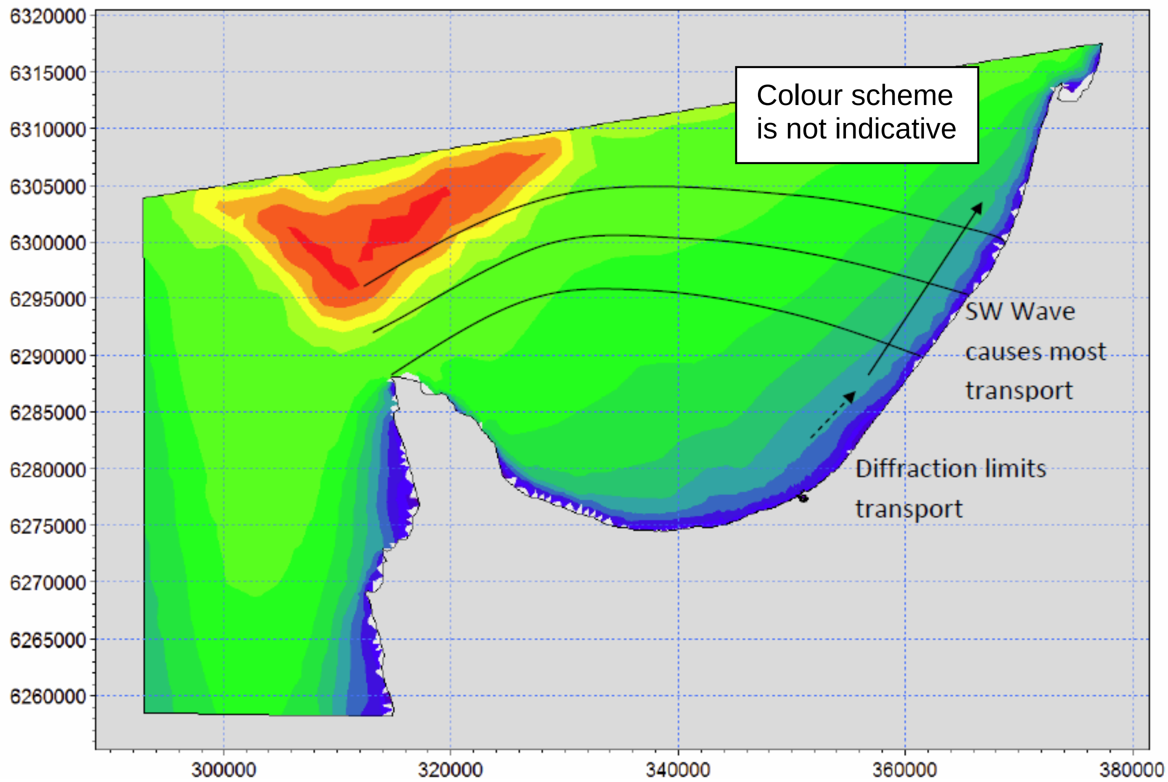


Figure 7-3: Schematic of Transport Due to Southwest Waves

Southwest waves, including the prevailing Indian Ocean swell are dominant for sediment transport east of Busselton region, producing northwards transport. West of Busselton, the Bay is sheltered by Cape Naturaliste (Figure 7-3).

Northeast waves are generated through high-pressure system winds blowing across Geographe Bay, most commonly during winter. As locally generated waves, they are controlled by the length of water over which the wind blows (the fetch) and the strength of the winds. Consequently, northeast waves are typically low energy, with limited significance in the eastern part of the Bay (Figure 7-4). These systems allow a variable direction of sediment transport to occur at Dunsborough [27].

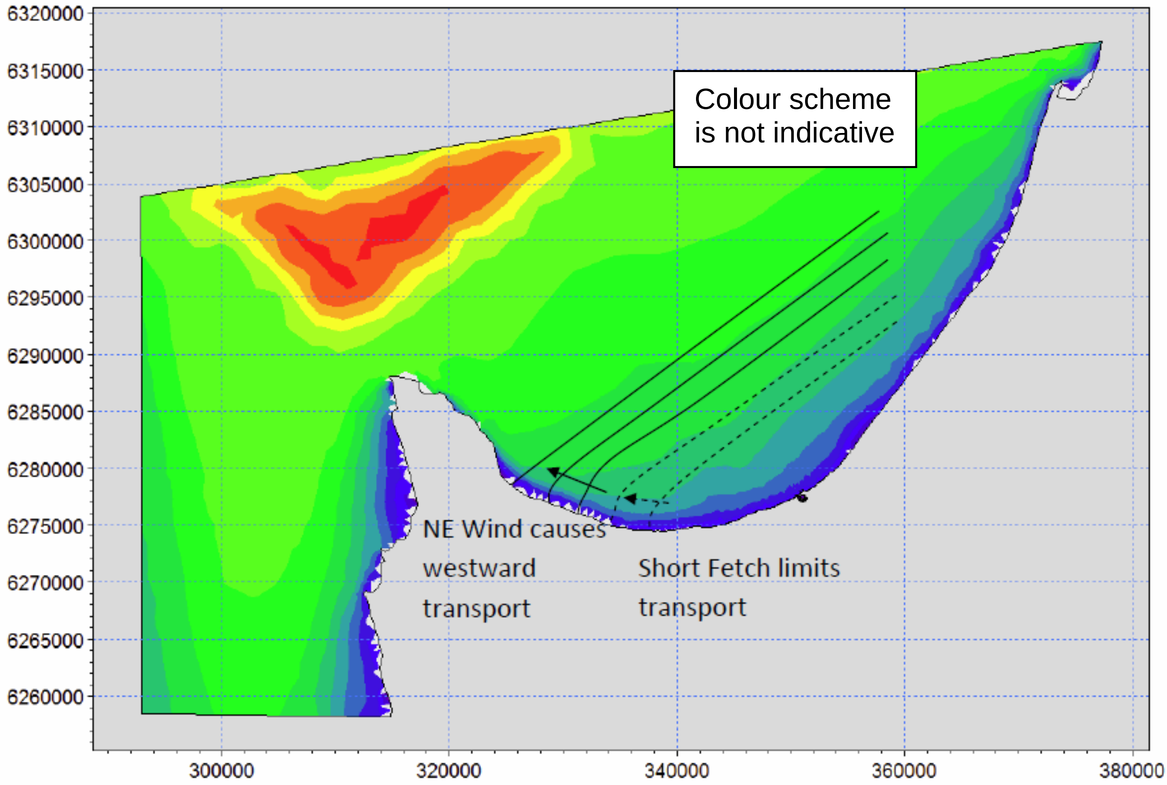


Figure 7-4: Schematic of Transport Due to Northeast Waves

The effect of these different zones of influence is such that transport occurs over a restricted spatial area, and declines to the east or west. As the erosion or accretion is determined by the spatial *gradient* of sediment transport, the resulting pattern of shoreline change produces a zone of erosion and a zone of accretion (Figure 7-5).

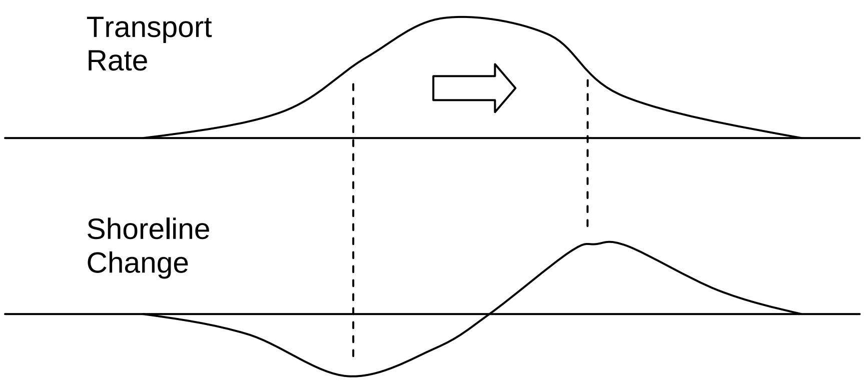


Figure 7-5: Schematic of Response to Variation of Alongshore Transport

In reality, the pattern of change from any single storm event is determined by the time sequence of the storm, as the wave direction and energy vary. Similarly, behaviour in the long-term is determined by the sequence of storm events. Local erosion focusing requires an extreme event from a relatively constrained direction, or repeated strong events from a similar direction.

The influence of different wave directions can be summarised by considering the expected relative sediment transport along Geographe Bay (Table 7-1).

Table 7-1: Influence of Different Wave Directions along Geographe Bay

Waves	**SW**	**W**	**NW**	**N**	**NE**
Source	Prevailing	Storms	Storms	Storms	Land Breeze
Max Strength	Extreme	High	High	Moderate	Low
Frequency	Common	Frequent	Rare	Very Rare	Common
Location					
Quindalup	Sheltered by Naturaliste	Sheltered by Naturaliste	East (sheltered)	East (small angle)	West
Siesta Park	Sheltered by Naturaliste	East (refracted)	East (small angle)	East (small angle)	West
Broadwater	Sheltered by Naturaliste	East	East (small angle)	West	West (small fetch)
Busselton	East (sheltered)	East	Negligible (small angle)	West	West (small fetch)
Wonnerup	East (sheltered)	East (small angle)	West (small angle)	West	Negligible (no fetch)

In summary, the influence of different wave directions varies along the Geographe Bay shoreline:

- At Quindalup, the coast is sheltered from westerly and southwest waves, and only influenced by northwest, northerly and northeast waves;
- At Siesta Park, westerly waves are dominant but limited due to refraction. Northwest and northerly waves produce limited eastwards transport due to the angle of the shore. Northeast waves have sufficient fetch to create limited transport westwards;
- At Broadwater, westerly waves are dominant, but limited due to refraction;
- At Busselton, westerly waves are dominant. Southwest waves contribute to transport, but are partly sheltered by Cape Naturaliste;
- By Wonnerup, southwest waves are dominant. Westerly and northwest waves have reduced influence due to their angle of approach.

8. Coastal Protection Structures

There are a large number of coastal protection structures along the Geographe Bay coast, the majority of which are owned and maintained by the Shire of Busselton [4].

