Technical Report

The coast of the Shires of Gingin and Dandaragan, Western Australia:
Geology, Geomorphology and Vulnerability

March 2012

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The Department of Planning engaged Damara WA Pty Ltd to prepare this report as a background technical guidance document only. Damara conducted this project in conjunction with the Geological Survey of Western Australia.

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Cover Photograph
The Hill River in flood discharge during June 2003 (Photographer: Ian Eliot).

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EXECUTIVE SUMMARY

The Study Brief for this project established an aim to:

> *"Provide strategic planning guidance, management strategies and direction on appropriate land uses for future subdivision and development of coastal land in the Shire of Gingin and the Shire of Dandaragan, by the identification of sediment cells that define coastal stability and susceptibility to change in the coastal zone".*

Approach

Certain landforms and coastal features are more vulnerable to climate and sea level variation than others. Hence the immediate aim of this project was to determine the vulnerability of landforms on the Gingin-Dandaragan coast to changing weather and oceanographic conditions, including projected changes in climate. The determination involved assessment of aerial photography of coastal landforms between Wreck Point and Fisherman Islands, site visits and a review of available meteorologic and oceanographic information. Interpretation of the information gathered was intended to identify vulnerable locations within the Study Area and assist decision-making regarding proposed coastal development and for coastal management purposes.

The natural structure and formation of landforms and coastal features between Wreck Point and Fisherman Islands is tied to outcrops of coastal limestone along the shore as well as the presence and shape of the nearshore reef system. This geological control was used to identify discrete sediment cells where changes to landforms in one part of a cell were highly likely to affect the remainder of the cell but with potentially limited affect on adjoining cells. Thirty six cells were identified along approximately 160 km of coast. Potential relationships between sand dune ridges (barriers) and the underlying coastal limestone topography were determined; landform patterns comprising the dune systems identified; and individual landforms described for each cell. The scales of description respectively correspond to scales used in the compilation of coastal management strategies and plans.

Landform vulnerability was estimated as a combination of the susceptibility of the geological structure supporting the landforms to environmental change and the current condition of the landforms as indicated by existing evidence of erosion. Together, a geological structure and the landforms it supports define a land system. The assessment involved consideration of the integrity of the geological or geomorphologic structures of land systems and the condition or stability of the landforms supported. Susceptibility rankings were determined from values assigned to marine topography near the shore; the shape of the shoreline; coastal orientation; and the prevailing type landforms present in the cell. Similarly, instability rankings were based on the proportion of rocky versus sandy seabed; beach type and/or beachface shape; whether the frontal dune complex has been eroded; and an overall estimate of vegetation cover on the sand barrier. The analysis was intended to be indicative rather than prescriptive and has application for strategic planning purposes as a first step to more detailed risk assessment procedures.

Land System Susceptibility

Results for the Gingin-Dandaragan coast revealed a substantial proportion (56%) of the 36 cells examined were moderately susceptible to change. Thirteen cells (36%) had a land system with a low susceptibility; and three cells (8%) were highly susceptible.

Tracts of land having low susceptibility occur between Wreck Point and the Moore River, Eagles Nest Bluff to South First Bluff, North Wedge to Grey and Middle Head to North Head. These were areas where the coast was protected by offshore reef, rock typically outcrops along the shore and the dune barrier was likely to be perched on a rock surface above High Water Level.

Sediment cells considered highly susceptible to change due to forcing by weather and ocean processes were Lancelin to Dide Point, Magic Reef to Wedge Island and South Booka Valley to Island Point. Combinations of some of the following factors indicated susceptibility of these parts of the coast to environmental change: limited protection by offshore reefs, exposure to NW storms, cuspate forelands, and sandy barriers inset between rocky outcrops.

Landform Stability

Estimated levels of instability for each of the cells along the Gingin-Dandaragan coast revealed a high proportion (78%) of the 36 cells examined were moderately stable. Five cells (14%) had a low instability ranking; and three cells (8%) were of high instability.

Sediment cells with low instability occur between Wreck Point and Two Rocks, Eagles Nest Bluff to Second Bluff, Pumpkin Hollow to North Head and along the coast north of Sandy Point. They were areas where there the shore was sheltered by inshore reefs and/or rocky pavement, the frontal dune complex was intact and the barrier dunes well vegetated.

Cells with high instability were Manakoora Sand Patch to Green Reef, Wedge Island to North Wedge and Hill River to South Booka Valley. Combinations of some of the following factors indicated current levels of landform instability: the inshore seabed was bare sand; beaches were commonly subject to high wave conditions or part of a barred river mouth; there was no foredune and the frontal dune was scarped; and vegetation cover was low and /or mobile sand sheets were present on the barrier.

Vulnerability

Vulnerability is a combination of land system susceptibility to change and landform instability. A cell ranked at one level is highly likely to contain components of susceptibility and/or instability ranked at another. In particular, a cell ranked at a moderate level may have elements that are highly susceptible to change in the metocean regime and/or has landforms that are currently unstable. The qualification is particularly important at increasingly broader levels in the land system hierarchy where a wider range of land systems and landforms is included at each compartmental scale.

Vulnerability rankings determined on a five-point scale for each sediment cell indicated four (11%) of the 36 cells examined had a low level of vulnerability; 10 (28%) were of low-to-moderate vulnerability; 16 (44%) were moderately vulnerable; six cells (17%) had a moderate-to-high vulnerability ranking; and none had high vulnerability.

Overview

Susceptibility, instability and vulnerability rankings as well as their implications for coastal planning and management were provided for each of the 36 cells examined. At a broad, strategic planning scale, distinct landform patterns were apparent in each of the secondary compartments in the Study Area. These were as follows:

1. The tertiary compartment between Wreck Point and the Moore River had a low susceptibility to change due to meteorologic and oceanographic (metocean) forcing. Its landforms had a low instability ranking and three of the four cells had a low-to-moderate vulnerability ranking.
2. Coastal vulnerability rankings ranged from low to moderate-to-high between the Moore River and Ledge Point, but the coast was mainly ranked as moderate. Lower rankings had been ascribed to the rocky coast between Eagles Nest Bluff and South First Bluff, and a moderate-to-high ranking for Manakoora Sand Patch to Green Reef. Between Moore River and Seabird, the coast was ranked as moderately vulnerable although it included the Moore River, its estuarine reaches and the more vulnerable stretch of coast at Seabird. This was a good example of a sediment cell with a lower ranking than would the individual landforms it contains. The estuarine system warrants separate, more detailed consideration in local area strategies and site plans.
3. The secondary compartment between Ledge Point and Wedge Island was the area of greatest variation in susceptibility, with rankings ranging from low in areas of rocky coast, as between Dide Point and Narrow Neck, to high on the flanks of large cuspate forelands at Wedge Island, Kangaroo Point and Island Point. The landforms were ranked moderately unstable, with several areas close to the high category. Overall 57% of cells examined were of moderate, and 29% of moderate-to-high, vulnerability.
4. The coast between Wedge Island and Thirsty Point mainly had a moderate susceptibility to change due to metocean forcing, apart from an area of low susceptibility to change along the rocky coast from North Wedge to Grey. Landform instability was also ranked as moderate, with the exception of the Wedge Island cell, which had extensive tracts of mobile dune on the northern flank of the cuspate foreland. The vulnerability was moderate-to-high in Wedge, low-to-moderate along the rocky coast between North Wedge and Grey and from Grey to Thirsty Point.
5. Vulnerability on the coast from Thirsty Point to North Head ranged between low and moderate-to-high levels. The highest vulnerability was between South Hill River and Island Point, respectively associated with the instability of the coastal dunes between the Hill River mouth and South Booka Valley, and the susceptibility of the southern flank of the cuspate foreland at Island Point to changing metocean processes.
6. Three cells north of North Head included tombolos and cuspate forelands with a moderate, verging on high, susceptibility to change due to metocean forcing. The dune landforms on the tombolo and cuspate foreland features were of moderate

instability with evidence of active blowouts. The coast was predominantly rocky north of Sandy Point and the dunes had a low instability ranking. The vulnerability scores were moderate but became increasingly low towards the northern rocky limit of the Study Area.

WEB SUMMARY

Some landforms and coastal features are more vulnerable to climate and sea level variation than others. Hence the immediate aim of this project was to determine the vulnerability of landforms on the Gingin-Dandaragan coast to changing weather and oceanographic (metocean) conditions, including projected changes in climate. Information was gathered on coastal landforms and coastal processes to identify vulnerable locations and assist decision-making regarding proposed coastal development and for coastal management purposes.

The natural structure and formation of landforms and coastal features between Wreck Point and Fisherman Islands is tied to outcrops of coastal limestone along the shore as well as the presence and shape of the nearshore reef system. This geological control was used to identify discrete sediment cells where changes to landforms in one part of a cell were highly likely to affect the remainder of the cell but with potentially limited affect on adjoining cells. Thirty six cells were identified along approximately 160 km of coast. Potential relationships between the sand dune ridges (barriers) and the underlying coastal limestone topography were determined; landform patterns comprising the dune systems identified; and individual landforms described for each cell. The scales of description respectively correspond to scales used in the compilation of coastal management strategies and plans.

Landform vulnerability was estimated as a combination of the susceptibility of the geological structure supporting the landforms to environmental change and the current condition of the landforms as indicated by existing evidence of erosion. Together, a geological structure and the landforms it supports define a land system. The assessment involved consideration of the integrity of the geological or geomorphologic structures of land systems and the condition or stability of the landforms supported in a matrix to estimate five grades of vulnerability (Figure A). Susceptibility rankings were determined from values assigned to marine topography near the shore; the shape of the shoreline; coastal orientation; and the prevailing type of landforms present in the cell. Similarly, instability rankings were based on the proportion of rocky versus sandy seabed; beach type and/or beachface shape; whether the frontal dune complex was eroded; and an overall estimate of vegetation cover on the sand barrier. The analysis was intended to be indicative rather than prescriptive, with applications for strategic planning purposes as a first step to more detailed risk assessment procedures.

Results included the definition of the 36 cells, which were named after their southern boundaries, and the estimated vulnerability of each cell (Table A & Figure B). Vulnerability rankings determined on a five-point scale for each sediment cell indicated four (11%) of the 36 cells examined had a low level of vulnerability; 10 (28%) were of low-to-moderate vulnerability; 16 (44%) were moderately vulnerable; six cells (17%) had a moderate-to-high vulnerability ranking; and none had a high vulnerability ranking. More detail is available from the full technical report *The Coast of the Shires of Gingin and Dandaragan, Western Australia: Geology, Geomorphology & Vulnerability*.

SUSCEPTIBILITY (STRUCTURE) (Potential change to geological structure)			INSTABILITY (CONDITION) (Existing morphologic change to land surface)		
			Low (Stable)	Moderate	High (Unstable)
			Example		
	Low	Barrier perched on extensive tracts of coastal limestone	(1) Vegetated swales in parabolic dunes landwards of a vegetated frontal dune ridge overlying coastal limestone above HWL	(2) Vegetated dunes landwards of a vegetated frontal dune ridge and perched on coastal limestone at HWL	(3) High foredune ridge and/or vegetated foredune plain overlying coastal limestone below HWL
	Moderate	Weakly lithified barrier with intermittent limestone outcrops	(2) Mainly vegetated swales in parabolic dunes landwards of a mainly vegetated frontal dune ridge	(3) Vegetated dunes landwards of a mainly vegetated frontal dune ridge (50 to 75% cover) and overlying coastal limestone	(4) Cliffed or discontinuous foredune fronting moderate numbers of mobile blowouts and sand sheets (<50% of the alongshore reach)
	High	Barrier comprised wholly of sand. No bedrock apparent along shore or in dunes	(3) Swales in parabolic dunes landwards of a partly vegetated frontal dune ridge	(4) Mainly vegetated dunes landwards of a partly vegetated frontal dune ridge with 25 to 50% cover	(5) No foredune. Eroded frontal dune with numerous mobile blowouts and sand sheets (>50% of the alongshore reach)

KEY	Combined estimate of vulnerability
	Low
	Low-to-moderate
	Moderate
	Moderate-to-high
	High

Figure A: Indicative Vulnerability Matrix for a Mixed Sandy and Rocky Coast

Note: Susceptibility of a geologic structure to environmental change and the current instability of coastal landforms were estimated for each coastal cell on a three point scale as being low, moderate or high. In the matrix these were combined to provide a five point estimation of the vulnerability.

Table A: Susceptibility, Instability and Vulnerability Rankings for Each Cell

Cell	Southern Boundary of Cell	Susceptibility Rank	Instability Rank	Vulnerability Rank
36	South Fisherman	L	L	L
35	Sandy Point	M	L	L-M
34	Sandland	M	M	M
33	North Head	M	M	M
32	Pumpkin Hollow	L	L	L
31	Middle Head	L	M	L-M
30	Island Point	M	M	M
29	South Booka Valley	H	M	M-H
28	South Hill River	M	H	M-H
27	Black Head	L	M	L-M
26	Thirsty Point	M	M	M
25	Hansen Head	M	M	M
24	Kangaroo Point	M	M	M
23	Boggy Bay	M	M	M
22	Grey	M	M	M
21	South Grey	L	M	L-M
20	North Wedge	L	M	L-M
19	Wedge Island	M	H	M-H
18	Magic Reef	H	M	M-H
17	Narrow Neck	M	M	M
16	Dide Point	L	M	L-M
15	Lancelin Island	H	M	M-H
14	Edward Island	M	M	M
13	South Pacific Reef	M	M	M
12	Ledge Point	M	M	M
11	Green Reef	M	M	M
10	Manakoora Sand Patch	M	H	M-H
9	South First Bluff	M	M	M
8	Second Bluff	L	M	L-M
7	Eagles Nest Bluff	L	L	L
6	Seabird	M	M	M
5	Moore River	M	M	M
4	South Moore River	L	M	L-M
3	North Two Rocks	L	M	L-M
2	Two Rocks	L	M	L-M
1	Wreck Point	L	L	L

Key	Vulnerability of environmental change	Implications for development
(green)	Low	Coastal risk is unlikely to be a constraint to development
(light green)	Low-to-moderate	Coastal risk may present a low constraint to development
(yellow)	Moderate	Coastal risk may present a moderate constraint to development
(peach)	Moderate-to-high	Coastal risk is likely to be a significant constraint to development
(red)	High	Coastal risk is a highly significant constraint to development

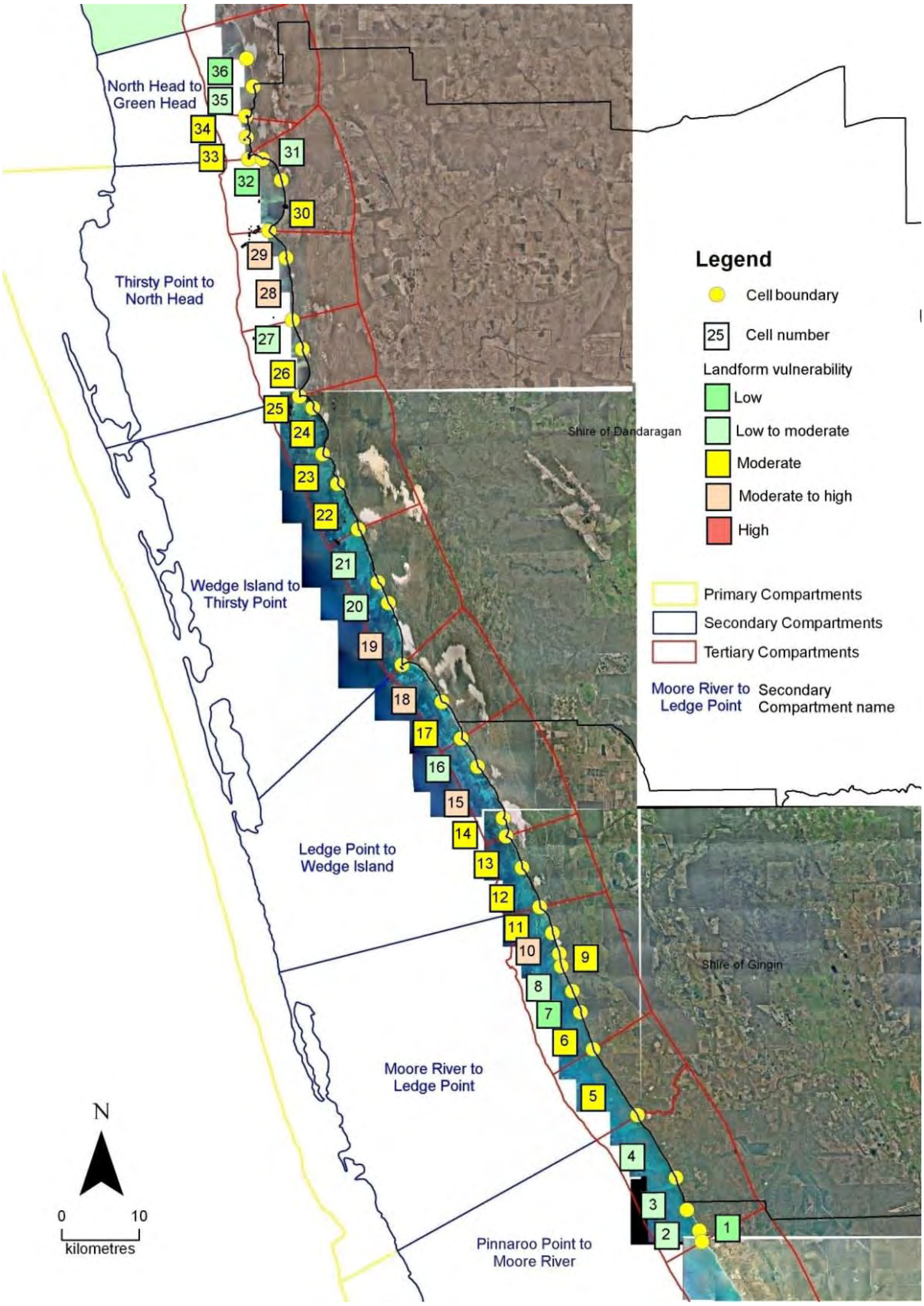

Figure B: Estimated Vulnerability Rankings for the Gingin-Dandaragan Coast

Note: Compartments were defined as large sections of coast with a common land system. Three levels were identified from primary to tertiary compartments, with the offshore boundaries at the 130m, 50m and 20m depth contours. Each compartment contained a number of sediment cells to which the vulnerability rankings were ascribed. The vulnerability rankings referred to the cell as a whole but not to individual landforms. Different landforms within each cell were likely to have higher or lower levels of vulnerability than the cell as a whole.

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1. Introduction

This project identifies the landforms that are likely to alter in response to changes in meteorologic and oceanographic processes along the coast between Wreck Point and Fisherman Islands (Figure 1-1). The study is intended to provide input to strategic planning, and also facilitate more detailed local-scale risk assessments. Changes of interest are those occurring over two time scales: observable landform changes presently taking place over sub-decadal time scales; and those projected to occur over a planning horizon of 100 years. Application of this project requires additional information to develop mitigation strategies. Further investigations will be required to identify and assess the magnitude and timing of specific risks to existing and planned uses of the coast as well as for development of strategies and detailed plans for risk management and mitigation.

1.1. AIMS AND OBJECTIVES

Nationally, Western Australia boasts an enviable diversity of coastal landforms. The diversity includes areas of outstanding beauty such as the World Heritage Area at Shark Bay (Department of Environment and Conservation: DEC 2008) as well as low lying areas in the Pilbara (Semeniuk 1996a) and estuaries of the south west coast (Brearley & Hodgkin 2005) that are prone to inundation by flooding and storm surge (Department of Climate Change: DCC 2009). This has been acknowledged through formulation and adoption of the *Coastal Zone Management Policy for Western Australia* (Western Australian Planning Commission: WAPC 2001) and the *Western Australian Coastal Management Plan* (WAPC 2002). The *Coastal Zone Management Policy* provides objectives for management of the coastal zone and the multiple uses it supports, with the *Coastal Management Plan* providing direction for where the policy should be applied. Operating under this policy and plan are the State Coastal Planning Policy SPP2.6 (WAPC 2003) that provides advice on calculating coastal setbacks and the Coastal Protection Policy (Department for Planning & Infrastructure: DPI 2006) which provides a framework for allocation of funding for erosion mitigation works through the Coastal Protection Funding Program. The policies are founded on long-standing governance of the coast by State and Local Government authorities and the well-founded interest and commitment of coastal communities.

Coastal management in Western Australia has long recognised the dynamic nature of coastal environments and its consequences for coastal development and land use. Coastal planning and management policies have been intended to mitigate existing and anticipated management problems in areas subject of coastal hazards through intelligent siting and design of infrastructure based on ongoing scientific research (WAPC 2001). Generally, the policies have provided space for natural coastal change to occur as well as facilitating conservation and recreation in many places around the State. Prior to their formulation, lack of focussed policy or subsequent poor application resulted in considerable cost to Local and State Government through the establishment of land uses dependent on recurrent maintenance or frequent replacement of amenities. The historical shortcoming devolved on-going management and maintenance responsibility to current and future generations. Long standing coastal management problems at Augusta, Busselton, Cottesloe, Cervantes, and Geraldton provide examples of historical management problems that persist today. More catastrophic problems have been experienced with severe flooding and the impacts of tropical cyclones in the Pilbara and Kimberley, as has been demonstrated by repeated destruction and relocation of townsite and jetty facilities at Onslow. Since adoption of coastal planning policies in the early 1970's, preparation of coastal plans, consultancy projects and local research has substantively added to our knowledge of coastal landforms and the processes shaping them. The policies essentially apply McHargian principles (McHarg 1995) to plan land use in the context of the natural environment. The investigations underlying them are now sufficiently detailed to assist mitigation of projected future problems. Hence, an aim of this report has been to review the available information and use it to assess potential landform change over a planning horizon of up to 100 years.

Examination of the coastal geomorphology between Wreck Point and Fisherman Islands involved assessment of aerial photography of the study area, site visits and a review of relevant and available metocean information. It was conducted at two spatial scales:

- First land systems and major landform components comprising discrete coastal compartments of the Study Area (Figure 1-2) were identified and for the purposes of the report they provide the geologic framework in which sediment cells are recognised. *Coastal compartments* are structural features. They are comprised of large scale geologic and geomorphologic features subject to significant changes over decades to millennia. The boundaries are identified in this report.
- Second, *sediment cells* along the coast were examined in more detail. Sediment cells commonly are smaller three-dimensional units (Figure 1-2) nested within the broader compartments. In the context of this report they are identifiable at scales of 1:10,000 to 1:25,000 or larger at a more detailed local level. Cells are functionally defined by the likely movement of unconsolidated sediments between source areas and sinks via transport pathways within geologic and geomorphic boundaries. Landforms comprising the cells are likely to change in response to sub-decadal, including seasonal and higher frequency changes in metocean processes. In part the distinction between compartments and cells also is based on the potential ease of determining a sediment budget from available information. Some tertiary compartments are large sediment cells.

Sediment cell and sediment budget concepts have been described in more detail by Davies (1974), Chapman *et al*. (1982), Dolan *et al*. (1987), Komar (1996), van Rijn (1998), Short (1999), Rosati (2005) and Whitehouse *et al*. (2009a).

Within the compartments and cells some landforms are more susceptible to long-term variation in climate and sea level than others. Additionally the current condition of landforms, either comprising an assemblage or as individual units varies from place to place. For example, a large barrier system with a wide and high dune field may be less susceptible to structural change than a narrow barrier with low dunes. However, dune fields on similarly-located high, wide barrier structures may have dunes that are currently stable and well vegetated or dunes that are highly unstable with mobile sand sheets present. Hence a distinction is made between the susceptibility and instability of landform associations.

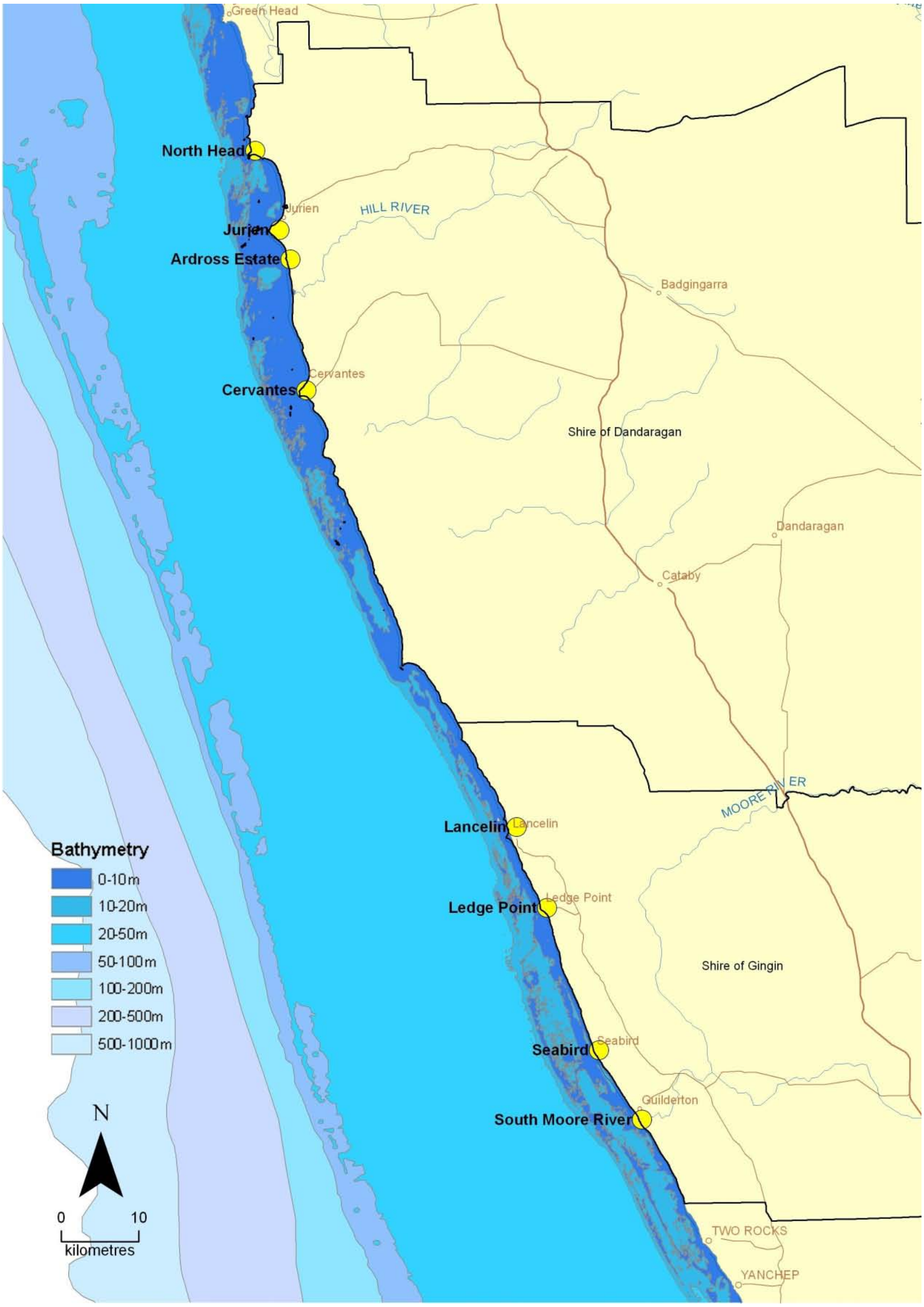


Figure 1-1: Study Area
The Study Area extends from Wreck Point to Fisherman Islands
Yellow dots identify Areas of Planning Interest