Table 8-1: Geographe Bay Coastal Protection Structures

ID	Sector	Description	Material	Structure length (m)
1	Dunsborough	Dunsborough Carpark Seawall	Rock - Lateritic Ironstone	90
2	Quindalup	Quindalup stone revetment (buried)	Rock - Lateritic Ironstone	250
3		Quindalup timber groyne	Timber	35
4	Toby Inlet	Station Gully Drain		
5	Siesta Pak Merribrook	Molloy Drain		
6		Lennox Drain		
7		East Lennox timber groyne 1	Timber	20
8		Jetty Groyne at "Serena" (Siesta Park)	Concrete	40
9	Siesta Pak East	Siesta Park Groyne	Rock - Lateritic Ironstone	100
10		Locke Swamp Drain		
11		Locke Estate Seawall	Rock - Lateritic Ironstone	300
12		Locke Estate timber groynes 1	Timber	40
13		Locke Estate timber groynes 2	Timber	40
14		Locke Estate timber groynes 3	Timber	40
15		Locke Estate timber groynes 4	Timber	40
16		Locke Estate timber groynes 5	Timber	40
17	Broadwater/Abbey	Buayanup Drain Training wall	Rock - Granite	100
18		Abbey Timber Groyne 1	Timber	40
19		Abbey Boat Ramp Hedland	Rock - Lateritic Ironstone	130
20		Abbey Timber Groyne 2	Timber	40
21		Abbey Timber Groyne 3	Timber	40
22		Abbey Rock Groynes 1	Rock - Lateritic Ironstone	50
23		Abbey Rock Groynes 2	Rock - Lateritic Ironstone	50
24		Abbey Rock Groynes 3	Rock - Lateritic Ironstone	50
25		Abbey Rock Groynes 4	Rock - Lateritic Ironstone	50
26	Beachlands	Dolphin Rd Boat Ramp	Timber	
27		Beachlands Timber Groyne 1	Timber	40
28		Beachlands Timber Groyne 2	Timber	40
29		Beachlands Rock Groyne	Rock - Lateritic Ironstone	50
30		Beachlands Seawall	Rock - Lateritic Ironstone	200

Table 8-1: Geographe Bay Coastal Protection Structures (continued)

ID	Sector	Description	Material	Structure length (m)
31		Beachlands 'Longard Tubes	Geotextiles	300
32		Vasse Diversion Outlet Training Wall	Rock - Granite	100
33	Busselton Main Beach	Busselton Beach Rock Seawall	Rock - Lateritic Ironstone	400
34		Busselton Seawall Geotextile	Geotextile	50
35		Busselton Jetty Geotextile Groyne 1	Geotextile	50
36		Busselton Jetty/seawall	Rock - Granite	60
37		Busselton Jetty Geotextile Groyne 2	Geotextile	50
38	East Busselton	East Busselton Groyne Field (×5) (buried)	Rock - Lateritic Ironstone	
39	Port Geographe	Breakwater West	Rock - Lateritic Ironstone	340
40		Breakwater East	Rock - Lateritic Ironstone	200
41		Port Geo Groyne 1	Rock - Lateritic Ironstone	200
42		Port Geo Groyne 2	Rock - Lateritic Ironstone	330
43	Wonnerup	Wonnerup Seawall	Rock - Lateritic Ironstone	350
44		Wonnerup Rock Groyne 1	Rock - Lateritic Ironstone	35
45		Wonnerup Rock Groyne 2	Rock - Lateritic Ironstone	35
46		Wonnerup Rock Groyne 3	Rock - Lateritic Ironstone	35
47		Wonnerup Rock Groyne 4	Rock - Lateritic Ironstone	35
48		Wonnerup Rock Groyne 5	Rock - Lateritic Ironstone	35
49		Wonnerup Rock Groyne 6	Rock - Lateritic Ironstone	35
50	Deadwater	Wonnerup Inlet		

The capacity of the coastal protection structures to capture sediment has been estimated using a simplified formula, as $V_C = 30\ L^2$, which implies a capture angle of 6^o and an "effective updrift influence" of 10L. This formula is possibly an underestimate for a number of the structures, as historic accumulation has demonstrated very extensive updrift influence from coastal protection structures such as Guerin Street, Siesta Park and Port Geographe. Between them, the coastal protection structures are estimated to capture approximately 2.3 million cubic metres of sand. Of this quantity, Siesta Park groyne is estimated to hold approximately 22%, and Port Geographe is estimated to hold 13%. Port Geographe is estimated to be at 30% of its ultimate capacity and therefore provides a potential sediment sink.

Despite the relative influence of protective structures on coastal configuration, they are generally impermanent when compared to a planning time scale of 100 years. Relative persistence of a structurally controlled coastline typically requires repeated maintenance, if not replacement, of key structures. However, in many instances changing conditions, including foreshore use or coastal climate, modify the need for the structure, prompting adaptation.

The concept of continuous adaptation has been previously applied for determination of a setback line along Busselton coast[3]. However, as noted within Section 9.5, this approach will come under increasing pressure as the rate of sediment demand approaches the rate of sediment supplied to Geographe Bay. For the range of climate change scenarios considered in this report, Busselton coast will move into net sediment deficit from 50-110 years hence.

Section 9.6 provides shoreline projections on the basis that existing coastal protection structures continue to be maintained but that no further structures are installed. These projections include two biases:

(i) The relative performance of seawalls for shoreline retention is exaggerated, as it has been assumed that their position will be maintained. This represents a significantly greater effort than is suggested by assuming groynes will be maintained;

(ii) The relative balance of material supply and demand has been assumed to be evenly distributed across the Busselton coast. In reality, supply is predominantly from the west and hence an uneven spatial distribution is likely, strongly influenced by coastal management effort. Active management such as installation of coastal protection structures would preferentially result in material capture to the west and erosion to the east.

Appendix C provides shoreline projections on the basis that existing coastal protection structures are removed. Whilst this proposition is unrealistic, it serves to highlight the relative significance of the structures and their influence on coastal configuration. The dominance of certain key structures has previously been identified through analysis of historic shoreline changes [3,28]. The projections identify six constructed protection systems that provide highly significant protection to infrastructure, including private residences, along the Busselton coast:

1. The breakwaters, groynes and revetment walling at Port Geographe retain 24 ha of land, extending along 1.9 km of coast. The area west of Port Geographe has not been allowed to fully saturate with sand, due to navigational and downdrift erosion issues;
2. A series of protective works in the vicinity of Busselton Jetty act to provide control, including revetment walls and groynes. These structures retain 13.5 ha of land, extending along 1.5km of coast, with roads and recreational infrastructure a short distance behind walling;
3. The revetment and perched beach system at Beachlands retain 9.2 ha of land, extending along 0.9 km of coast, with a roadway and housing immediately behind the revetment;
4. Siesta Park groyne retains 9.0 ha of land along 0.6 km of coast, of which 3.0 ha has sufficient buffer to effectively protect against projected shoreline retreat and storm erosion;
5. Holgate Road groyne retains 2.8 ha of land, extending along 0.3 km of coast;
6. Abbey boat ramp and its hardstand retain 0.6 ha of land, extending along 0.2 km of coast.

In addition to the key structures, two natural sand feeds that help to provide a significant coastal buffer occur at Dunn Bay sandbar and Abbey bar.

9. Setback Assessment Methodology

The setback assessment method has been developed using the general principles of SPP 2.6. However, the method differs slightly from those previously applied to the Geographe Bay coast by incorporating a number of the local processes, including the ongoing accretion of the coast and the localised erosion patterns, such as caused by downdrift erosion, the cumulative downdrift lag effect of multiple structures and alongshore variation of sediment transport. Further, the morphology of the Busselton coast has been considered when assessing the influence of mean sea level change: response to sea level change has been estimated using geometric rise, plus cross-shore modelling, rather than applying the Bruun ratio of 1m of erosion for every 0.01m of mean sea level rise.

It should be noted that the methodology used creates a systematic bias in the presence of coastal protection structures, by assuming that the general form of such structures will be preserved. On the setback plans, this suggests that seawalls protect the foreshore position more effectively than groynes. However, the assumed maintenance of form inherently implies an order of magnitude greater effort to maintain a seawall in the face of shoreline retreat than is necessary for a groyne.

9.1. DEFINITION OF HORIZONTAL SETBACK DATUM

SPP 2.6 recommends that for a sandy coast, the horizontal setback datum (HSD) may be defined using the seaward limit of permanent vegetation, based upon current aerial imagery.

Due to the potential for relatively small scale and rapid variations associated sandbar salients and drains, the seaward projection of vegetation line associated with these features has been removed.

9.2. ALLOWANCE FOR ACUTE EROSION (S1)

Acute erosion has been calculated using a combination of cross-shore and alongshore transport processes:

- Cross-shore erosion has been calculated using SBEACH, applying the July 1996 storm to the existing profile generated from the LIDAR data;
- For beach cells defined by coastal structures less than 500m apart, the influence of beach rotation during an acute storm event increases with beach cell scale. A downdrift erosion allowance has been calculated using an assumed 2^o rotation of the beach to the nearest downdrift structure, or change in shoreline orientation;
- Downdrift of major structures or collective sets of minor structures, the lag between storm erosion and recovery (through alongshore transport) provides increased shoreline variability. An allowance for lag has been calculated by using the standard deviation of detrended shoreline position.

Cross-shore erosion at 1km intervals along the Shoreline from Dunsborough to Wonnerup has been calculated (Figure 9-1). The average erosion distance is 28m, with the most susceptible section of coast being Abbey to East Busselton. This distributive nature of the shore (including sink-source effect of drainage structures) suggests that allowance for acute erosion can be taken as 20m to the west of Siesta Park groyne, and 30m to the east.

Acute erosion associated with seawalls has not been included in the assessment, as this will vary significantly with the position relative to the coast and the relative potential for wave reflection. Erosion mechanisms include flanking, downdrift and wave reflection effects[29]. For the majority of shallow-founded coastal seawalls along Busselton coast, increased wave height caused by deepening will cause structural collapse prior to the seawall acting as a groyne.

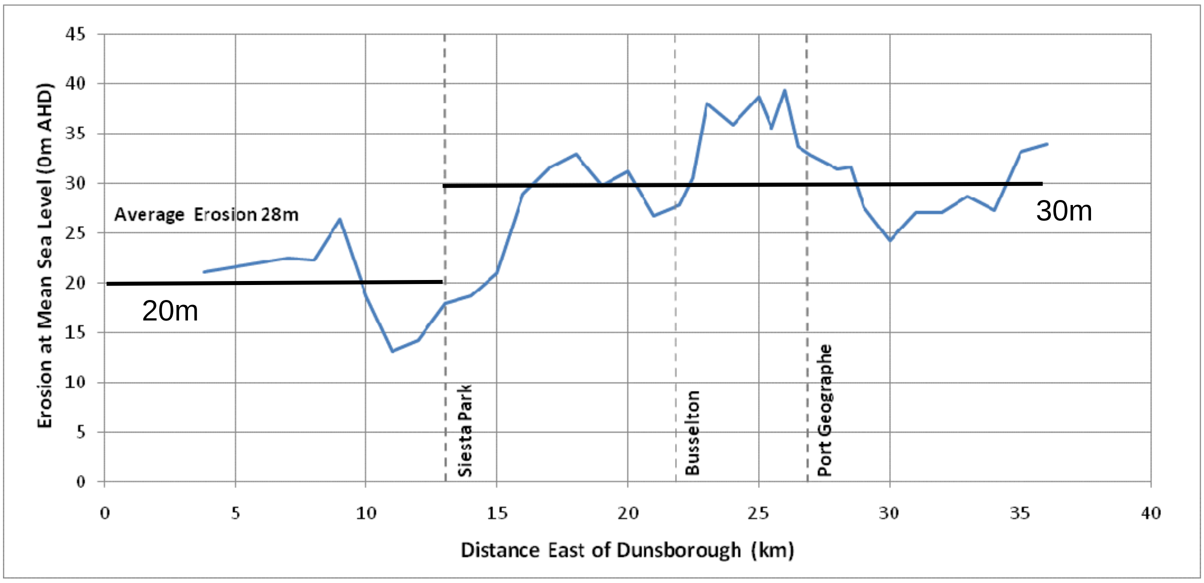


Figure 9-1: Cross-shore Erosion Distances Calculated using SBEACH

9.3. ALLOWANCE FOR CHRONIC EROSION (S2)

Busselton coast as whole has been accreting over the historic period, with sandbars providing a major feed of sediment to the coast, estimated to be approximately 100,000m^3 p.a. on the basis of historical aerial imagery, which is equivalent to 42m horizontal accretion over a 100 year time frame. Over the 100 year time frame considered, the long-term sediment supply will act as a major offset to the erosive effect of climate change. However, when considered more locally, chronic erosion is possible at several sections of coast:

- At Quindalup, reduction of sand supply from the Dunn Bay Bar may produce shoreline retreat;
- Eastwards of Siesta Park groyne and Port Geographe, the imbalance between the quantity of material bypassing the structures and the downdrift alongshore transport rates has caused historic erosion, which has gradually propagated east.