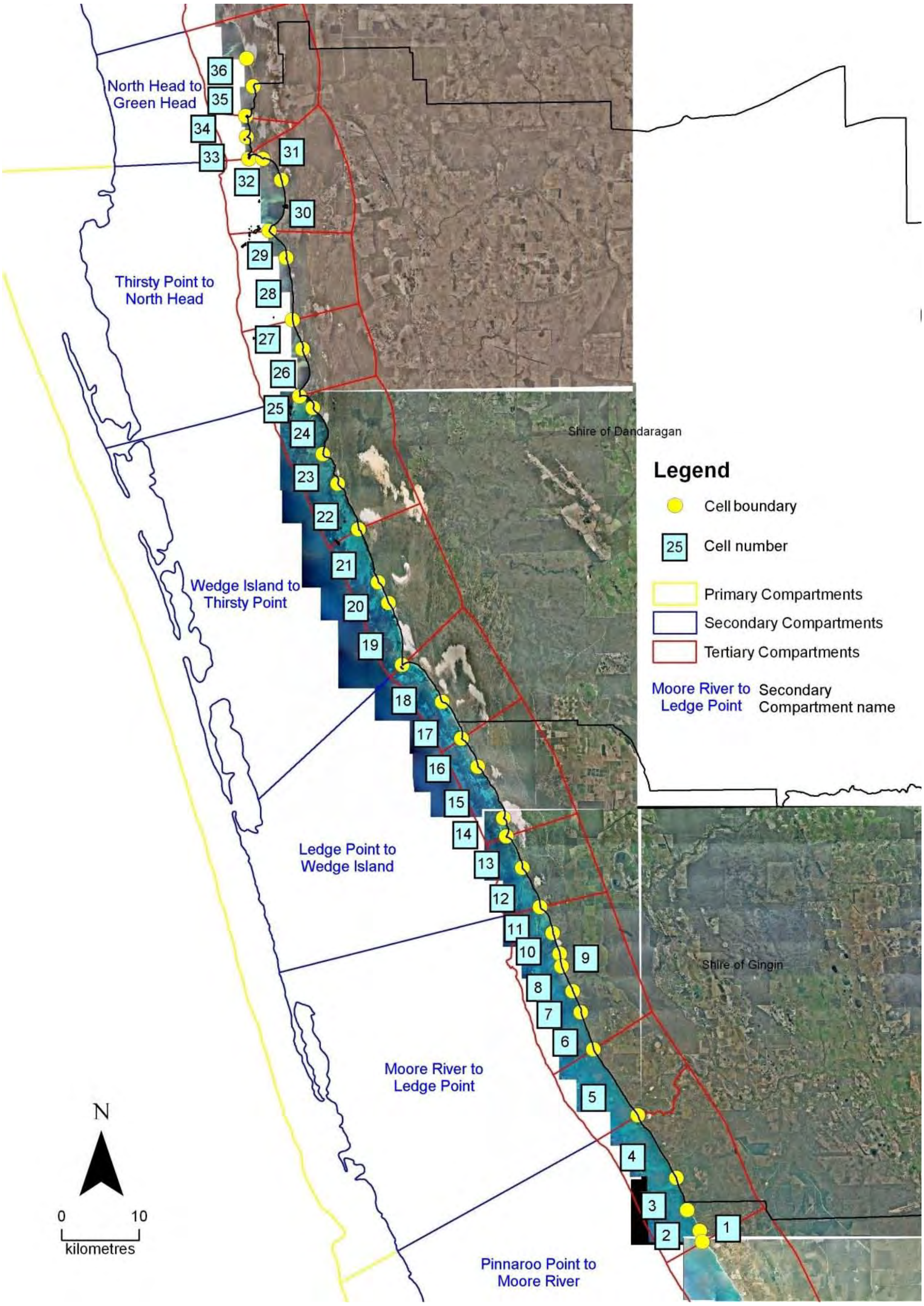


Figure 1-2: Compartments and Sediment Cells

Offshore boundaries are at the 130m, 50m and 20m bathymetric contour for primary to tertiary compartments (Table 2-4) and correspond with significant geologic features and metocean conditions (Eliot *et al.* 2011a). The primary boundary follows the offshore reef.

The examination was consistent with the brief for the project which is included as Appendix A. For the purposes of this report the brief establishes an aim to:

> *"Provide strategic planning guidance, management strategies and direction on appropriate land uses for future subdivision and development of coastal land in the Shires of Gingin and Dandaragan by the identification of sediment cells that define coastal stability and susceptibility to change in the coastal zone".*

Some direction concerning projected future change to the coastal environment was provided by the Department of Climate Change (2009: 41). The agency noted that an expected impact of projected climate change will be accelerated coastal erosion due to rising sea levels. However this concept is necessarily dependent on the availability of unconsolidated sediment to accommodate short-term instability of landforms without a tipping point being reached which changes the geological structure supporting them. The response of the coast to projected change is complex due to the space and time scales at which different metocean conditions, local lithology and sediment factors affecting the morphology operate, including the following:

1. Local topographic factors, including the geologic framework supporting the coast;
2. The inherent susceptibility of different unconsolidated sedimentary landforms due to their structure and composition;
3. Coastal sediment budgets, including geomorphic features that act as sediment sinks or sources; and
4. Natural geographic variability in the metocean processes, particularly changes in sea level and the wave regime, affecting the stability of landform in the area of interest.

The objectives of the project are to describe the geomorphology of the coast of the Shires of Gingin and Dandaragan in Western Australia (Figure 1-1); determine land systems or structures that are susceptible to change over a long period; identify landforms that are currently unstable; and assess the vulnerability of different parts of the coast to projected change in metocean forcing. In turn the information presented is intended to identify the nature and degree of investigation required to support management proposals for the land system or landform under consideration.

It was intended these objectives would be met by:

1. First–pass identification and description of coastal landforms, with particular reference to coastal dunes, beaches, rocky shores and inshore morphology.
2. Broad-scale identification of landforms and reaches of coastal land susceptible to risks related to natural variation in climate and sea level fluctuations, and which may be affected by projected changes in climate.

The outcomes are anticipated to contribute to strategic planning for the Study Area as well as to add detail to state and National databases particularly the Oil Spill Response Atlas: OSRA (Australian Maritime Safety Authority: AMSA 2006) and Smartline (Sharples *et al.* 2009) databases for the coastal area being examined.

1.2. TASKS

A key task in the examination of coastal land systems for strategic coastal planning in the shires of Gingin and Dandaragan was to provide an indicative assessment of coastal vulnerability to changing metocean processes that is consistently applicable at all planning scales, which guides potential land use and potentially has relevance to upscaling and downscaling responses to risk aversion or mitigation. The following steps were completed in order to accomplish this task and fulfil the objectives:

1. Identify natural resource management units at scales commensurate with regional and local planning scales recommended by the WAPC (2003);
2. Describe the geology and Holocene landforms, those developed over the past 6,000 years, comprising each planning unit;
3. Through comparison of the physical features in each planning unit, determine areas of coastal land likely to require different planning and management approaches;
4. Develop a framework for assessment of coastal vulnerability that is consistently applicable at all planning scales; and
5. Apply the framework at broad scale strategic and local planning scales through its application to large sediment cells.

1.3. APPROACH

In this report the approach used is a hierarchical land system analysis focussing specifically on description of a framework provided by the geology and geomorphology of the coast. It has similarities to the hierarchical classification used for mapping of soils in WA (Schoknecht *et al.* 2004; van Gool *et al.* 2005). Land system analysis is used because it:

> *'… provides a framework by which appropriately formulated policies can be linked to distinctive components of the landscape (hierarchically arranged as land systems and constituent land units) and their various features and management needs.'* (Hames Sharley 1988: 12)

The approach used here has been adapted to coastal planning purposes similar to those applied by Whitehouse *et al.* (2009a) in the characterisation and prediction of large scale, long-term change of coastal geomorphological behaviour around the coast of the United Kingdom. A similar approach has been applied to Coffs Harbour in NSW by Rollason *et al.* (2010) and Rollason & Haines (2011). Rollason *et al.* (2010) noted that the *Guidelines for preparing Coastal Zone Management Plans* (Department of Environment, Climate Change and Water NSW 2010)

> *'separate the coastline into its broad geomorphologic sub-groups, being either sandy beach systems, bluffs and cliffs comprising rock and other consolidated material, or the entrance area of estuaries/watercourses at the coast.'*

They established methods for application of the *AS/NZS ISO 31000:2009 Risk Management Principles and Guidelines* (Standards Australia 2009) to coastal management. In their methodology it is important to set the context for which a land system or all of the geomorphologic components a risk assessment and management plan is intended to address. Description of the context is the first phase of the risk assessment process and accords with the coastal processes and hazards definition phase of the traditional coastal planning process (Rollason *et al.* 2010).

The projected changes of interest are those spanning two time and space scales; short (sub-decadal) and long (over a planning horizon of 100 years) term changes occurring at secondary compartmental (approximately 1:100,000) and primary sediment cell (approximately 1:25,000) scales. This necessarily requires examination of changes at land system (landform pattern) and landform levels in the land system hierarchy, with the broader scales providing context for more detailed interpretation and morphologic changes at the more detailed scales potentially providing explanation for long-term change.
The land system approach adopted has three significant features:

1. The scalar hierarchy is commensurate with regional and local planning scales recommended by the WAPC (2003);
2. It has been applied to coastal or marine management elsewhere in Australia (NSW Government 1990; Government of South Australia 2006; Rollason & Haines 2011) and overseas (Kelley *et al.* 1989; Hart & Bryan 2008; and Whitehouse *et al.* 2009a, b); and
3. A method of analysis can be developed for consistent application at all levels in the hierarchy.

The methods used facilitated assessment of a combination of coastal susceptibility to projected environmental change and current landform stability. As indicated above the combination is based on the identification of large sediment cells. Compartments are intended for strategic regional planning and policy development, and cells for local area planning. Coastal vulnerability for each compartment or cell is estimated as a function of the susceptibility of the geologic structure or land system of the coast to changing metocean regime and the present condition or stability of each landform the land system supports. The estimated vulnerability provides an indication of the management pressures likely to accord for land-use within each whole compartment or cell relative to others in a series described for a region or administrative coastal area. The methods used to evaluate coastal susceptibility, stability and vulnerability are outlined in Section 2.

1.4. DOCUMENT USE

A methodology developed to assess coastal vulnerability to changes in climate and sea level has been developed at a sediment cell scale, which approximately corresponds to a 1:100,000 map scale, suitable for strategic regional planning. An overall estimate of vulnerability has been made for each sediment cell. The overall vulnerability is intended to provide an indication of the management pressures likely to accord for land-use <u>within the cell as a whole</u> as well as to facilitate comparison between different sectors of coast.

As a consequence, the estimate of vulnerability <u>does not</u> provide an adequate measure of stability for specific land-uses that may be active within a limited portion of the cell. It should be clearly recognised that landform classification provides only a basic, qualitative measure of potential for change, and hence the information should be used with caution. Equally, the high resolution landform mapping presented offers further spatial refinement, but the stability of individual landforms within such classes is quite variable. Hence, this report provides direction regarding the suitability of coastal land for specific uses, but further detailed risk assessment at a local, site scale may be necessary.

2. Methods

Coastal vulnerability was estimated as follows:

1. Separate planning units were identified at a scale appropriate to strategic and local area planning;
2. Landforms were identified and mapped for each planning unit at a sediment cell scale;
3. Ranking scales for susceptibility and instability were derived from published conceptual models respectively describing sequences of coastal development or different degrees of coastal instability.
4. The major natural structural features of planning units were described and ranked according to their likely susceptibility to change;
5. Landforms within cell were described and ranked according to their present stability and an overall ranking of instability ascertained;
6. The overall susceptibility and instability rankings were separately grouped into low, moderate and high categories for each cell; and
7. The vulnerability of each cell was estimated by combining the overall rankings of susceptibility and instability in a matrix to identify the likelihood of geomorphic change, grouped into low, low-to-moderate, moderate, moderate-to-high and high categories.

Consequences for the resulting vulnerability estimates were then interpreted for each cell and form the basis of recommendations made in the report. These steps are outlined below.

2.1. IDENTIFICATION OF PLANNING UNITS

The planning units of sediment cells are nested within a hierarchy of coastal compartments (Table 2-1; Figure 1-2). In the context of this report sediment cells are areas sharing physical features apparent at mapping scales appropriate to local and regional planning. The approach used focused on description of the structural framework provided by the geology, and to a lesser extent, large geomorphic features formed of unconsolidated sandy sediment.

Four sets of features were used to identify the alongshore boundaries of coastal compartments and sediment cells. These are listed in Table 2-2 and examples of boundaries are provided in Figure 2-1. The offshore boundaries of the compartments and cells as well as their interpretation in terrestrial coastal planning are outlined in Table 2-3. Onshore, the boundary of the compartments and cells is either the landward extent of marine and eolian sediments deposited over the past 10,000 years, during the Holocene, as the present coast developed; or approximately 500 metres landward from the rocky shoreline. At each scale, landforms and the processes affecting them (Table 2-4) provide an approach to interpretation and implementation of the State Coastal Planning Policy SPP2.6 (WAPC 2003) and/or the Coastal Protection Policy (DPI 2006).

Overall, the approach is multi-scalar and the methodology was applied at the scale of the primary sediment cells in this report. The approach ranges from broad-scale strategic consideration of the compartments to more detailed identification of areas nominated as requiring special consideration for planning purposes. At each scale this could be done through facilitation of a qualitative ranking of landforms to risk of change based on separate estimates of geologic and geomorphic features to potential change in combination with the current condition or instability of the land surface. These are then combined to provide a ranked estimate of vulnerability.

Table 2-1: Compartments and Sediment Cells

<table>
<tr><th colspan="3">Compartment</th><th>Sediment Cell</th></tr>
<tr><th>Primary</th><th>Secondary</th><th>Tertiary</th><th>Primary</th></tr>
<tr><td rowspan="4">BEAGLE: North Head to Glenfield (beyond Study Area)</td><td rowspan="4">North Head to Green Head (beyond Study Area)</td><td rowspan="2">Sandy Point to Green Head (beyond Study Area)</td><td>36. South Fisherman to Fisherman Islands</td></tr>
<tr><td>35. Sandy Point to South Fisherman</td></tr>
<tr><td rowspan="2">North Head to Sandy Point</td><td>34. Sandland to Sandy Point</td></tr>
<tr><td>33. North Head to Sandland</td></tr>
<tr><td rowspan="28">HILL: Moore River to North Head</td><td rowspan="7">Thirsty Point to North Head</td><td rowspan="3">Island Point to North Head</td><td>32. Pumpkin Hollow to North Head</td></tr>
<tr><td>31. Middle Head to Pumpkin Hollow</td></tr>
<tr><td>30. Island Point to Middle Head</td></tr>
<tr><td rowspan="2">South Hill River to Island Point</td><td>29. South Booka Valley to Island Point</td></tr>
<tr><td>28. South Hill River to South Booka Valley</td></tr>
<tr><td rowspan="2">Thirsty Point to South Hill River</td><td>27. Black Head to South Hill River</td></tr>
<tr><td>26. Thirsty Point to Black Head</td></tr>
<tr><td rowspan="7">Wedge Island to Thirsty Point</td><td rowspan="4">Grey to Thirsty Point</td><td>25. Hansen Head to Thirsty Point</td></tr>
<tr><td>24. Kangaroo Point to Hansen Head</td></tr>
<tr><td>23. Boggy Bay to Kangaroo Point</td></tr>
<tr><td>22. Grey to Boggy Bay</td></tr>
<tr><td rowspan="3">Wedge Island to Grey</td><td>21. South Grey to Grey</td></tr>
<tr><td>20. North Wedge to South Grey</td></tr>
<tr><td>19. Wedge Island to North Wedge</td></tr>
<tr><td rowspan="7">Ledge Point to Wedge Island</td><td rowspan="2">Narrow Neck to Wedge Island</td><td>18. Magic Reef to Wedge Island</td></tr>
<tr><td>17. Narrow Neck to Magic Reef</td></tr>
<tr><td rowspan="3">Edward Island to Narrow Neck</td><td>16. Dide Point to Narrow Neck</td></tr>
<tr><td>15. Lancelin Island to Dide Point</td></tr>
<tr><td>14. Edward Island to Lancelin Island</td></tr>
<tr><td rowspan="2">Ledge Point to Edward Island</td><td>13. South Pacific Reef to Edward Island</td></tr>
<tr><td>12. Ledge Point to South Pacific Reef</td></tr>
<tr><td rowspan="7">Moore River to Ledge Point</td><td rowspan="6">Seabird to Ledge Point</td><td>11. Green Reef to Ledge Point</td></tr>
<tr><td>10. Manakoora Sand Patch to Green Reef</td></tr>
<tr><td>9. South First Bluff to Manakoora Sand Patch</td></tr>
<tr><td>8. Second Bluff to South First Bluff</td></tr>
<tr><td>7. Eagles Nest Bluff to Second Bluff</td></tr>
<tr><td>6. Seabird to Eagles Nest Bluff</td></tr>
<tr><td>Moore River to Seabird</td><td>5. Moore River to Seabird</td></tr>
<tr><td rowspan="4">SWAN: Robert Point (beyond Study Area) to Moore River</td><td rowspan="4">Pinnaroo Point (beyond Study Area) to Moore River</td><td rowspan="4">Wreck Point to Moore River</td><td>4. South Moore River to Moore River</td></tr>
<tr><td>3. North Two Rocks to South Moore River</td></tr>
<tr><td>2. Two Rocks to North Two Rocks</td></tr>
<tr><td>1. Wreck Point to Two Rocks</td></tr>
</table>

In the literature a sediment cell is defined as a reach of coast, including the nearshore terrestrial and marine environments, within which movement of sediment is largely self-contained (Mc Innes *et al.* 1998). Cells include areas of sediment supply, transport pathways and sediment loss from the nearshore system (Figure 2-2). The definition of cells as being largely self-contained is not always applicable along much of the Western Australian coast.

Coastal sediment cell boundaries may be spatially fixed, because of the presence of rocky headlands or structures, or ambulatory with changing sediment transport conditions (Carter 1988). Sediment exchange across boundaries between adjacent cells occurs, but may be constrained and/or highly variable over time. When sediment exchange between adjacent cells is limited, cells may be used for estimation of a coastal sediment budget (Komar 1996; Rosati 2005). Significantly, this includes identification of areas undergoing erosion or accretion and the linkages between them. It provides a clear link between sediment budget estimation and coastal management (eg. Hooke *et al.* 1996; Cooper *et al.* 2001).

Whether morphologic changes within the cells reflect spatial variation in the coastal energy regime is highly probable but open to question. Herein, the cells have been used to structure identification of the geomorphic components of the coast and nearshore waters. Cells have also been used for comparative purposes to establish areas of relative stability along the coast.

Table 2-2: Features Used to Establish the Boundaries of Each Coastal Compartment

Priority	Feature	Examples
1	Changes in geology	Metamorphic to sedimentary rocks; lithified to unconsolidated sediments
2	Rock structures (topography)	Rocky capes, peninsulas, termination of extensive cliffs
3	Geomorphic features (morphology)	Large cuspate forelands and tombolos; extensive sandy beaches
4	Change in aspect of the shore	Bald Head at the entrance to King George Sound; changes in aspect along Eighty Mile Beach

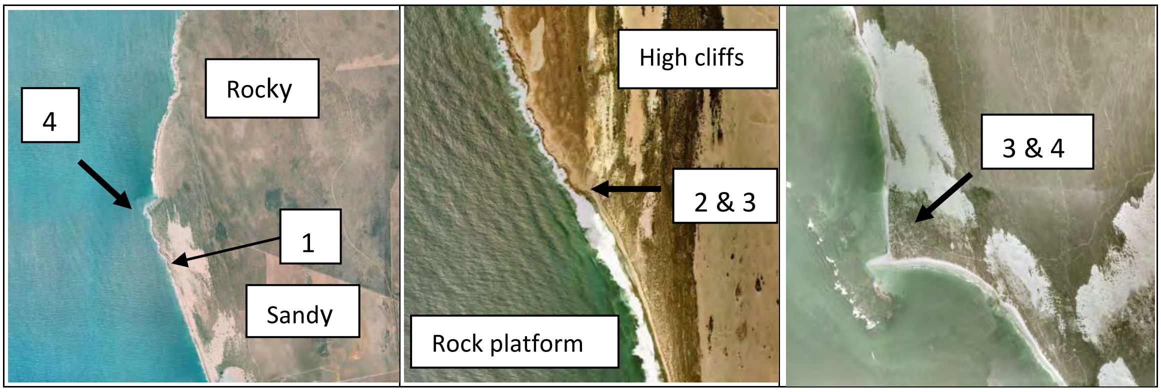


Figure 2-1: Examples of Compartment Boundaries
1 = change in geology; 2 = rock structure; 3 = geomorphic feature; and 4 = change in aspect
= Primary boundary = Secondary boundary

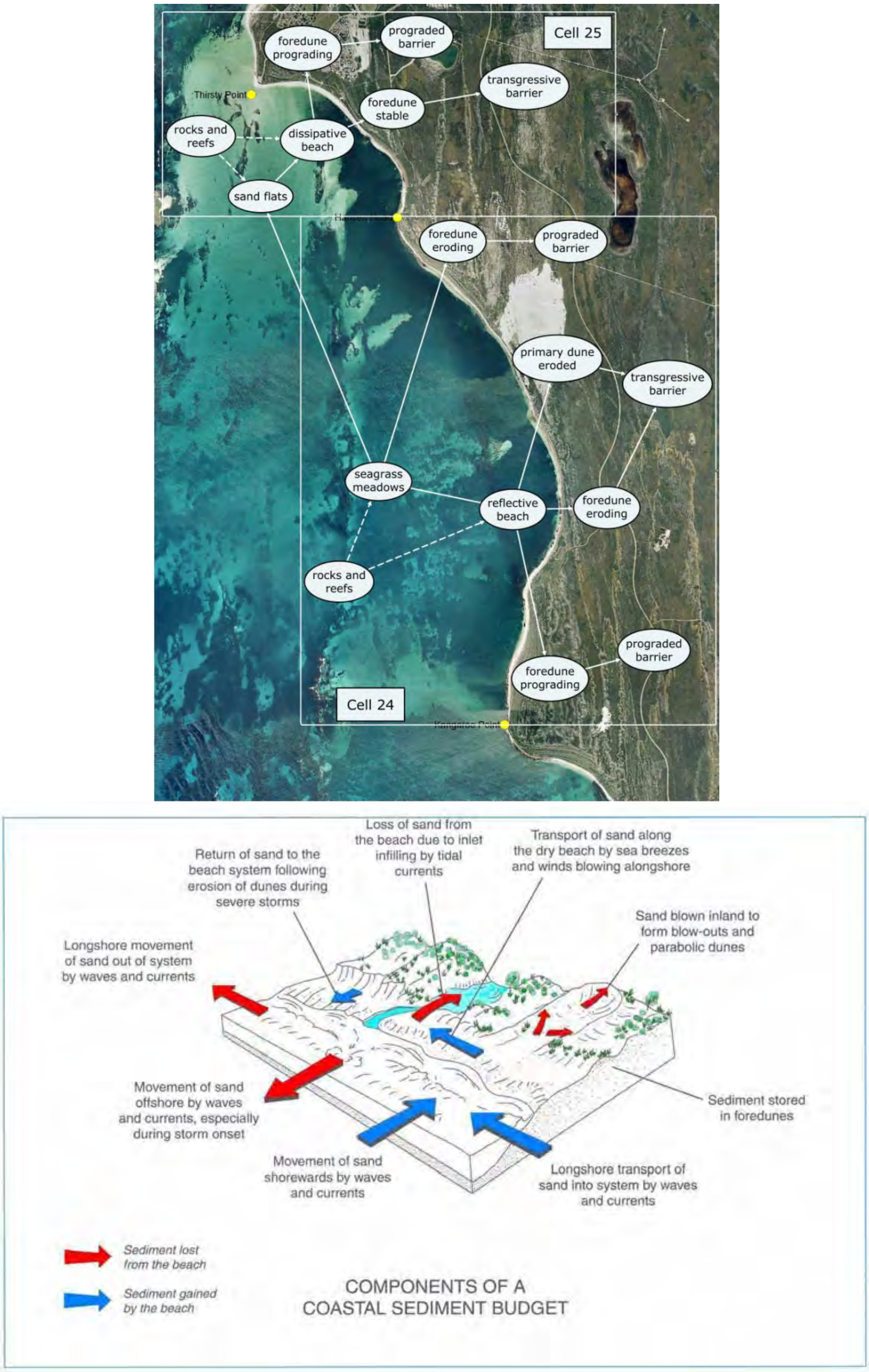


Figure 2-2: Sediment Budget Components
(A) Components of a Sediment Cell; and (B) A Conceptual Sediment Cell in which the Components of the Sediment Budget Have Been Identified
(Source: WAPC 2002)