The influence of reduced sand supply has been considered, with sand feeds modified to account for the potential loss of wave energy under sea level rise scenarios, with 12%, 25% and 30% reductions estimated to occur during low, medium and high scenarios of climate change respectively. The influence of these potential reductions has been considered using the local sediment budget indicated in Section 6. The calculations suggest that variation of sand feed is only likely to play a significant role on shoreline position at Quindalup (Table 9-1), with the effect at other sand feeds more widely dispersed due to interaction with greater alongshore sediment transport.

Table 9-1: Chronic Setback Allowance for Dunsborough-Quindalup

Climate Scenario	Existing	Low	Medium	High
S2 Allowance	0m	0m	11m	20m

Behaviour at Siesta Park and Port Geographe requires special consideration when interpreting historical shoreline changes. These two major structures do not allow bypass at the same rate as the alongshore transport downdrift of them. Although the historic behaviour shows sustained erosion, reorientation of the shoreline to the east of these structures causes a slowing of the alongshore sediment transport rate. This reduces the supply to areas further downdrift, and induces a gradual propagation eastwards, with a lessening of transport rates to those indicated by historical patterns.

At Siesta Park, an extended period of erosion for the Locke Estate coast has progressively slowed. It is considered that reorientation of the coastline has occurred, that reduces the rate of alongshore sediment transport, and therefore distributes the imbalance between supply and transport rates downdrift. The potential for further erosion is partly limited by supply from the sandbar at Abbey, but is also offset by reducing alongshore sediment transport rates towards Busselton. This provides a length of 8 km over which the difference between supply and transport rates has been used to estimate an allowance for chronic erosion (Table 9-2).

Table 9-2: Chronic Setback Allowance for Locke Estate-Abbey

Climate Scenario	Existing	Low	Medium	High
S2 Allowance	3m	7m	12m	14m

At Port Geographe, the difference between updrift supply and downdrift transport rates has been partly offset through the use of mechanical bypassing. The effectiveness of this approach has been reduced through migration of the Wonnerup sandbar, and the relative stability of transport rates further east. There is potential for chronic erosion to occur approximately 6km east of Port Geographe (Table 9-3).

Table 9-3: Chronic Setback Allowance for Geographe-Wonnerup

Climate Scenario	Existing	Low	Medium	High
S2 Allowance	0m	7m	19m	24m

It is worth noting that the chronic erosion allowance as defined in Schedule One of SPP 2.6 contains an additional level of conservatism that has not been reflected in these calculations. Specifically, the schedule requires that an allowance of 20m be included instead of projected behaviour if accretion or erosion is less than 20m over 100 years (13.4m over 1941 to 2008). Although the historic shoreline changes (or even reduced sand supply) suggest a net accretion rate of more than 20m per 100 years, this has not occurred evenly. When considered against the variable pattern of erosion and accretion, application of the Schedule would effectively reduce the sediment input by 25,000 m^3.

9.4. ALLOWANCE FOR SEA LEVEL RISE (S3)

As identified in Section 5.4.1, the morphology of the south Geographe Bay coast is that of a transgressive barrier on a shallow rock base, which has dynamics that invalidate the use of the Bruun ratio applied in SPP 2.6. An estimate of shoreline response to sea level rise has been derived from coastal geometry, plus an estimate of the volume of sediment required in a barrier system to prevent overwash. This volume has been calculated by using SBEACH at 1km intervals along the coast under the climate change scenarios – as the existing profile will be highly modified through the effects of ongoing accretion, erosion distances are not considered meaningful. The volume has been converted to an equivalent horizontal distance by dividing by 6.5m, which is determined from the average dune crest height (2.5 m AHD) to the typical change in beach grade (-4.0 m AHD). Geometric change has been calculated using a ratio of 25:1 horizontal change to sea level rise, based upon observed change from 1993 to 2000 and typical profile grades.

Despite the significant difference in the methods of calculation, the derived setback allowance for sea level rise (averaged across the Bay) is comparable to using a Bruun ratio of 50:1, which is applicable for low energy coasts (Table 9-4).

Table 9-4: Comparison of Methods Assessing Sea Level Rise Setback Allowance

Scenario	Low	Medium	High
Bruun Ratio 100:1	40 m	90 m	110 m
Bruun Ratio 50:1	20 m	45 m	55 m
Erosion Modelling	26 m	45 m	51 m

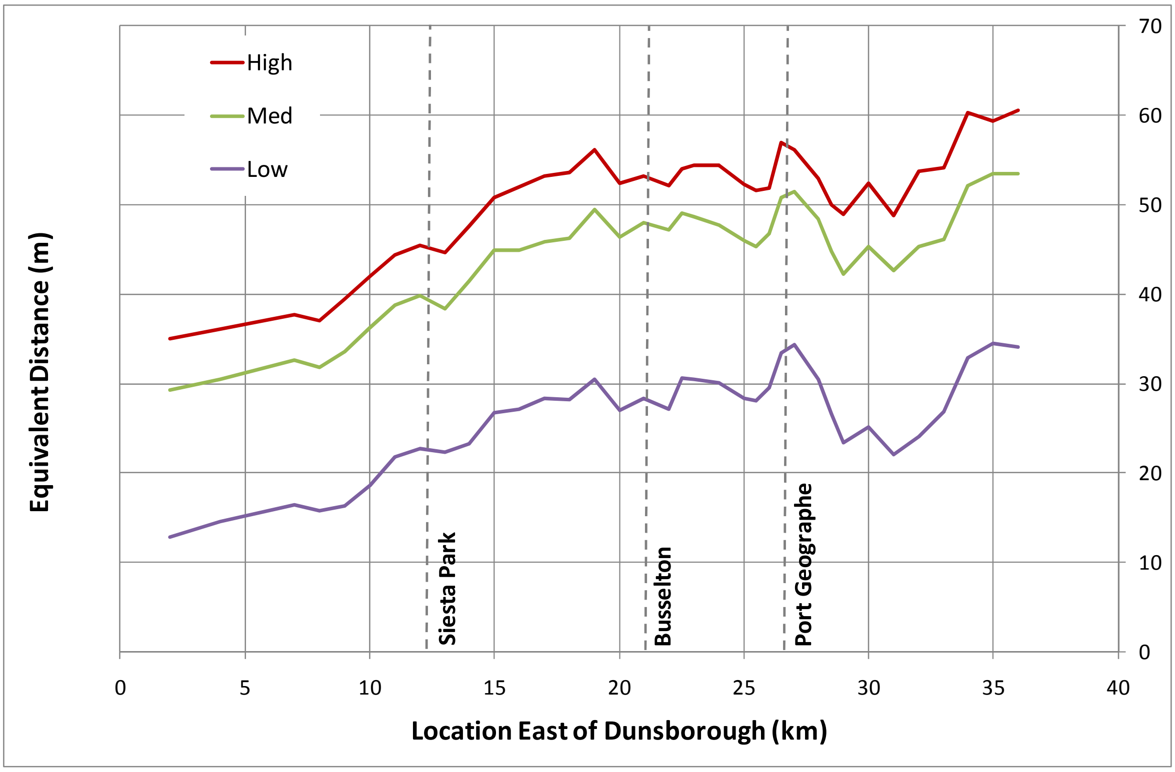


Figure 9-2: Erosion Volume Derived from SBEACH Modelling

9.5. AVERAGE COASTAL BEHAVIOUR

The long-term average behaviour for the coast can be considered as the difference between sediment supply and the material required for the shore profile to adjust to sea level rise. When considered as an average over the entire coast between Dunsborough and Wonnerup, the balance shifts according to the climate change scenario applied (Table 9-5). Accretive behaviour is maintained, although slowed, under a low scenario. Erosive behaviour occurs under medium or high scenarios. The behaviour is not spatially uniform, with erosive behaviour expected to be increasingly dominant towards the east. The approximate time frame for switching to erosion has been determined by considering when supply and demand balance, using the projected sea level rise curves and the derived demand ratio.

Table 9-5: Balance of Supply and Demand over 100 Years

Scenario	Low	Medium	High
Average Supply	250 m^3 per m	210 m^3 per m	190 m^3 per m
Average Demand	170 m^3 per m	290 m^3 per m	330 m^3 per m
Difference	+80 m^3 per m	-80 m^3 per m	-140 m^3 per m
Shoreline Change	12 m accretion	12 m erosion	20 m erosion
Switch to Erosion*	> 100 years	70 years	55 years

* The time scale for regime shift is in the order of +/- 20 years.

The shift in the general trend of the coast from accretion to erosion represents a significant change in behaviour that is dissociated with the rate of sea level rise (Figure 9-3):

- Whilst in a generally accretive phase, the shoreline response to sea level rise will be largely geometric (roughly 25:1) with generally narrow beaches, but limited scarp formation and reasonable recovery after storms;
- After shifting to the generally erosive phase, the shoreline response to continuing sea level rise will be associated with barrier retreat and overwash, at a significantly larger ratio (50:1 to 200:1) with widespread, sustained scarping and limited recovery after storms.

It is also relevant to highlight that shoreline change will be associated with episodic storm events rather than progressive retreat.