Table 2-3: Offshore Boundaries of Coastal Compartments and Coastal Planning and Management Applications

Boundary (isobath)	Land System/Landform Scale and Geology	Management Application
Primary Compartments (130 metres)	Mega-scale land systems e.g. Barriers, river deltas, zeta-form beaches Geological development of the coastal plan form occurs at this scale. Marine processes affecting the inner continental shelf establish the geological setting of coastal land and its broad susceptibility to long-term erosive forces operating over decades, centuries and millennia.	The inner continental shelf is significant for marine resource planning and management because it supports a high proportion of aquatic biota fished for commercial and recreational purposes, and which demand land based infrastructure for its exploitation. Primary compartments are areas of substantial overlap between Commonwealth and State interests. Waters beyond State Water boundary at 3nm (approximately 6km) are jointly managed through an intergovernmental agreement.
Secondary Compartments (50 metres)	Meso- to Macro-scale land systems and landforms e.g. Cuspate forelands, tombolos and dune sequences Holocene, including present day, development of the coastal plan form occurs at this scale. The topographic structure of the inner continental shelf affects wave patterns and nearshore water circulation. Coastal changes are apparent at interannual to decadal time periods.	Closer to shore, this is the area of most intense use of the marine environment for commercial and recreational purposes, including recreation and tourism. Meso-scale landforms are apparent as components of coastal sediment cells and sediment budgets at this scale. They identify areas of relative coastal stability as well as susceptibility to change, and hence indicate potential problems for coastal planning and management. In this context there may be a requirement for detailed studies at a local scale.
Tertiary Compartments (20 metres)	Micro- to Meso- scale landforms. e.g. beaches, foredunes and blowouts. Inshore topography landward of the 20m isobath determines the nearshore wave regime and current patterns that drive the coastal sediment budget. It has a direct affect on the stability of coastal landforms, particularly those comprised of unconsolidated sediment. Coastal changes are apparent at seasonal and interannual to decadal scales.	The inshore waters and coastal lands are critical for provision and maintenance of marine based infrastructure (harbours and marinas). In addition to its commercial value, the area comprises a substantial proportion of State Waters and is highly significant for coastal recreation. Landforms within the tertiary components are directly related to sediment cells. They include indication of areas likely to be unstable and which may require special consideration for coastal management at a local level.
Sediment Cell (Offshore boundary linked to local sediment movement)	Micro- to meso-scale landforms associated with areas of active sediment production, mobilisation, transport and deposition. e.g. seagrass beds, scour channels, longshore troughs, beaches and mobile dunes. Micro- to meso-scale landforms comprise the major components of the coastal sediment budget and are directly related to coastal stability. Landform change may be apparent at hourly to seasonal scales.	The active components of the coast are considered under Section C of the State Coastal Planning Policy (SPP 2.6) in the calculation of requirements for the set back of development from the active beach. They are identified through changes in the beach profile, the position of the shoreline and migration of active dunes.

Table 2-4: Application of Coastal Compartments & Sediment Cells at Planning Scales

COMPARTMENT		DESCRIPTORS			
PLAN (Compartment)	**OFFSHORE LIMIT (Depth Contour)**	**GEOLOGY & GEOMORPHOLOGY**	**Meteorologic**	**KEY PROCESSES Oceanographic**	**Landform Change**
POLICY (State or Region)	Continental shelf boundary (250m isobath)	Broad scale geology & coastal land systems	Climate zone & global weather scales such as the Walker Circulation & Southern Oscillation	Broad-scale tidal environment; Deepwater wave environment; Geographic variation in major ocean currents	Main structural features & landscapes; Broad-scale (geologic) evolution of the coast
STRATEGIC PLAN (Primary Compartment)	Interglacial low sea level (130m isobath)	Shoreface geological structures & coastal land systems and form patterns (eg. Episodic transgressive sand barrier)	Distribution of major weather systems affecting the region, including those associated with extreme events	Broad-scale tidal regime; Inter-annual and long-term variation in mean sea level; Deepwater wave environment; Outer shelf current regime	Geological development of major land systems apparent at a regional scale (eg. barrier type)
REGIONAL PLAN (Secondary Compartment)	Present day shoreface (50m isobath)	Sub-regional geologic framework & large geomorphic responses (eg. Nested blowouts overlying long-walled parabolic dunes)	Major weather systems & assessment of regional scale risks associated with their onset & passage	Water level characteristics & range (tide & surge); Seasonal to inter-decadal fluctuation in mean sea level; Inner-shelf wave & current regime	Landform patterns (eg. nested dunes on a barrier); Broad changes occurring to coastal landforms at seasonal, inter-annual and inter-decadal time scales
LOCAL or SITE PLAN (Tertiary Compartment)	Inshore sediment movement (Offshore 20m isobath)	Local geologic framework, geomorphologic structures & individual landforms (eg. Mobile sand sheet and active parabolic dune)	Regional & local weather systems together with local or site scale assessment of risks associated with their onset & passage	Water level regime at site level; Seasonal and inter-annual fluctuation in mean sea level; Nearshore wave & current regimes	Landforms and landform elements; Description of shoreline movement and landform change at sub-decadal intervals; Local dynamics in response to metocean processes
LOCAL or SITE PLAN (Sediment Cell)	Depends on the size of the cell and location of offshore sediment sinks, hence overlap with planning scales	Areas of sediment movement: sources, transport paths & sinks identified at local and site scales	Identification of local and site scale weather systems driving processes at a sediment cell scale	Water level regime at site level; Seasonal and inter-annual fluctuation in sea level; Nearshore wave & current patterns	Inter-annual resolution of the coastal sediment budget for cells at the planning scale

2.2. LAND SYSTEM AND LANDFORM IDENTIFICATION

Land systems and landforms for parts of the Study Area previously have been described in a wide variety of plans, reports and technical papers, including:

- Coastal management plans (Chalmers and Davies 1984; Lobry de Bruyn and Ochman 1987; Hames Sharley 1988; Thomas *et al.* 1990; Landvision *et al.* 1999);
- Marine conservation plans (Marine Parks and Reserves Authority: MPRA 2000);
- Regional planning strategies (WAPC 1996);
- Technical reports (Public Works Department: PWD 1984; Eliot 1992; Tinley 1992; Griffin & Associates 1993; Department of Planning and Urban Development: DPUD 1994; Gozzard 2011a, b); and
- Scientific papers (Mc Arthur & Bettenay 1960; Playford *et al.* 1976; Woods 1983a; Gozzard 1985; Woods *et al.* 1985; Moncrieff and Tuckson 1987; Maxwell 1995; Sanderson & Eliot 1996; Sanderson & Eliot 1999; Sanderson 2000; Short 2005).

While these provide insight into the variety and distribution of landforms along the coast only four are of direct relevance to the current project, although Hames Sharley (1988:12) adopted a similar approach in recommending and applying a land system approach to coastal planning for the Shire of Gingin.

The articles of direct relevance examine the geology and geomorphology of the Gingin-Dandaragan coast. First, Searle & Semeniuk (1985) identified the natural sectors of the Rottnest Shelf coast adjoining the Swan Coastal plain, including the coast of the Study Area and its wider environmental context. Their research identified and linked coastal landforms to their marine setting and placed the Gingin-Dandaragan coast into two sectors; Whitfords to Lancelin and Lancelin to Dongara. Second, Gozzard (1985) identified, described and mapped the geology, geomorphology and land use capability of the coast between Guilderton and Green Head. His work underpinned much of the planning to follow and has been expanded in *WACoast* (Gozzard 2011a, b), part of which is incorporated in this report. Third, a detailed determination of coastal compartments based on the distribution and characteristics of sediments along the shore between the Moore River and Cliff Head was made by Sanderson (1992) and later published as Sanderson & Eliot (1996). Her findings were incorporated in a fourth document, the *Central Coast Regional Profile* (DPUD 1994), in which seven coastal sectors were identified along the coast between the Guilderton and Dongara, four of which lie between the Moore River and Fisherman Islands. The sectors approximate the secondary compartments identified in this project, but specifically are geomorphic units.

The prior studies identify the major land systems and landforms present in the Study Area (Table 2-5) and have been used in the estimation of coastal vulnerability to metocean changes (Section 4).

Three areas of landform development are commonly identified. These are the nearshore, shore and onshore zones or components of the marine and coastal environment. Herein *nearshore* is determined by scale and refers to the offshore boundary of a compartment or cell; *shore* encompasses the shape of the shoreline in plan and its aspect or orientation with respect to dominant and/or prevailing wave directions, as well as the type of active beach present; and *onshore* refers to rocky coast and Holocene dune complexes as well as landforms of fluvial or tidal origin. A different suite of landforms may be identifiable at a regional, land system and landform scale for the same reach of coast.

Detailed maps of onshore landforms have been used in the assessment of vulnerability at a sediment cell scale (Figure 2-3). Apart from the application at Areas of Planning Interest (Section 6), information relevant to landuse on *specific landforms* is outside the scope of this report. However, it may be derived from several sources for local area planning:

1. It may be extracted from the instability scores for each landform type used in estimating vulnerability. However, it should be clearly recognised that the level of landform classification provides only a basic measure of potential for change, and hence the information should be used with caution.
2. In some instances, more detailed estimates of landform stability may be compiled for places of particular planning or management interest, such as green field sites nominated for future development as rural urban areas or tourism development sites. Although the high resolution landform mapping offers further spatial refinement the stability of individual landforms within such classes is quite variable. For example, frontal dunes subject to erosion by blowouts are considered to be less stable than fully vegetated, undisturbed frontal dunes in the context of the assessment, but are classified in the same landform category.

Detailed mapping of landforms and description of the conceptual models applied to them has been completed for the Western Australian coast between Cape Naturaliste and Kalbarri by the Geological Survey of Western Australia as part of the WACoast Project (Gozzard 2011a, b).

Table 2-5: Major Landform Associations
(After: Searle & Semeniuk 1985)

Cross-Shore Location	Landform
(1) Nearshore Morphology	Islands Linear reefs and submarine ridges Pavements Sand banks Sand flats and seagrass meadows
(2) Landforms of the Shore	Shoreline shapes (straight, irregular, arcuate and zeta-form) Rocky coasts (cliffs, ramps and platforms) Beaches (sheltered and exposed forms)
(3) Onshore Landforms	Limestone plateaux and outcrops Foredunes Frontal dunes (blowouts and parabolic dunes) Barriers Estuaries Deltas Coastal lagoons and wetlands

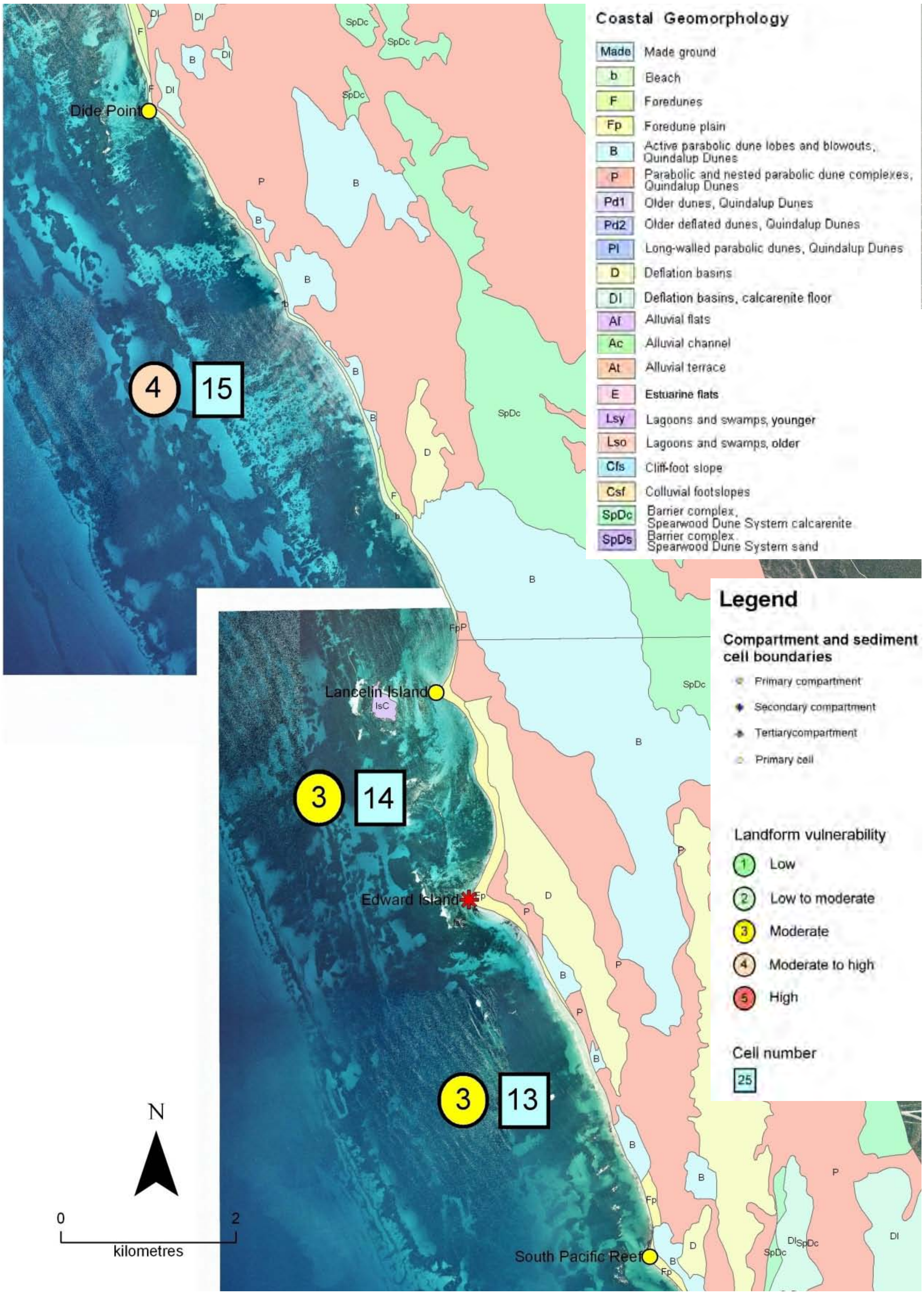


Figure 2-3: Landforms and Sediment Cells in the Vicinity of Lancelin
Landform Maps for all Cells are in Appendix C