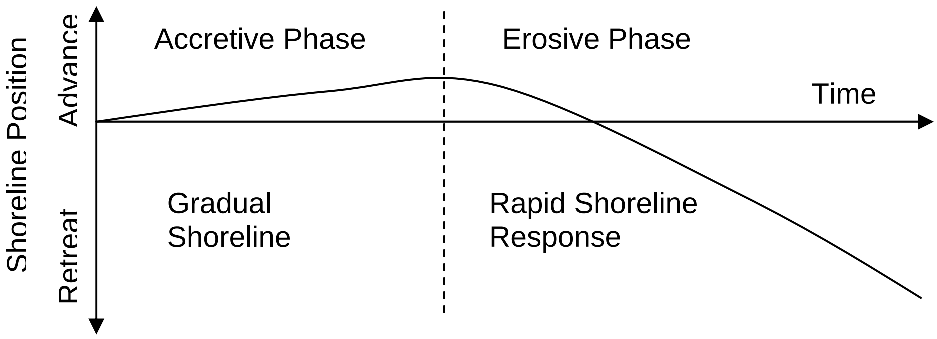


Figure 9-3: Schematic Shoreline Response to Regime Shift

9.6. SETBACK PLANS

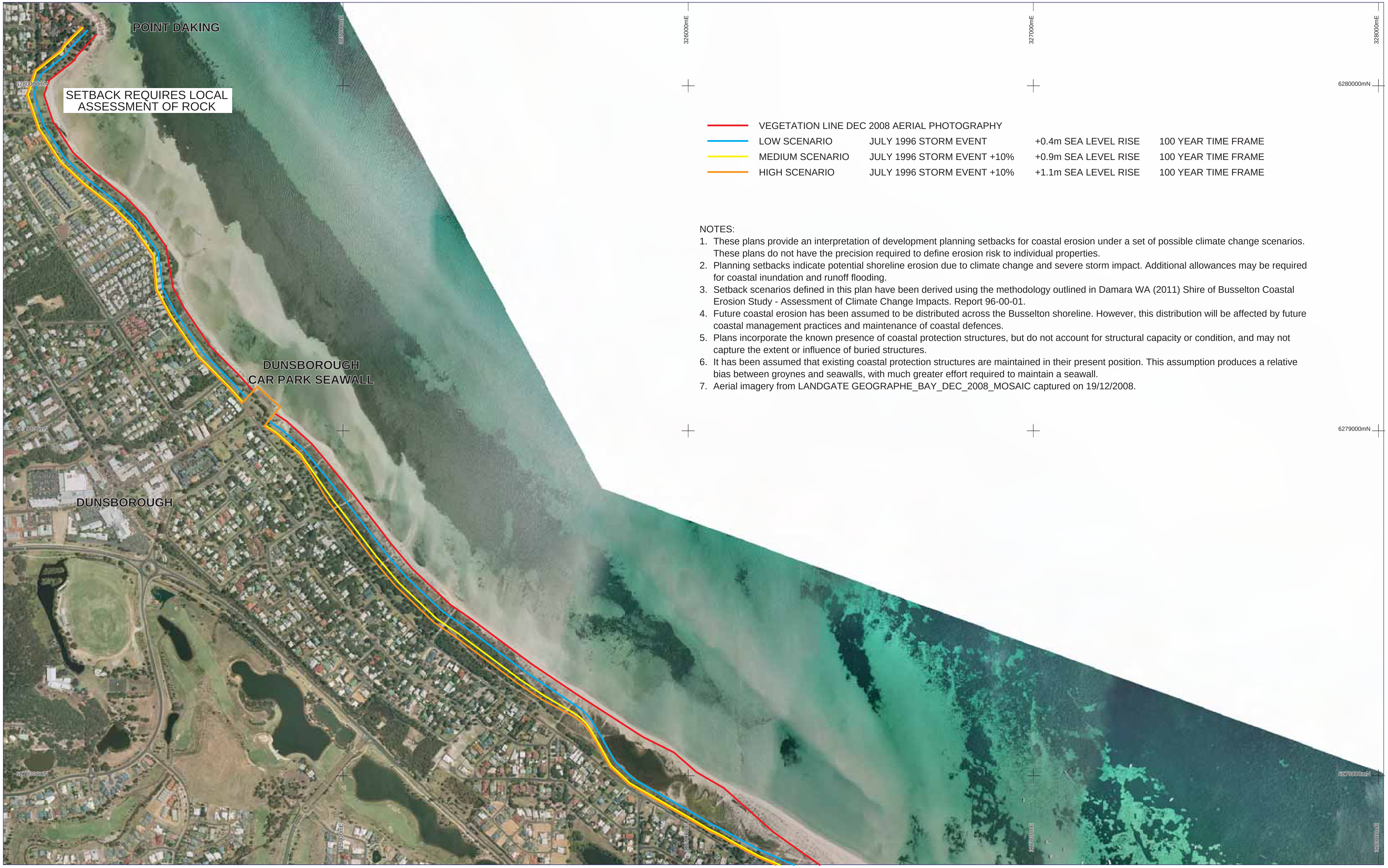
Setback Plans derived using the study methodology are included in this Section. Setbacks that would be required in the absence of coastal protection structures are included in Appendix C.

Table 9-6: Derived Setback Plans

DA 2044-1-1-C	Busselton Shire. Vegetation Line and Setbacks. Dunsborough-Quindalup
DA 2044-1-2-C	Busselton Shire. Vegetation Line and Setbacks. Quindalup-Toby Inlet
DA 2044-1-3-C	Busselton Shire. Vegetation Line and Setbacks. Toby Inlet-Lennox Drain
DA 2044-1-4-C	Busselton Shire. Vegetation Line and Setbacks. Siesta Park
DA 2044-1-5-C	Busselton Shire. Vegetation Line and Setbacks. Broadwater
DA 2044-1-6-C	Busselton Shire. Vegetation Line and Setbacks. Beachlands
DA 2044-1-7-C	Busselton Shire. Vegetation Line and Setbacks. East Busselton
DA 2044-1-8-C	Busselton Shire. Vegetation Line and Setbacks. Geographe
DA 2044-1-9-C	Busselton Shire. Vegetation Line and Setbacks. Wonnerup
DA 2044-1-10-C	Busselton Shire. Vegetation Line and Setbacks. Forrest Beach

General guidance notices that are included within the plans include:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.



NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-1C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

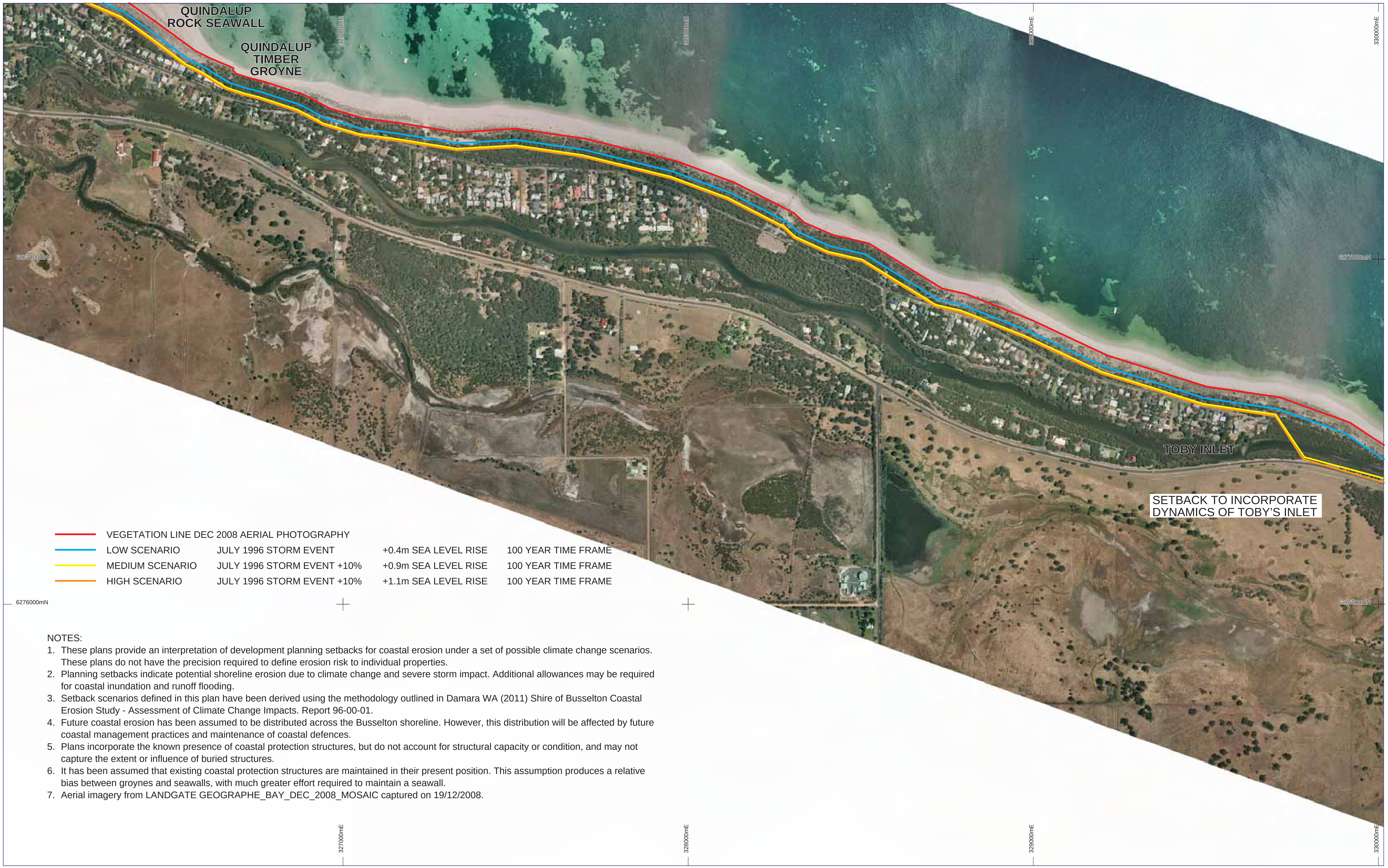
ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
DUNSBOROUGH-QUINDALUP

DRAWING NUMBER DA 2044 - 1 - 1 REVN C



VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY				
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:
1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-2C.dgn | PROJECT No

NOTES

SCALE 1 : 10000
100 0 500 METRES

DATUM
VERTICAL N/A
HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

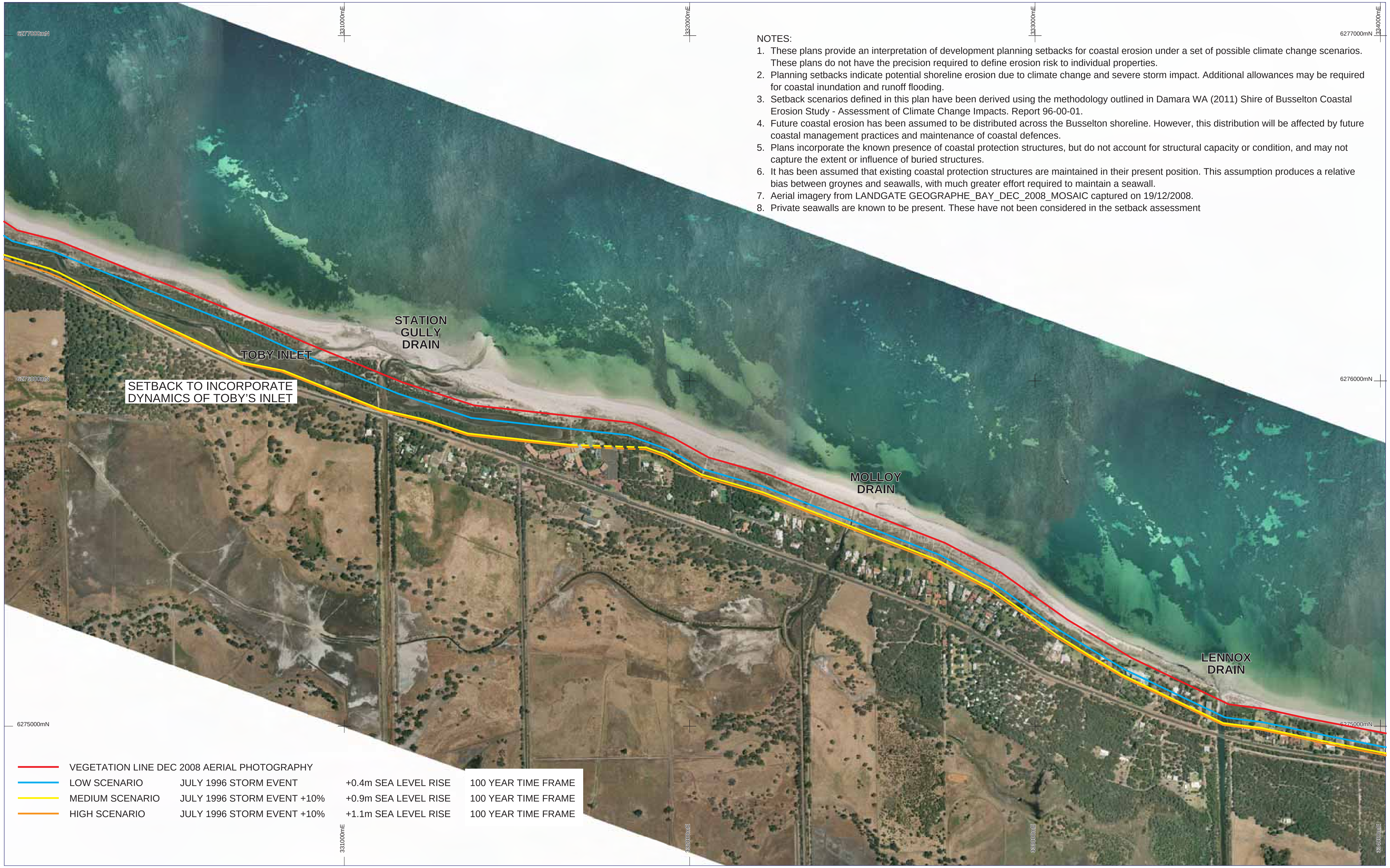
ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
QUINDALUP-TOBY INLET