2.3. RANKING LAND SYSTEM AND LANDFORM SUSCEPTIBILITY AND INSTABILITY

Landform associations common to the nearshore, shore and onshore zones of the coastal environment provide a basis to assess the susceptibility of the coast to change in the natural change and the current stability of the landforms each structure supports. The landform stability describing each ranking level has been taken from conceptual models described in the geological and geomorphologic literature.

Within each landform association the rank of individual landform associations and landforms indicates the likelihood of geomorphic change. A low rank (1) indicates a low risk of change to the natural structural or that the landforms on the geologic structure supporting them currently have a low level of instability. Conversely a high rank (5) indicates the natural structure is likely to change or cause change over a planning horizon of 100 years, and that the landforms present are currently unstable. Rationale for the ranking is discussed below. The criteria used to rank susceptibility and instability of landforms of the Gingin-Dandaragan coast are listed in Table 2-6.

Susceptibility ranking is based on five stages in the evolution of major Land Systems in response to long term (inter-decadal and longer) changes in metocean processes, brief but extreme high magnitude events or the cumulative effect of persistent short term changes to the land surface. In all instances the changes taking place may cross multiple zones of the nearshore, shore and onshore. Instability refers to a single landform or landform associations on the land surface. It also is ranked on a five point scale based on comparison of current landform condition or changes taking place over less than a decade.

2.4. SUSCEPTIBILITY AND INSTABILITY

Susceptibility and instability are related concepts drawn from geological and geomorphological literature respectively describing the evolution of disparate land systems, and landform change in response to metocean processes and change in sediment supply over different intervals of time. For this study, the relative importance of different processes has been considered with respect to five land systems and landform units. Key references considered in the evaluation of susceptibility and instability includes:

1. Deltas, estuaries and rivers: Wright (1985); Perillo (1995); Brearley & Hodgkin (2005).
2. Cuspate forelands & Tombolos: Zenkovich (1967); Sanderson & Eliot (1996); Sanderson (2000).
3. Barriers: Chapman *et al.* (1982); Cowell & Thom (1994); Roy *et al.* (1994); Hesp & Short (1999a); Masetti *et al*. (2008).
4. Beaches: Nordstrom (1980, 1992); Wright & Short (1984); Jackson *et al.* (2002); Short (2005); Eliot *et al.* (2006); Green (2008); Doucette (2009).
5. Coastal Dunes: Semeniuk *et al.* (1989); Hesp & Short (1999a, b); Hesp (2002); Houser & Matthew (2011).

References such as those by the Department of Planning and Urban Development (1994) describing land systems on the Western Australian coast and Hsu *et al.* (2008) describing topographic control of the shoreline geometry have been used where appropriate and available. However there are gaps in knowledge, particularly with respect to mixed sandy and rocky coast where the geologic framework is a major factor.

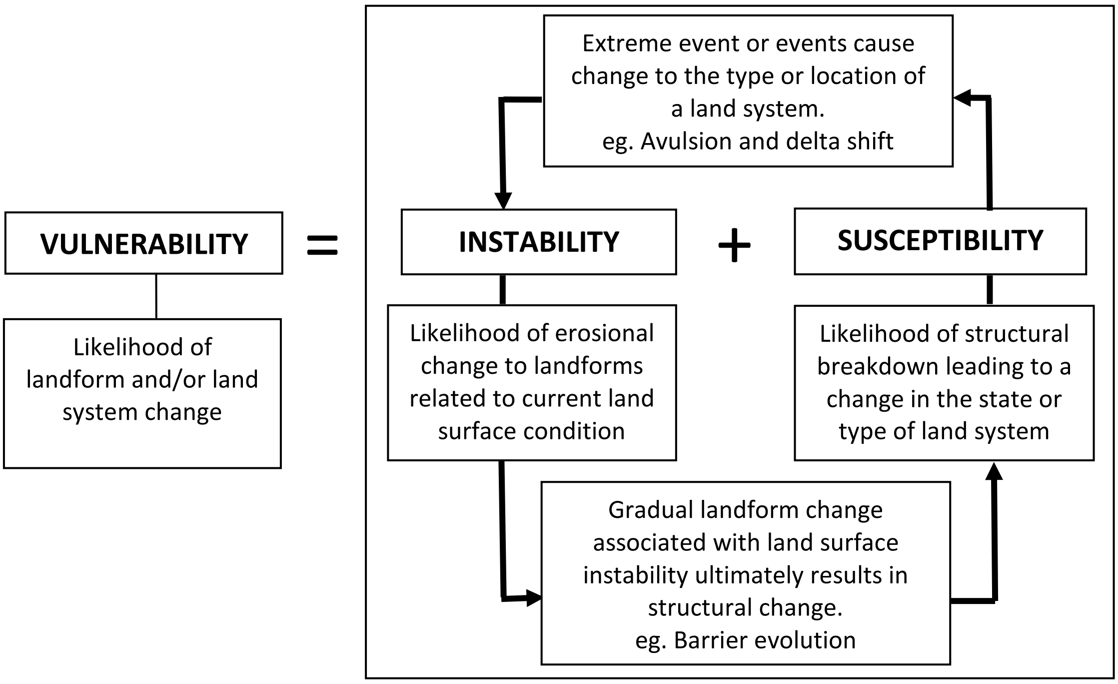
Table 2-6: Criteria for Landform Susceptibility and Stability on a Mixed Sandy and Rocky Coast

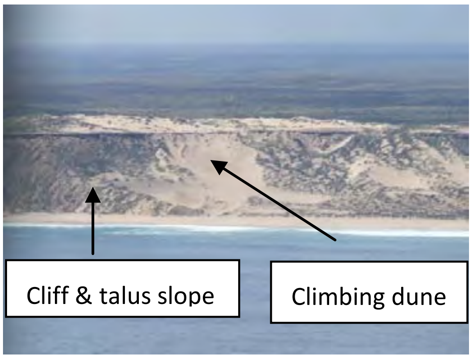
(A) SUSCEPTIBILITY (Potential for structural impacts)		(B) INSTABILITY (Current changes to land surface)	
NEARSHORE MORPHOLOGY (Depth <25m)	**Rank**	**INSHORE SUBSTRATE (Depth <5m)**	**Rank**
Continuous offshore reef; shallow lagoon or shelf (platform or bank)	1	Hard rock (Granite) OR Greater than 75% reef or pavement	1
Discontinuous offshore reef; deep lagoon or shelf (platform or bank)	2	Moderately hard rock (Sandstone) OR 50 to 75% reef or pavement	2
Shallow intermittent reef or broken pavement (Depth <10m)	3	Moderately soft rock (Limestone) OR 25 to 50% reef or pavement	3
Deep intermittent reef or broken pavement (Depth >10m)	4	Soft rock (Eolianite or calcarenite) OR Less than 25% reef or pavement	4
Unconsolidated sediments Bare sand or seagrass banks	5	Bare sand: No rock outcrop	5
SHORELINE CONFIGURATION		**BEACHFACE MORPHOLOGY & PROFILE**	
Straight or seawardly convex rocky coast; made beaches	1	Sheltered - flat or segmented	1
Irregular or rhythmic shoreline	2	Sheltered - rounded (curvilinear)	2
Arcuate or zeta-form, shallowly indented	3	Exposed - reflective	3
Arcuate or zeta-form, deeply indented	4	Exposed - transitional	4
Cuspate forelands & tombolos	5	Exposed - dissipative OR Barred river mouth	5
COASTAL ORIENTATION (With respect to major storms)		**FRONTAL DUNE COMPLEX (Frontal dune and foredune)**	
South (SSE -SSW)	1	Continuous frontal dune & foredune ridges; Vegetation cover >75%	1
South West (SSW-WSW)	2	Discontinuous frontal dune & foredune ridges; Vegetation cover 50 -75%	2
North (NNW-NNE)	3	Partly scarped foredune Frontal dune vegetation cover 25-50%	3
North West (WNW-NNW)	4	Continuously scarped foredune Frontal dune vegetation cover <25%	4
West (WSW -WNW)	5	Frontal dune scarped OR mobile sand sheet OR no barrier	5
BARRIER (a) OR SAND BODY (b)		**BARRIER VEGETATION COVER**	
(a) Episodic, Transgressive Barrier OR (b) Perched dunes on supratidal or higher rock surface	1	Undisturbed dune sequence Fully vegetated (>75% cover on barrier)	1
(a) Prograded Barrier OR (b) Perched beaches on intertidal or lower rock surface	2	50 to 75% vegetation cover on barrier <25% active dunes or bare sand	2
(a) Stationary Barrier OR (b) Tombolo	3	25-50% vegetation cover on barrier 25-50% mobile dunes	3
(a) Receded Barrier OR (b) Salient & Cuspate foreland	4	<50% vegetation cover on barrier 50-75% active dunes or bare sand	4
(a) Mainland beach OR (b) Narrow spit or chenier	5	Mobile sand sheets <25% vegetation cover on barrier	5

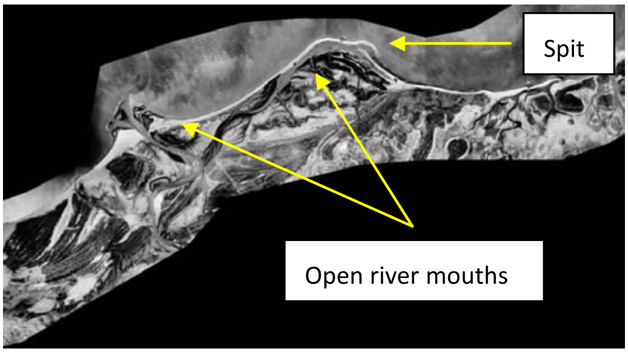
Together, the concepts of susceptibility and instability describe the *vulnerability* of coastal land systems and landforms to metocean change (Figure 2-4). Briefly, if current landform change is continued for long enough, exacerbated by natural changes in climate, or an extreme event occurs the land system on which the landform changes are taking place may reach a tipping point where the land system changes state. If a land system is susceptible to change it is highly likely that it is comprised or consists of or supports unstable, mobile landforms. For example a barrier system may be comprised of stable or unstable sand dunes where the current state of instability is evidenced by the proportion of the land surface under vegetation cover. Destabilisation of a barrier system on a stable coast may occur when barriers change from progradational to erosional forms as a result of prolonged loss of sediment from the coast (Roy *et al.* 1994; Hesp & Short 1999a; Masetti *et al.* 2008). Such large geomorphic changes have been modelled numerically, including modelling by Stive & de Vriend (1995), Cowell *et al.* (2003a, 2003b, 2006) and Stive *et al.* (2009).

The twin concepts of susceptibility and instability are linked by four key, interacting facets of the coastal environment: the geologic framework which supports the present landform systems; sediment compartments and cells in which the systems have developed; sediment supply to the cells and sediment accumulation or loss from the cells; and the resulting stability of landforms along the coast. These four components define large scale morphodynamic systems (Figure 2-5) and their interactions establish trends for changes occurring at all scales. Although linked by common metocean processes, coastal susceptibility and landform stability occur at disparate temporal and spatial scales; they have independent likelihoods of change and hence present different aspects of coastal vulnerability. These are combined in analysis ranking the vulnerability of different sections of coast, the compartments and cells.