DRAWING NUMBER DA 2044 - 1 - 2 REVN C



NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.
8. Private seawalls are known to be present. These have not been considered in the setback assessment

VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY			
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-3C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
TOBY INLET - LENNOX DRAIN

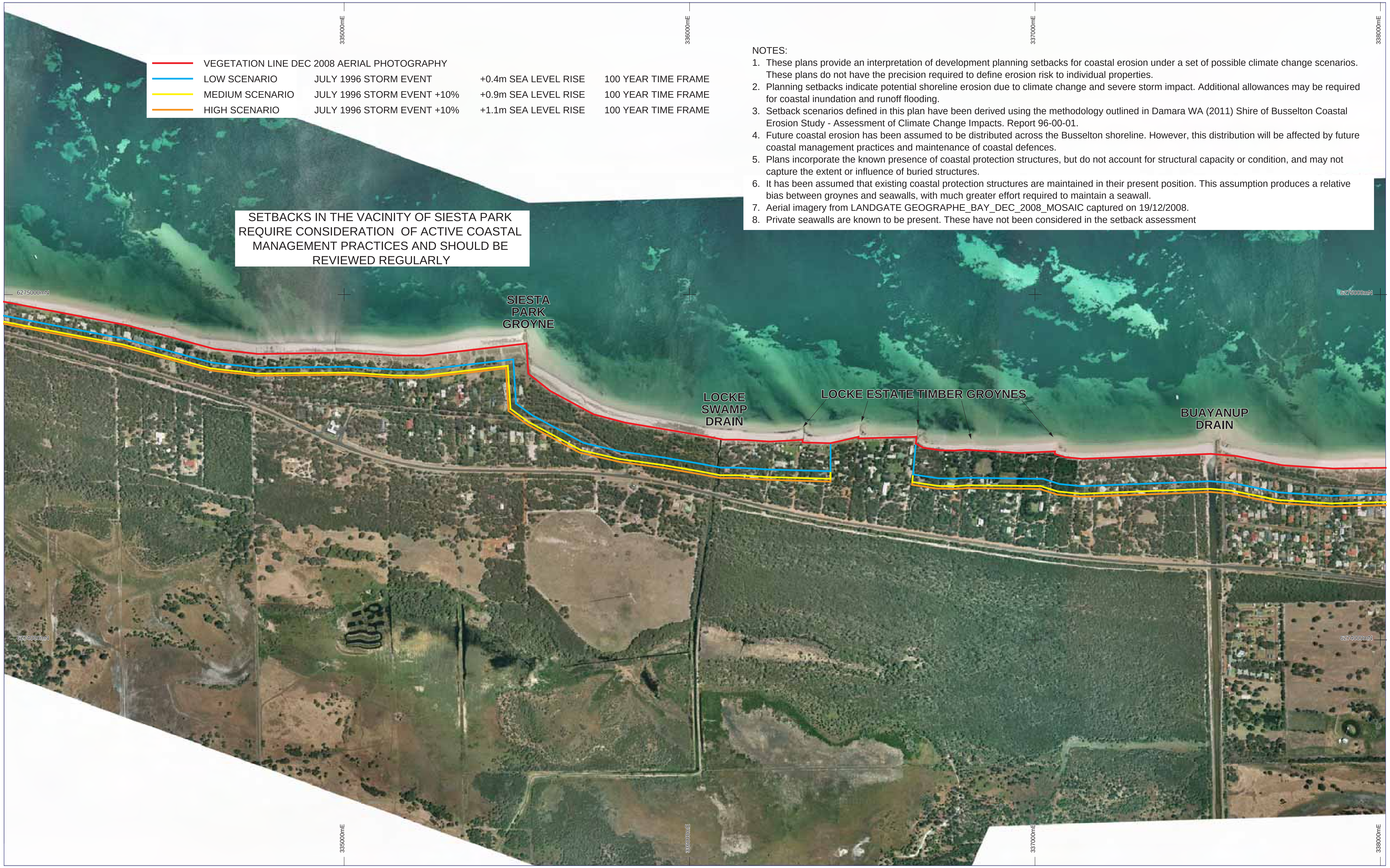
DRAWING NUMBER DA 2044 - 1 - 3 REVN C

VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY			
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.
8. Private seawalls are known to be present. These have not been considered in the setback assessment

SETBACKS IN THE VACINITY OF SIESTA PARK REQUIRE CONSIDERATION OF ACTIVE COASTAL MANAGEMENT PRACTICES AND SHOULD BE REVIEWED REGULARLY



C	22/03/2011	AMENDED SETBACKS ANDADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	
REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL

ORIG SIZE A3 | ARCHIVE DA-2044-1-4C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

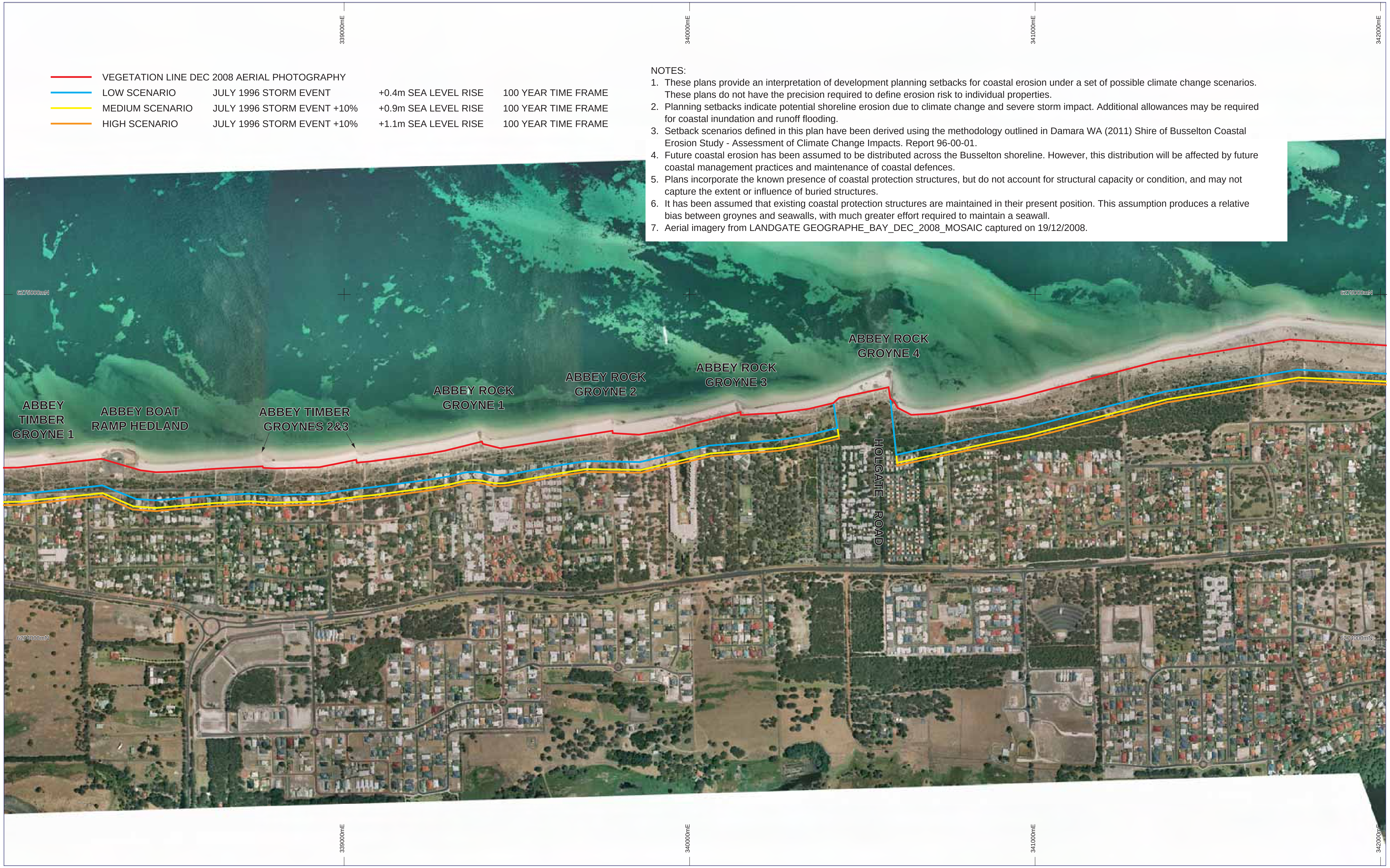
ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
SIESTA PARK

DRAWING NUMBER DA 2044 - 1 - 4 REVN C



VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY				
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-5C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
BROADWATER

DRAWING NUMBER DA 2044 - 1 - 5 REVN C

VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY			
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.

C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	SMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	
REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL

ORIG SIZE A3 | ARCHIVE DA-2044-1-6C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
BEACHLANDS

DRAWING NUMBER DA 2044 - 1 - 6 REVN C

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-7C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM
VERTICAL N/A
HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

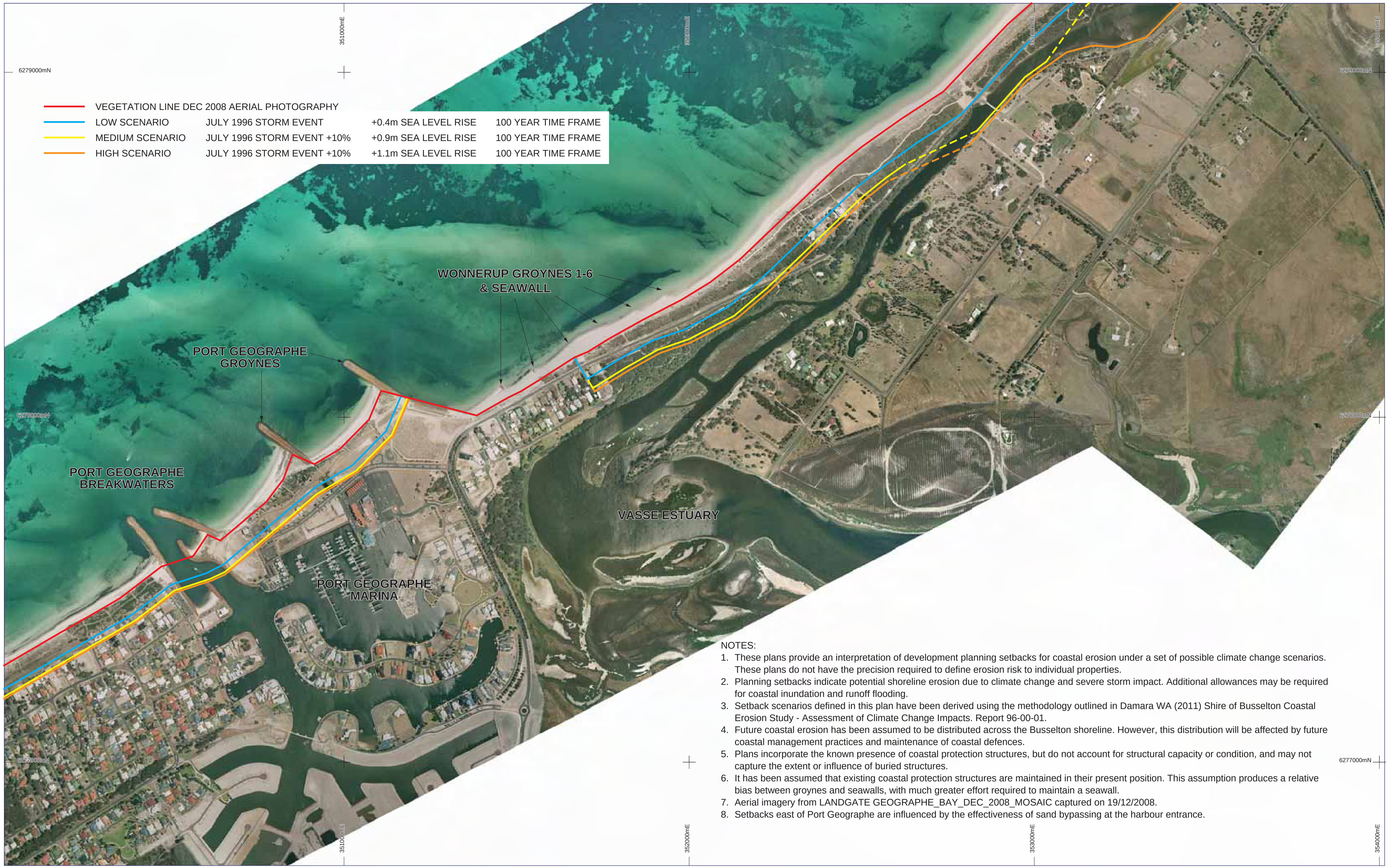
ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
EAST BUSSELTON

DRAWING NUMBER DA 2044 - 1 - 7 REVN C



NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.
8. Setbacks east of Port Geographe are influenced by the effectiveness of sand bypassing at the harbour entrance.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-8C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
GEOGRAPHE

DRAWING NUMBER DA 2044 - 1 - 8 REVN C

VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY			
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.
8. Setbacks east of Port Geographe are influenced by the effectiveness of sand bypassing at the harbour entrance.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	12/10/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-9D.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		12/10/2010
DRAWN	S.Mouchemore		12/10/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
WONNERUP

DRAWING NUMBER DA 2044 - 1 - 9 REVN C

VEGETATION LINE DEC 2008 AERIAL PHOTOGRAPHY			
LOW SCENARIO	JULY 1996 STORM EVENT	+0.4m SEA LEVEL RISE	100 YEAR TIME FRAME
MEDIUM SCENARIO	JULY 1996 STORM EVENT +10%	+0.9m SEA LEVEL RISE	100 YEAR TIME FRAME
HIGH SCENARIO	JULY 1996 STORM EVENT +10%	+1.1m SEA LEVEL RISE	100 YEAR TIME FRAME

NOTES:

1. These plans provide an interpretation of development planning setbacks for coastal erosion under a set of possible climate change scenarios. These plans do not have the precision required to define erosion risk to individual properties.
2. Planning setbacks indicate potential shoreline erosion due to climate change and severe storm impact. Additional allowances may be required for coastal inundation and runoff flooding.
3. Setback scenarios defined in this plan have been derived using the methodology outlined in Damara WA (2011) Shire of Busselton Coastal Erosion Study - Assessment of Climate Change Impacts. Report 96-00-01.
4. Future coastal erosion has been assumed to be distributed across the Busselton shoreline. However, this distribution will be affected by future coastal management practices and maintenance of coastal defences.
5. Plans incorporate the known presence of coastal protection structures, but do not account for structural capacity or condition, and may not capture the extent or influence of buried structures.
6. It has been assumed that existing coastal protection structures are maintained in their present position. This assumption produces a relative bias between groynes and seawalls, with much greater effort required to maintain a seawall.
7. Aerial imagery from LANDGATE GEOGRAPHE_BAY_DEC_2008_MOSAIC captured on 19/12/2008.

REVN	DATE	AMENDMENT	DRN	DESIGN APPROVAL
C	22/03/2011	AMENDED SETBACKS AND ADDED NOTES	SM	
B	15/02/2011	AMENDED SETBACKS	SM	
A	25/11/2010	INITIAL ISSUE FOR CLIENT REVIEW	SM	

ORIG SIZE A3 | ARCHIVE DA-2044-1-10C.dgn | PROJECT No

NOTES

SCALE 1 : 10000

100 0 500 METRES

DATUM

VERTICAL N/A

HORIZONTAL MAP GRID OF AUSTRALIA, BASED ON GDA94

GDA

ACTION	NAME	SIGNATURE	DATE
ENGINEER	G.McCormack		25/11/2010
DRAWN	S.Mouchemore		25/11/2010
ENGINEERING CHECK	M.Eliot		
CARTOGRAPHY CHECK	G.Bebbington		
APPROVED PROJECT MGR			

Damara WA Pty Ltd

BEBBCART BEBBINGTON CARTOGRAPHICS Pty Ltd

BUSSELTON SHIRE
VEGETATION LINE AND SETBACKS
FORREST BEACH

DRAWING NUMBER DA 2044 - 1 - 10 REVN C

9.7. COMPARISON WITH SPP 2.6 SCHEDULE ONE

The approach developed for calculation of recommended setbacks has modified the provisions of SPP 2.6 Schedule One. Specifically:

- Acute erosion allowance has included the effects of beach rotation and downdrift lag due to the partitioned nature of the coast;
- Chronic erosion allowance has been considered in terms of net sediment budget, including ongoing sediment supply, with local variations associated with major control structures;
- Allowance for sea level rise has been derived from a calculation of sediment movement from the beach to the coastal barrier, rather than from the beach to offshore.

These modifications are aimed at more accurately capturing the dynamics of the Shire of Busselton's northern coastline. However, by doing so, the derived setbacks are demonstrably less conservative than would be calculated through a direct application of Schedule One. An understanding of the significance of the modifications is provided through explanation in terms of sediment deficit and corresponding average shoreline retreat over the entire coast (Table 9-7).

Table 9-7: Implications of Study Approach Relative to SPP 2.6 Schedule One

Process	SPP 2.6	Difference* (vol)	Difference* (m)
Sediment Input	Not included	100,000 m^3 p.a.	42m
Beach Rotation & Lag	Not included	Net zero.	(20m)
Variation of Sandbar Feed	Not included	30,000 m^3 p.a.	(13m)
Chronic Erosion	+/-20m trend set to 20m allowance	25,000 m^3 p.a.	11m
Sea Level Rise	100:1 Bruun ratio	135,000 m^3 p.a.	59m
		TOTAL	79m

* Differences noted for "high" scenario

It is apparent that application of Schedule One results in a significantly more conservative outcome, with the average setback being 79m greater for a high climate change scenario than is derived in the present study. Order of significance for the contributing factors is:

1. Assumed Bruun ratio;
2. Inclusion or neglect of net sediment input; and
3. Calculation of distributed or local chronic erosion allowance.

The difference between outcomes is major:

- Application of Schedule One implies that climate change impacts are catastrophic to the Shire of Busselton, with the majority of land between the coast and Caves Road under threat within a 100 year time frame;
- The present study suggests that erosion due to climate change over the next 100 years may affect 10-20% of existing developments along the Busselton coastline.

Despite this difference, the potential significance of climate change impacts should be clearly recognised. Due to the progressive nature of sea level rise and its projected continuing climb over the 22nd Century, amendment of study methodologies merely refines the <u>immediacy</u> of adverse coastal impacts.

10. Coastal Management

10.1. COASTAL PROTECTION STRUCTURES

The existing erosion management strategy requires the maintenance and ongoing adaptation of coastal protection works along the coast between Dunsborough and Wonnerup. Whilst this may be an achievable strategy over the next 50 years or so due to the volume of incoming sediment, it is unlikely to remain practical over longer time frames due to anticipated increasing costs, and the potential for the coast to shift into a net erosive trend. Within the context of projected impacts of climate change, this regime shift is considered to be more a matter of “when” than “if” it will occur.

Changes that would occur due to sea level rise include:

- Reduction in the availability of sediment;
- Increased areas ‘demanding’ sediment after storm events;
- Slower beach recovery after storms and increased downdrift erosion;
- Structural damage due to increased water levels and incident waves.

Management of sediment supply and demand will become increasingly complex, potentially requiring ongoing bypassing at major nodes such as Siesta Park and Port Geographe.

In order to extend the existing ‘50-year defendable’ setback line to a 100 year time frame, the potentially increased average erosion suggested by Table 9-5 should be considered. The additional allowance required for medium or high climate change scenarios would either require the line to be setback further than is presently applied, or that selected areas are allowed to undergo managed retreat. Under the high scenario, approximately 20% of the coast would be subject to sustained erosion. However, this potentially understates the likely constraint: although there may be sufficient material to provide a balance in the long-term, the sediment supply is not evenly distributed, and is subject to significant short-term (storm-driven) variations. The existing coastal protection structures have mainly originated in response to such events.

The issue of managing sediment distribution across an extended section of coast is complex, politically as well as technically. For most areas of coast with limited sediment supply, there is considerable pressure to protect against erosion, with little willingness to release sediment from accreting areas. Consequently, whilst a long-term balance may be possible, increased levels of coastal stress typically occur to locations further away from sediment supply. For the Busselton coast, this generally corresponds to increased pressure towards the east, although this is modulated by sand feeds at Abbey and East Busselton, such that the highest pressures occur in the vicinity of Locke Estate and Wonnerup.

Threatened areas likely to require additional coastal protection facilities include (from west to east):

- East Quindalup;
- Smith to Mitchell Streets;
- Locke Estate;
- Abbey;
- Beachlands (upgrade of existing revetment);
- Margaret Street;
- Busselton Town Beach (upgrade of existing seawall);
- Herring to Mann Streets; and
- East Wonnerup.

Implications of failing to maintain each coastal protection structure have been identified by defining the area of sand controlled by each structure (see Section 9.6). In addition, the potential for shoreline rotation has been estimated, which may increase between larger beach cells. The relative importance of managing and maintaining structures should be considered with respect to the width coastal buffers. Where narrow buffers occur, even partial damage to structures may have significant implications. This requires a regular inspection regime and responsive maintenance programme.

Interpretation of modifications to the coastal protection system requires recognition that the modelled shoreline changes are based on the existing configuration of structures. Any modification of this configuration (including allowing the structures to degrade) would cause change to the alongshore sediment transport rates, and consequently affect how the coast responds – hence the modelled shoreline change could be completely invalidated through installation of a major structure.

10.2. DUNE MANAGEMENT

Dunes along the Busselton coast have an unusual geomorphic origin from those occurring along most of southwest Western Australia, and therefore require different management practices. Specifically, onshore winds are rare, and therefore the Aeolian process of beach to dune sand transfer is limited, with minor wind-blown transport largely parallel to the shoreline. This enables only low dunes to form, with the majority of accretion occurring as beach width growth. The few dunes above 2.5 m AHD present along Busselton shoreline are relicts from periods of higher sea level, which has declined over the last 2,500 years.

Under present-day conditions, energetic winter swells and higher water levels play a significant role in Busselton dune dynamics, as they push beach material landward and upward. Vertical beach growth, which occurs mainly over winter, subsequently assists foredune initiation during lower energy periods. During storm conditions, this foredune material is available for redistribution, which includes a quantity of overwash (refer to Figure 5-11). However, it is also under these conditions that scarp formation may occur, with the front of the dune eroded. The balance of landward material transport (overwash) against offshore transfer determines whether a storm event has been accretive or erosive. The potential for storm erosion to occur whilst the foredune is being initiated creates major challenges for dune management: as it may truncate the season of onshore sediment supply; and creates high stresses on any structures intended to encourage dune growth.