Viewing metocean change and landform responses at a particular scale is a matter of convenience. In reality, the environment is dynamic at all scales with slower evolutionary changes providing a long-term context for faster responses to metocean forcing (Figure 2-6). Hence, metocean processes and landform change need to be considered at multiple scales. At the broadest evolutionary scale of coastal development it is pertinent to recall the vulnerability ranking for the overall Land System, which is likely to include finer, more detailed features having a very different ranking. The level of vulnerability estimated at any scale should be set in the context of coarser and finer assessments of landform susceptibility to the natural variability of metocean drivers and the current condition (instability) of the land surface. At this scale the responses of individual landforms or landform elements to metocean events is apparent. Each scale provides an indication of management pressures likely to accord to land-use *within each* <u>*whole cell*</u> at that scale relative to others in a series described for a region or administrative coastal area.

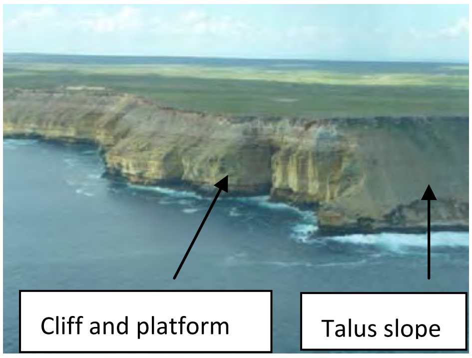


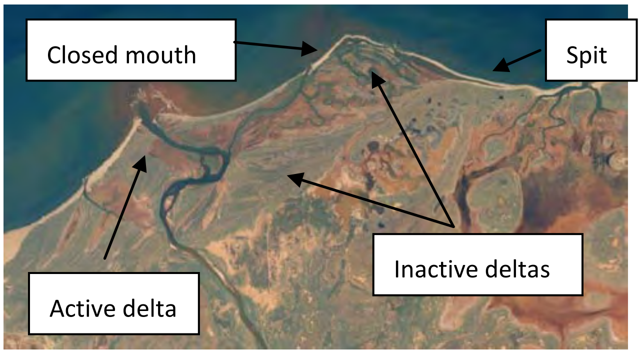




Above: Perched barrier and climbing dunes
Below: No barrier. Perched beach and old dunes

Above: Ashburton River Delta 1963
Below: Ashburton River Delta 2009





Incremental change: Gradual sediment loss from accretionary landforms such as beaches and foredune plains adjoining cliffs results in change to the natural structure including loss of the barrier and exposure of the cliff.

Extreme event: Sediment of deposited during flooding of the Ashburton River after 1963 closed the eastern mouth and formed an elongate spit extending eastward from the river mouth. Subsequent migration of the spit is apparent by 2009.

Figure 2-4: Instability, Susceptibility and Vulnerability

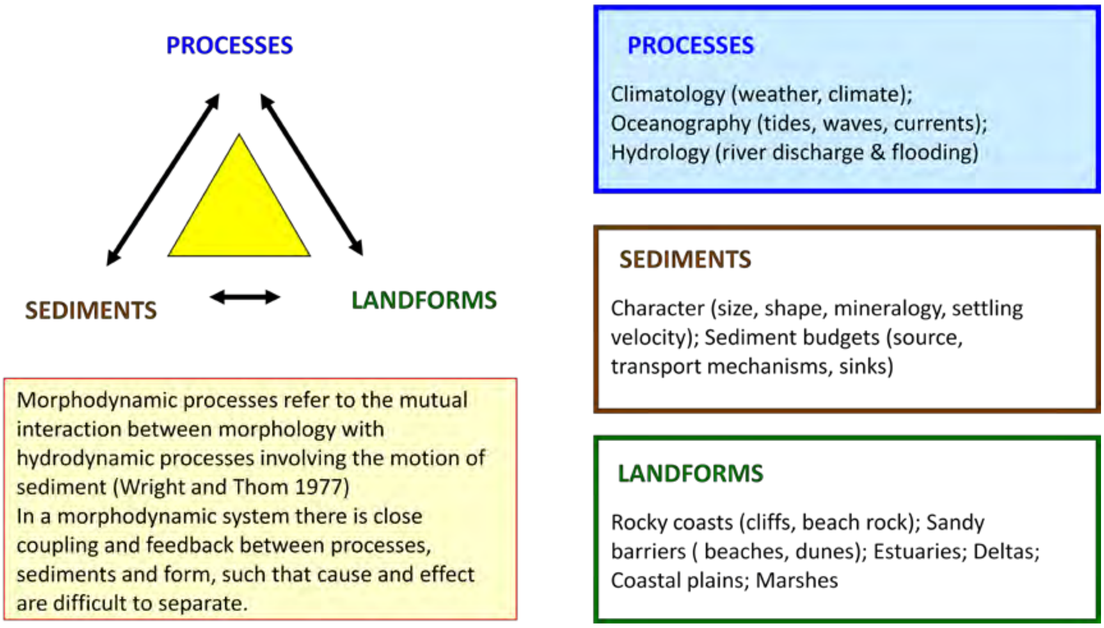


Figure 2-5: Components of a Morphodynamic System on a Sandy Coast

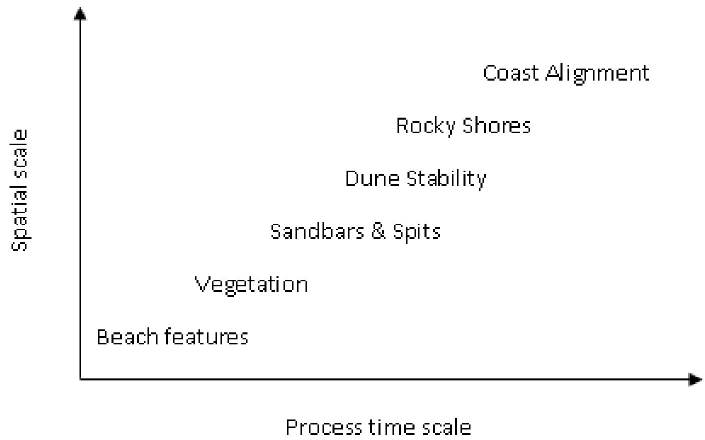


Figure 2-6: Scales of Coastal Change for Different Coastal Features

2.4.1. Land System Susceptibility

Estimation of the *susceptibility* of land systems to large-scale change in the natural structure is based on published descriptions of coastal evolution over the past 6,000 years; however the focus of the report is on large scale landform changes likely to occur over a planning horizon of 100 years. Some of these features for barrier systems are illustrated in Figure 2-7. The generalised morphology and stratigraphy of different types of coastal sand barriers in eastern Australia has been described by Roy *et al.* (1994) with a more complex conceptual model of southern Australian barriers presented by Short (1988). More recently, Hesp & Short (1999a) have described barriers attached to or overlying cliffs. The conceptual models of Roy *et al.* (1994) and Hesp & Short (1999a) are illustrated in Figure 2-7. In this report attached barriers are referred to as perched barriers and the typology extended to include barriers overlying rock pavement, platforms and irregular bedrock surfaces as well as cliffs. These forms commonly occur around the coast of Western Australia.

2.4.2. Landform Instability

Landform *instability r*efers to the current condition of the land surface and changes taking place over short to medium time scales; those commonly occurring at less than interdecadal frequency. For the purposes of this study stability is indicated by current evidence of erosion, particularly on unconsolidated sandy coast. Examples of different levels of stability on similar landforms are illustrated in Figure 2-8 and Figure 2-9. On coastal sand barriers the instability includes historical shoreline movement, foredune washover, foredune destruction, scarping of the foredunes and frontal dunes, gullying, slumping, blow-out activity and migration of mobile sandsheets. Hesp (1988, 2002) presented a conceptual model of recurrent foredune development, destruction and reformation (Figure 2-9) which he related to shoreface processes. His observations, with those of Short (1999) are built on an understanding of the interaction of inshore, beach and dune processes, in which short-term variation in coastal stability is both affected by and affects the long-term evolution of the coast.

2.5. ESTIMATION OF VULNERABILITY

In summary, steps to derive an estimate of vulnerability for each cell were as follows:

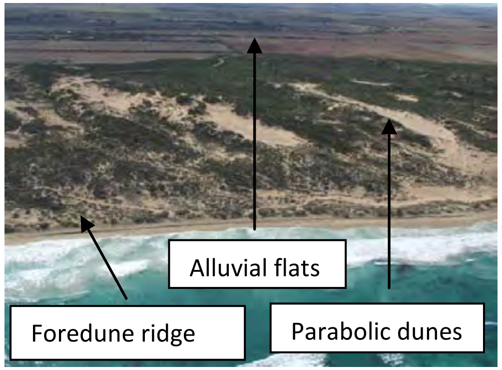
Step 1: Landform descriptions incorporating the criteria used to separately describe the susceptibility and instability of a cell were compiled for the inshore, beachface and backshore, as well as the shoreline. An example for Lancelin is provided in Table 2-7. Descriptions of landforms for each of the cells along the Gingin-Dandaragan coast are in Appendix D.

Step 2: A five point ranking was determined for each of the criteria used (Table 2-6);

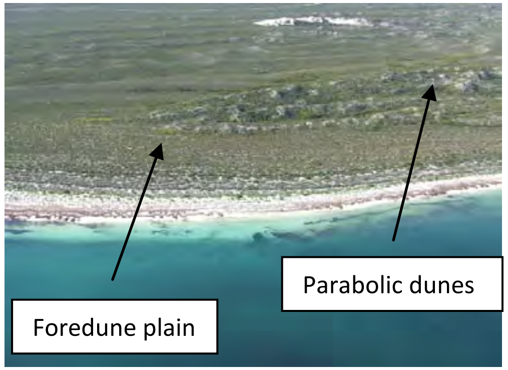
Step 3: The rank scores for the susceptibility and instability criteria were separately ordered into four zones (Table 2-8) and summed for each cell;

Step 4: The likelihood of geomorphic change in susceptibility or instability was assigned a likelihood rank of low, moderate or high, for total susceptibility or instability rank scores of 4 to 9, 10 to 14 and 15 to 20 respectively; and

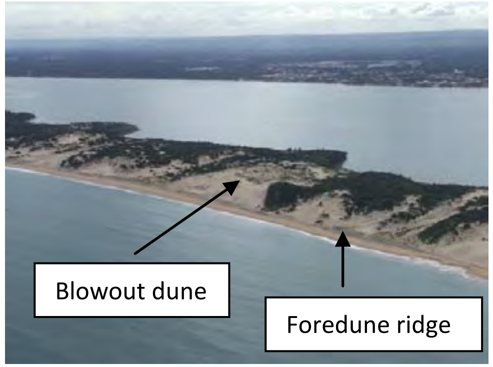
Step 5: The likelihood ranks were then combined to identify the indicative or relative vulnerability of each cell (Table 2-9). The steps used to combine the ranks are described in Section 2.6.



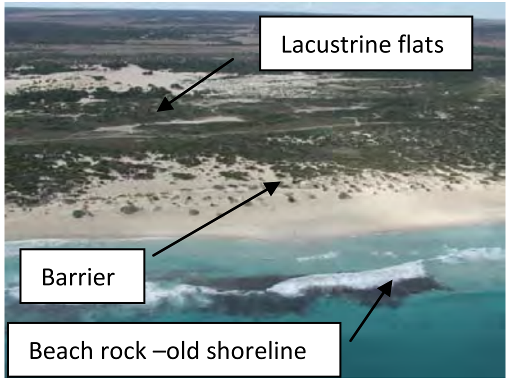
Rank 1: Episodic Transgressive Barrier
High ridge of nested blowouts and parabolic dunes. Here they abut and overlie alluvial flats.



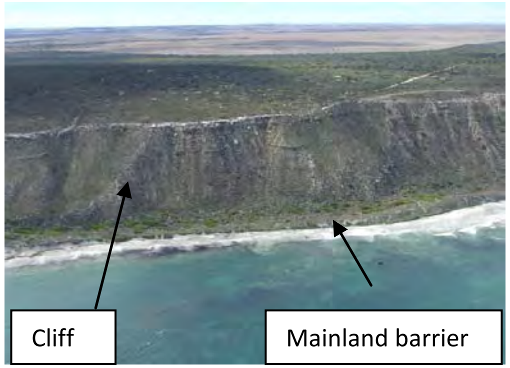
Rank 2: Prograded Barrier
Low plain comprised of foredune ridges. In this instance the plain abuts and older dune field.



Rank 3: Stationary Barrier
Low or narrow ridge of blowouts and parabolic dunes



Rank 4: Receded Barrier
Low narrow dune ridge with older sediments exposed along the shore.



Rank 5: Mainland Beach
Narrow foredunes and beach abutting bedrock. Dunes may not be present in some circumstances.

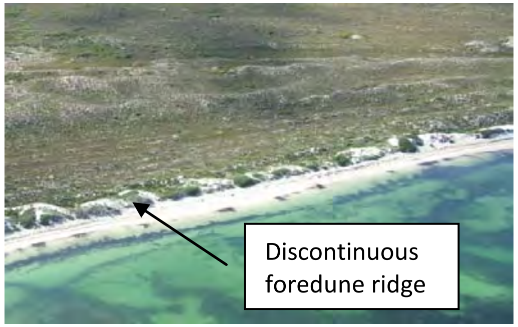
The *susceptibility* of a sandy barrier refers to the likelihood of the *natural structure* altering in response to projected changes in metocean conditions.

Barrier formation occurs over a long period, commonly millennia, although change in the natural structure from one type to another may occur within tens to hundreds of years.