Recognising the limited onshore Aeolian transport and the active process of overwash along Geographe Bay shoreline, effective dune management may need to incorporate:

- Provision of near-coast alongshore control structures, which connect the upper beach to the dune – the landward end of timber groynes has provided this role effectively;
- Installation of dune fencing at an angle (northwest) to the shoreline to deflect alongshore transport landward;
- Swales behind the most seaward dune should preferably not be infilled, to encourage effective overwash.

11. Inundation

The coast from Dunsborough to Wonnerup has an existing high risk of inundation. Storm surges are locally enhanced due to the orientation of the shore and there is generally low lying topography due to the weak dune-building capacity of waves and winds in southern Geographe Bay. The existing extreme water level climate, derived from tide gauge observations within Port Geographe, suggests a 1% annual exceedance (100 year ARI) extreme water level of approximately 2.8m CD, which is 2.1m AHD (Figure 11-1).

Inundation risk is locally higher than this level due to the nearshore effects of wave setup and wave runup. These vary across the shore cross-section and will be affected by short-term storm erosion. Making allowance for wave setup and runup, a dune level of 3.0m AHD will typically be sufficient to prevent inundation during a storm water level of 2.1m AHD. Post-storm measurements after TC Alby recorded a maximum inundation level of 2.92m AHD (3.6m CD), with the tide gauge record peaking at 1.9m AHD (PWD Plan Set 51019).

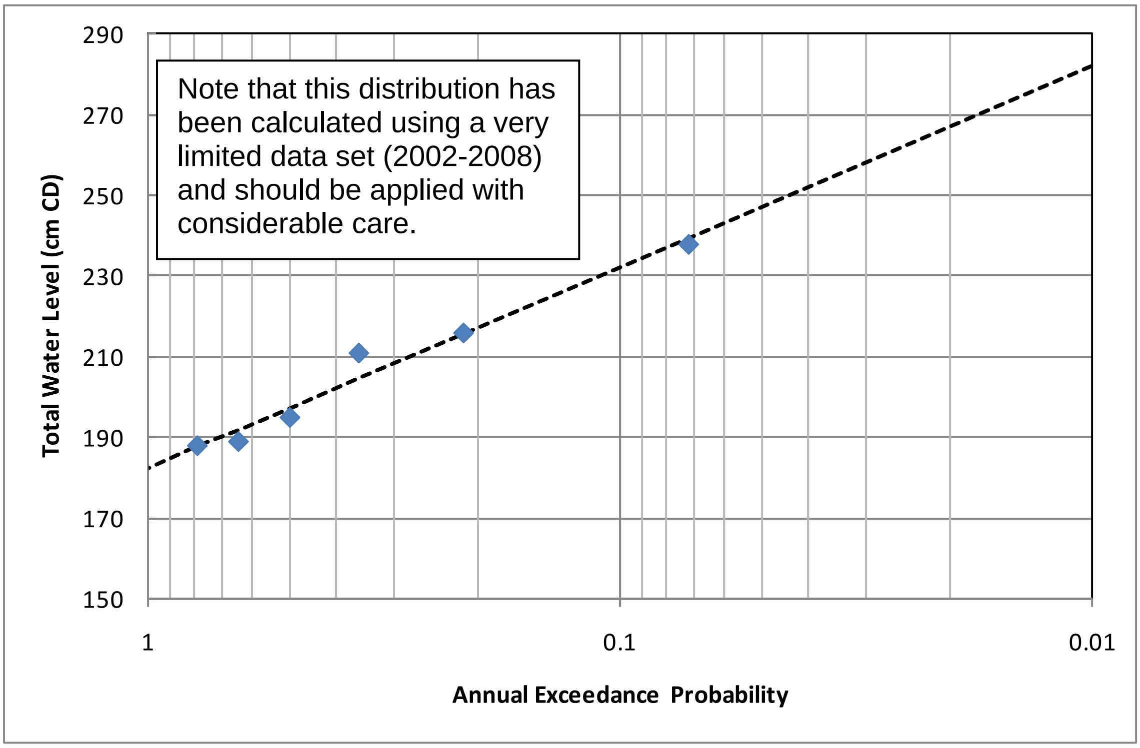


Figure 11-1: Existing Extreme Water Level Distribution

Although climate change is anticipated to raise sea levels, the change is risk is not wholly related to mean sea level change as there is a continuous process of coastal adjustment to the rising levels. Consequently, the risk is locally reduced where there is increased capacity for dune-building, which requires sediment supply, active vegetation growth and onshore energy through wind or waves. Of these mechanisms, only vegetation growth can be artificially encouraged, through access management, dune fencing and irrigation. Dune management will be ineffective where there is active erosion.

Along the Dunsborough to Wonnerup shoreline, six locations have been identified using available topography (Department of Transport Plan Set 433) that do not have a sufficiently high dune field to act as a buffer against inundation:

- Area around Tulloch Street, Quindalup;
- Around Smith Street, Mary Brook;
- West of Siesta Park groyne;
- Locke Estate;
- East of Buayanup Drain, Abbey;
- Near Bower Road, Beachlands;
- Ford Road to Morgan Street, East Busselton;
- On Layman Road, east of McCormack St, Wonnerup.

A more detailed assessment of inundation has been completed by Shore Coastal (Plan Set 2091) which delineates these areas.

12. Conclusions & Recommendations

The concept of a 'defendable line' erosion management strategy presently being used by the Shire of Busselton remains a valid approach, possibly even when applied over a 100-year time frame. However, the Shire must acknowledge the cost implications of maintaining and adapting coastal structures. The 'defendable line' should be reviewed specifically in terms of coastal flooding under climate change scenarios.

From a planning perspective, the ultimate need to change this strategy over long time frames should be recognised, and any areas possibly available for managed retreat should be identified. Adoption of a revised coastal development line would require consideration of planning options for 'undefendable' situations (eg resuming leases) or differential rates to fund defences (see Section 0). There is a need to use common sense when applying infill criteria from the WAPC (2003) Coastal Planning Policy. In particular, sites that are already subject to coastal stress should not be used as justification for the development of adjacent properties.

This study has identified that the Busselton coastline between Dunsborough and Wonnerup is susceptible to moderate to high risk of erosion due to climate change over a 100 year time frame (albeit likely not catastrophic). There is a general spatial trend for increased erosive tendencies to the east of the Busselton coastline. However, areas most susceptible to ongoing erosion are downdrift of large coastal protection structures at Siesta Park and Port Geographe, caused by the imbalance of net sediment transport on either side of the structure.

Regular monitoring of the coastal climate and ongoing shoreline changes is essential to evaluating the future coastal management needs.

In terms of local government actions to manage the coastal impacts of climate change, these are summarised in Table 12-1.

Table 12-1: Local Government Actions

Local Government Function	Present Day Actions	2030
Infrastructure & Property Services	• Inspection of coastal protection works. • Asset management plan • Emergency management (coastal erosion & flooding)	• Monitoring & maintenance • Adaptation of existing coastal structures • New coastal structures or works
Recreational Facilities	• Asset management plan	• Monitoring and review • Adapt as necessary
Planning & Development Approvals	• Consider existing developed areas in terms of 100-year defendable line • Identify areas of no further development • Review ESL in terms of coastal flooding • Community education	• Monitoring and review • Adapt as necessary
Natural Resource Management	• Foreshore Management Plan • Dune Management • Beach monitoring	• Dune Management • Beach monitoring

Appendix A Wave Climate Analyses

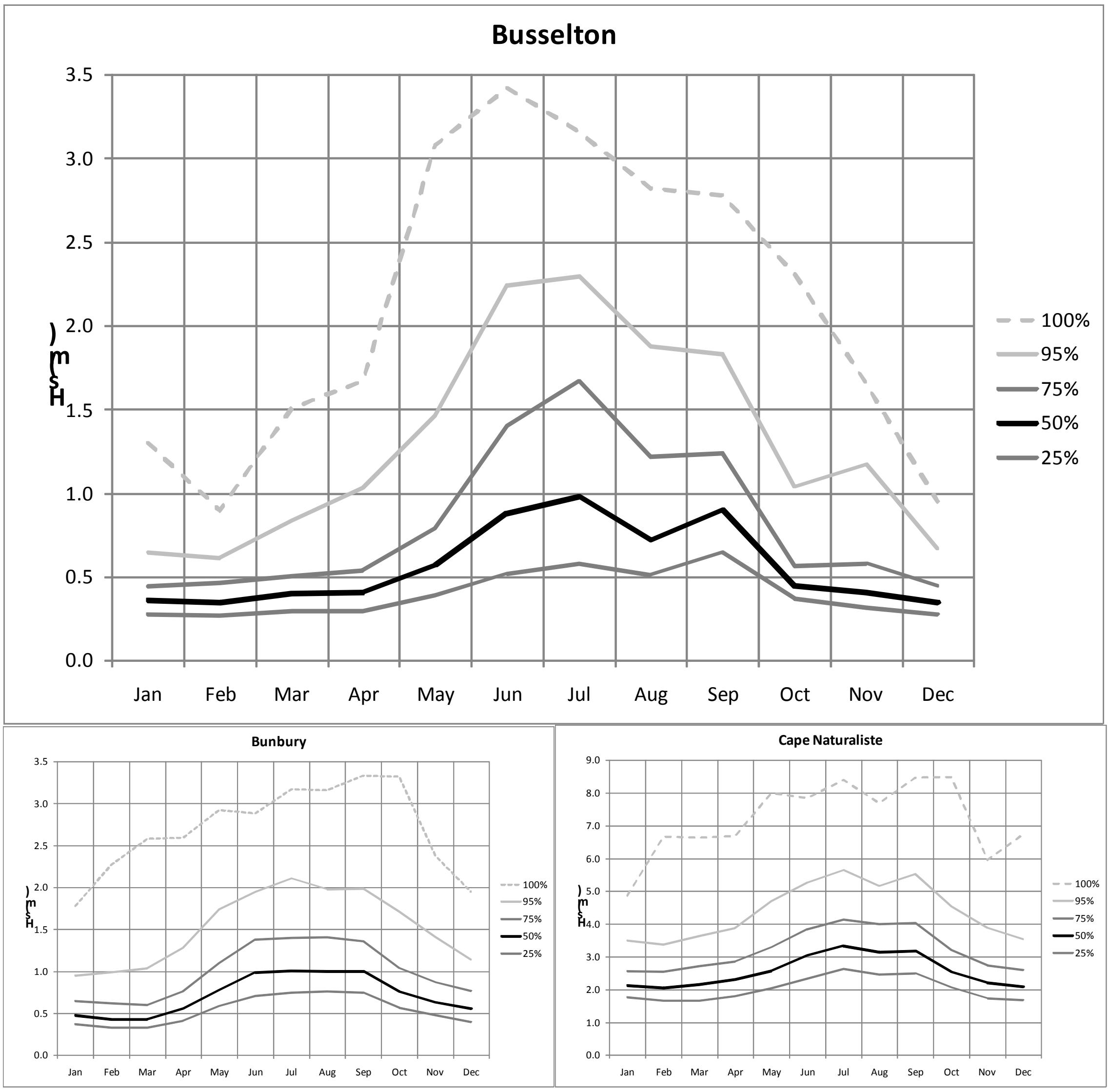


Figure 12-1: Monthly Wave Height Distributions

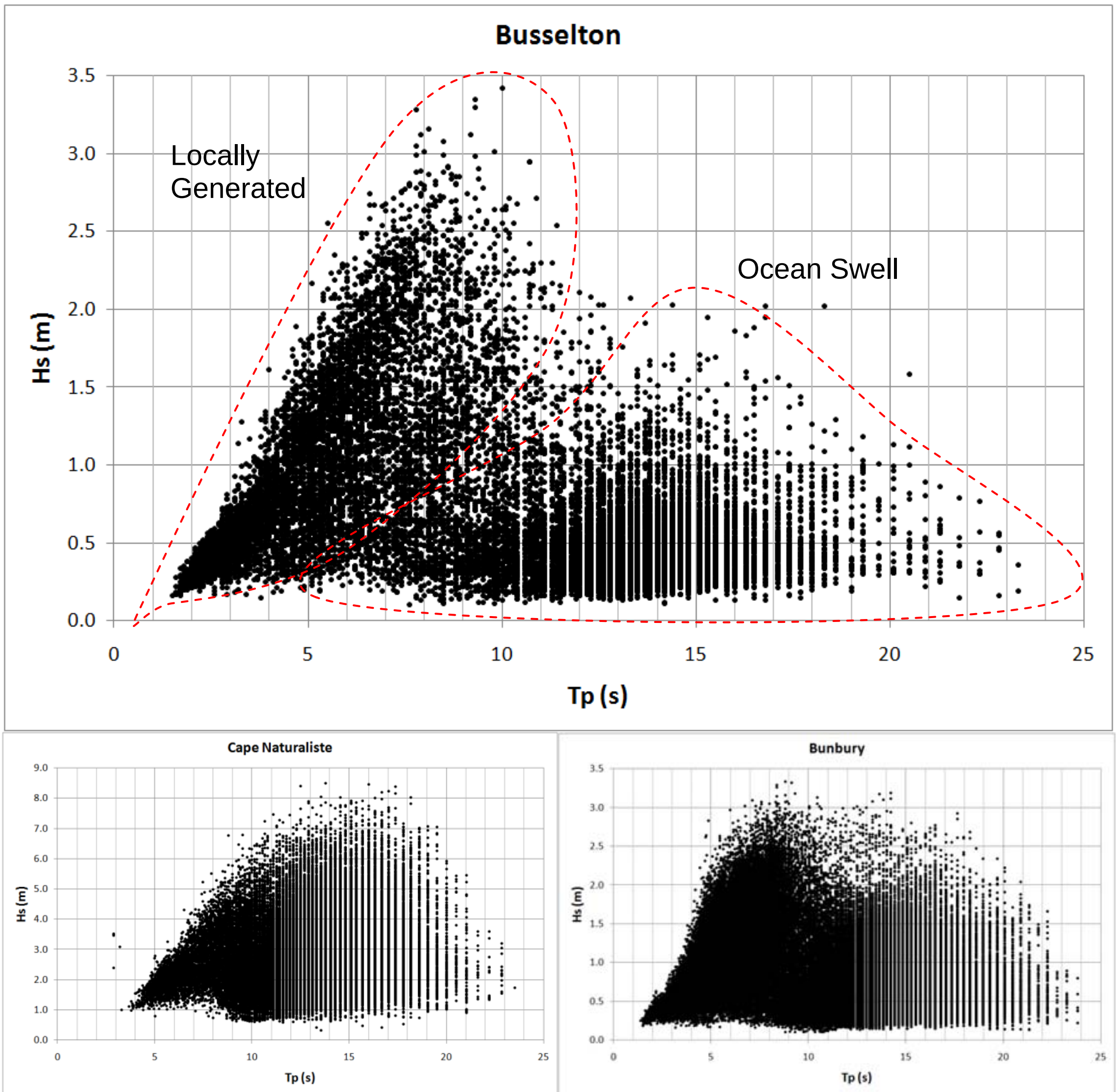


Figure 12-2: Wave Height & Period Crossplots

Appendix B Adaptation Strategy Options

Extract from Shire of Busselton, Planning Section.

For any given portion of coastline there are two fundamental adaptation strategy options: (i) Coastal Defence; and·(ii) Managed Retreat. If a defence strategy is pursued for a given section of coastline, consideration needs to be given to the following fundamental questions:

- When will defence works be necessary or appropriate? (e.g. when will a given piece of public infrastructure, such as a road, come under threat from coastal erosion?)·
- What sort of coastal defense works is most appropriate? (e.g. groyne, sea wall, beach nourishment, artificial reef, or some combination of these)·
- How will the development and maintenance of coastal defence works be funded? (e.g. private funding, specified area rate, general revenue, State/Commonwealth funding, or some combination of these)

If a managed retreat strategy is pursued for a given section of coastline, consideration needs to be given to the nature of that strategy, which could consist of one or more of the following:

- Not approving development in areas thought to be at risk;
- Only approving development in areas thought to be at risk subject to a 'sunset clause', which would require planning approval to be renewed after a given time, and if planning approval is not renewed then the development must be removed at the owner's cost and without compensation;
- Only approving development in areas thought to be at risk subject to conditions requiring removal of the development at the owner's cost and without compensation should the shoreline erode to within a specified distance of the development;
- Where land is in public ownership and is being leased for development purposes, ensuring that the lease terms end before it is thought that the land may be at risk, and/or terminating the lease if the land is exposed to risk; or
- Acquisition of private land, either voluntarily or compulsorily, particularly if there are seen to be benefits in the creation and/or enhancement of coastal reserves (which may be to accommodate a dune system that will assist in retaining a beach useable by the public and/or protecting land further inland from coastal erosion in a more cost-effective manner).

Appendix C Setbacks without Coastal Structures

Derived Setback Plans without Coastal Structures

DA 2044-2-1-A	Busselton Shire. Undefended Setback Lines. Dunsborough-Quindalup
DA 2044-2-2-A	Busselton Shire. Undefended Setback Lines. Quindalup-Toby Inlet
DA 2044-2-3-A	Busselton Shire. Undefended Setback Lines. Toby Inlet-Lennox Drain
DA 2044-2-4-A	Busselton Shire. Undefended Setback Lines. Siesta Park
DA 2044-2-5-A	Busselton Shire. Undefended Setback Lines. Broadwater
DA 2044-2-6-A	Busselton Shire. Undefended Setback Lines. Beachlands
DA 2044-2-7-A	Busselton Shire. Undefended Setback Lines. East Busselton
DA 2044-2-8-A	Busselton Shire. Undefended Setback Lines. Geographe
DA 2044-2-9-A	Busselton Shire. Undefended Setback Lines. Wonnerup
DA 2044-2-10-A	Busselton Shire. Undefended Setback Lines. Forrest Beach

References

[1] Kay R, Eliot IG & Klem G. (1994) *Analysis of the IPCC Sea-level Rise Vulnerability Assessment Methodology Using Geographe Bay, Southwestern Australia, as a Case Study: Coastal Risk Managment*, p 12, Canberra.

[2] Department of Climate Change. (2009) *Climate Change Risks to Australia's Coast*. Department of Climate Change, Canberra.

[3] Andrew WS. (2003) *Busselton Foreshore – Erosion Management of Residential Development*. Report to DPI (Maritime).

[4] Shore Coastal. (2008) *Inspection of Coastal Protection Structures*. Prepared for the Shire of Busselton.

[5] Western Australian Planning Commission. (2001) *Coastal Zone Management Policy for Western Australia: draft for public comment*. Western Australian Planning Commission.

[6] Western Australian Planning Commission. (2003) *Statement of Planning Policy No. 2.6: State Coastal Planning Policy.* Government of Western Australia, Perth.

[7] Western Australian Planning Commission (2010) *Position Statement - State Planning Policy No. 2.6 State Coastal Planning Policy* Schedule *1 Sea Level Rise*. Perth, Western Australia.

[8] Oumeraci H. (2005) Integrated Risk-Based Design and Management of Coastal Flood Defences. In : (Ed) Hofstede J. (2005) *COMRISK. Common Strategies to Reduce the Risk of Storm Floods in Coastal Lowlands*. Die Kuste Special Edition, 70: 151-172.

[9] Intergovernmental Panel on Climate Change (2007) Climate Change 2007: *The Physical Science Basis. Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[10] Hunter J. (2008) Ways of estimating changes in sea-level extremes under conditions of rising sea level. IPWEA National Conference on Climate Change Response, Coffs Harbour, 3-5th August.

[11] Steedman & Associates Pty Ltd. (1982) *Record of Storms, Port of Fremantle 1962-1980*. Report No. R112, Steedman & Associates, Perth.

[12] Panizza V. (1983) *Westerly storms of the Perth metropolitan coast, Western Australia*. Honours Thesis. University of Western Australia, Dept of Geography.

[13] CSIRO (2007) *Climate Change in Australia*. Technical Report.

[14] Indian Ocean Climate Initiative. (2005) *Indian Ocean Climate Initiative Stage 2: Report of Phase 1 Activity*. Indian Ocean Climate Initiative Panel, Perth, Australia

[15] Haigh ID, Eliot M & Pattiaratchi C. In Press. Changes in storm surge activity around southwest Australia. Ocean Dynamics.

[16] Department of Defence. (2010) *Australian National Tide Tables*. Australian Government Printing Service, Canberra.

[17] Searle DJ & Logan BW. (1978). *A Report on Sedimentation in Geographe Bay*, Sedimentology and Marine Geology Group, Department of Geology, University of Western Australia.

[18] Woods PJ. (1983) *Evolution of and Soil Development on Holocene Beach Ridge Sequences, West Coast, Western Australia*, Unpublished PhD Thesis, Department of Soil Science and Plant Nutrition, University of Western Australia.

[19] Damara WA. (2010) *Port Geographe Sand Management: Busselton Sediment Sampling*. Prepared for the Department of Transport.

[20] Carter RWG. (1991) Near-future sea level impacts on coastal dune landscapes. *Landscape Ecology*, 6: 29-39.

[21] Collins, L. (1988). Sediments and history of the Rottnest Shelf, Southwestern Australia: A swell-dominated, non-tropical carbonate margin. *Sedimentary Petrology*, 60: 15-49.

[22] Riedel & Byrne Consulting Engineers and LeProvost Semeniuk & Chalmer. (1988) *Port Geographe Coastal Processes Study*. Department of Marine and Harbours. Perth, Western Australia

[23] Oceanica Pty Ltd. (2004) *Geographe Bay Scoping Study; Stage 1*, Report No. 392/1

[24] Whitehouse R, Balson P, Beech N, Brampton A, Blott S, Burningham H, Cooper N, French J, Guthrie G, Hanson S, Nicholls R, Pearson S, Pye K, Rossington K, Sutherland J & Walkden M. (2009) *Characterisation and prediction of large-scale, long-term change of coastal geomorphological behaviours: Final science report*. Joint DEFRA / Environment Agency, Flood and Coastal Erosion Risk Management R & D Programme. Science Report: SC060074/SR1.

[25] Komar PD, McDougal WG, Marra JJ & Ruggerio P. (1999) The Rational Analysis of Setback Distances: Applications to the Oregon Coast. *Shore & Beach*, 67(1): 41-49.

[26] Van Rijn LC. (1996) *Principles of Coastal Morphology*. Aqua Publications, Amsterdam

[27] Oceanica Pty Ltd. (2005*) Geographe Bay Scoping Study; Stage 2*, Report No. 392/2

[28] Shore Coastal Pty Ltd. (2010) Geographe Bay Shoreline Movement. For Shire of Busselton. SCR 1001.

[29] Sumer BM & Fredsoe J. (2002) *The Mechanics of Scour in the Marine Environment*. Advanced Series on Ocean Management, 17, World Scientific.