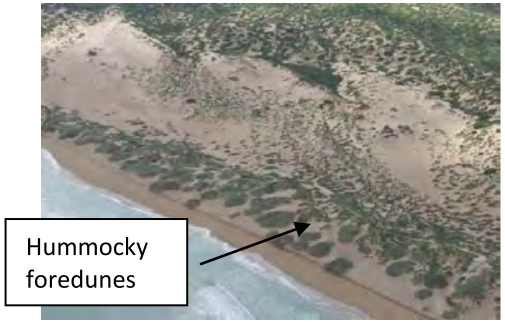
The sequence illustrated here broadly follows that described by Roy *et al* (1994)

Figure 2-7: Coastal Shoreface Structures, Land Systems and Susceptibility Rankings for Barrier Systems (After: Roy *et al.* 1994)

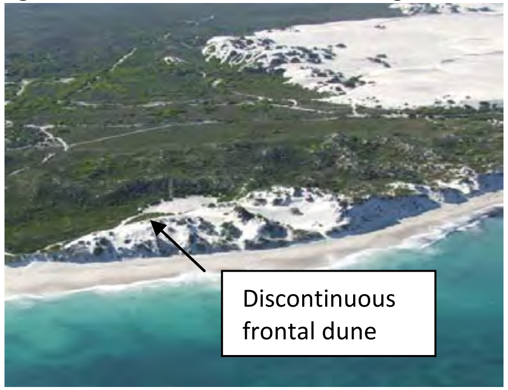
Rank 1: Continuous foredune and frontal dune ridges; Vegetation cover on the foredune ridge is >80%.



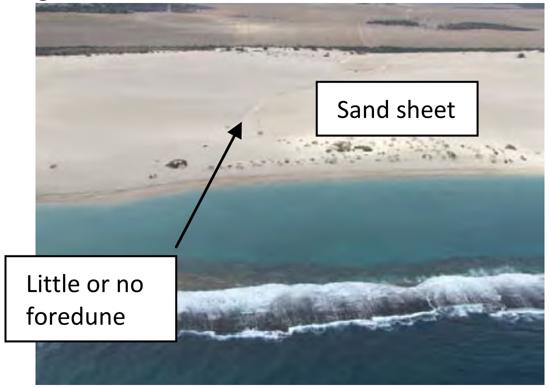
Rank 2: Discontinuous foredune ridge; small blowouts; vegetation cover on the foredune 50 to 75% cover.



Rank 3: Partly scarped foredune ridge: vegetation cover 25 to 50%; Small to moderate size blowouts



Rank 4: Continuously scarped foredune OR partly scarped frontal dune; vegetation cover <25%



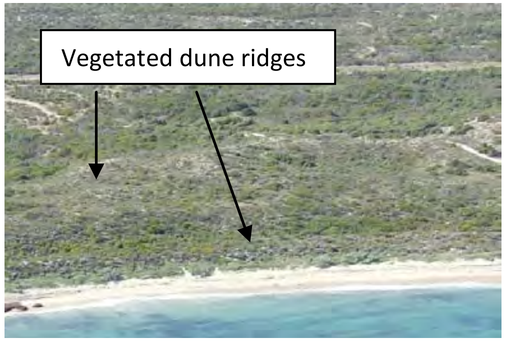
Rank 5: No foredune; scarped frontal dunes; beach directly connected to mobile sand sheet.

Estimates of *instability* are based on the land surface condition and the proportion of area in a compartment or cell that is currently bare sand or subject to erosion.

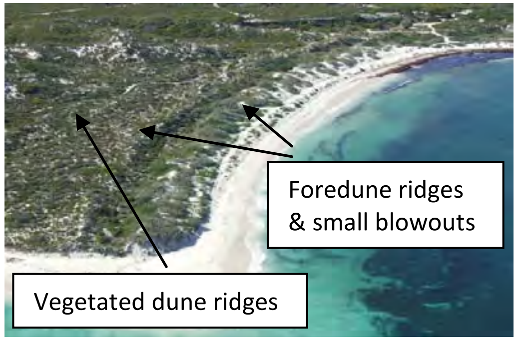
Destabilisation of dunes commonly occurs with destruction of a foredune, formation of blowouts and landward migration of the sand sheets, after which the foredune may reform. The quasi-cyclic changes take place in less than 50 to 100 years.

The ranked sequence illustrated follows the pattern of foredune destruction reported for Scarborough (Eliot & Clarke 1984) and elsewhere by Hesp (1988, 2002).

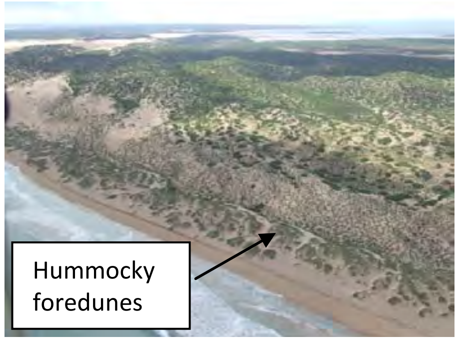
Figure 2-8: Stability of a Foredune-Frontal Dune Complex



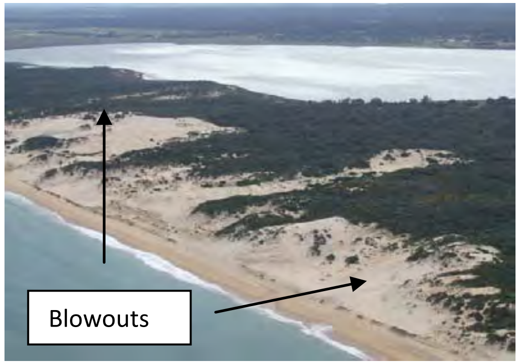
Rank 1: Gently undulating, continuous ridges of nested blowouts and parabolic dunes; Vegetation cover on the barrier is >75%.



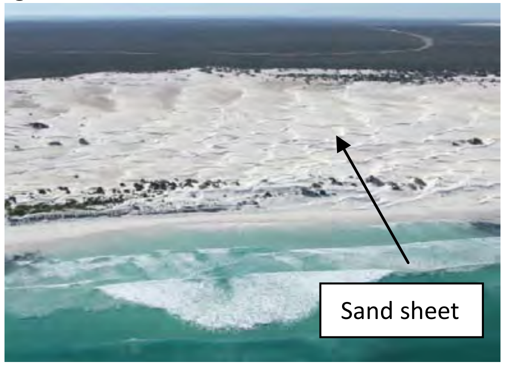
Rank 2: Complete ridges of nested blowouts and parabolic dunes with <25% active. Minor variation in vegetation cover on the barrier with >75% cover



Rank 3: Hummocky topography: 25 to 50% mobile dunes. Small to moderate size blowouts; Complete ridges of nested blowouts and parabolic dunes.



Rank 4: 50 to 75% active dunes or sand sheets
Active blowouts, parabolic dunes & sand sheets; diverse topography with 25 to 50% vegetation cover



Rank 5: Mobile sand sheets
Large blowouts, deflation basins, remnant knobs, & sand sheets; <25% vegetation cover on the barrier

Estimates of *instability* are based on the land surface condition and the proportion of area in a compartment or cell that is currently bare sand or subject to erosion.

Destabilisation of dunes occurs with destruction of a foredune, scarping of the frontal dunes or removal of the vegetation cover. The changes take place in a short period, commonly sub-decadally.

The sequence illustrated ranges from fully vegetated to active sand sheet without vegetation cover and broadly follows that described by Short (1988).

Figure 2-9: Dune Stability on an Episodic Transgressive Barrier

Table 2-7: Example of Landform Descriptions for Sediment Cells

Cell	S	N	INSHORE	SHORE	BACKSHORE
15	Lancelin Island	Dide Point	The offshore area has two ridges of intermittent reef extending parallel to the shore. Closer to shore limestone outcrops as intermittent reef.	The shoreline consists of four shallowly indented arcuate embayments formed by small salients landward of rock outcrops at Virgin Reef, Bob's Corner and Dide Point. The exposed WSW facing beaches have reflective to transitional morphologies.	An episodic, transgressive barrier approximately 3.5km wide overlies an older barrier complex. There is between 25 and 75% vegetation cover on the barrier with mobile sandsheets in southern and northern areas at the heads of parabolic dunes. The frontal dunes of the three southern embayments have <25% cover and are disturbed by ORV tracks. Vegetation in the northern embayment is between 25 and 75%. The frontal dune has been eroded.
14	Edward Island	Lancelin Island	The cell is enclosed by a nearly continuous reef between Edward Island and Lancelin Island. The limestone reef is approximately 1km off shore and encloses a shallow lagoon.	The shoreline is comprised two arcuate shallowly indented embayments facing W to WSW. The beach is continuous, and because of the reef, its morphology varies from sheltered flat beaches in the south, to reflective beaches in the north.	Mobile sand sheets from the parabolic dunes sourced to the south have migrated northwards across a low marl surface immediately seaward of the frontal dune complex. This in an area of rural urban development between the mobile sandsheet and the shore. Landward of the mobile dunes, the episodic, transgressive barrier has greater than 75% vegetation cover.

Table 2-8: Coastal Zones Used to Collate the Scores on Criteria for Ranking of Susceptibility and Instability

	SUSCEPTIBILITY	INSTABILITY
1	NEARSHORE MORPHOLOGY (Depth <25m)	INSHORE SUBSTRATE (Depth <5m)
2	SHORELINE CONFIGURATION	BEACHFACE MORPHOLOGY AND PROFILE
3	COASTAL ORIENTATION	FRONTAL DUNE COMPLEX
4	BARRIER OR SAND BODY	BARRIER VEGETATION COVER

Table 2-9: Cell Susceptibility, Instability and Vulnerability Ranking for Cells at Lancelin

Cell	Southern Boundary of Cell	Nearshore Morphology	Shoreline Configuration	Orientation	Barrier	Susceptibility Score	Susceptibility Ranking	Inshore Substrate	Beachface Profile	Frontal Dune	Barrier Vegetation	Instability Score	Instability Ranking	MATRIX SCORE	Vulnerability Ranking
15	Lancelin Island	4	4	5	4	17	**H**	3	4	4	3	14	**M**	4	**M-H**
14	Edward Island	1	3	5	4	13	**M**	3	2	2	5	12	**M**	3	**M**

2.6. INTERPRETATION OF VULNERABILITY RANKING

The susceptibility and instability rankings have been interpreted by combining the susceptibility and instability rankings for each compartment or cell as follows:

- First, the susceptibility value assigned to a compartment or cell provides an estimate of its natural structural integrity based on the developmental state of similar natural structures elsewhere. This enables comparative estimate of the likelihood of change over a 100 year planning horizon for compartments or cells within the coastal area of interest. The implications of the comparison in which the susceptibility of each compartment or cell is assigned a low, moderate or high likelihood of occurrence are shown in Table 2-10a.
- Second, landform instability is comparatively ranked according to the current state of the land surface in each compartment or cell, which provides an estimate of the likelihood of landform change within the next decade. Again, the estimates are assigned a low, moderate or high likelihood of occurrence and are shown in Table 2-10b.
- Third, for each compartment or cell the susceptibility and instability ranks are combined in a matrix in which the combined likelihood of short to long term changes provide a five-fold estimate of vulnerability (Figure 2-10). In turn the vulnerability rankings derived from the matrix have been interpreted as a combination of those for susceptibility and instability (Table 2-11).

Table 2-10: Recommended Consequences for Coastal Management

(a) SUSCEPTIBILITY (Long-term integrity of the natural structure)

Susceptibility Scores	Indicative Susceptibility	Site Implications
4 - 9	Low	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management.
10 – 14	Moderate	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.
15 - 20	High	Natural structural features are extensively unsound. Major engineering works are likely to be required.

(b) LANDFORM INSTABILITY (Current condition of the land surface)

Instability Scores	Indicative Instability	Site Implications
4 - 9	Low	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough).
10 - 14	Moderate	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).
15 - 20	High	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton).

SUSCEPTIBILITY (STRUCTURE) (Potential change to geological structure)			INSTABILITY (CONDITION) (Existing morphologic change to land surface)		
			Low (Stable)	**Moderate**	**High (Unstable)**
			Example		
	Low	**Barrier perched on extensive tracts of coastal limestone**	**(1) Vegetated swales in parabolic dunes landwards of a vegetated frontal dune ridge overlying coastal limestone above HWL**	**(2) Vegetated dunes landwards of a vegetated frontal dune ridge and perched on coastal limestone at HWL**	**(3) High foredune ridge and/or vegetated foredune plain overlying coastal limestone below HWL**
	Moderate	**Weakly lithified barrier with intermittent limestone outcrops**	**(2) Mainly vegetated swales in parabolic dunes landwards of a mainly vegetated frontal dune ridge**	**(3) Vegetated dunes landwards of a mainly vegetated frontal dune ridge (50 to 75% cover) and overlying coastal limestone**	**(4) Cliffed or discontinuous foredune fronting moderate numbers of mobile blowouts and sand sheets (<50% of the alongshore reach)**
	High	**Barrier comprised wholly of sand. No bedrock apparent along shore or in dunes**	**(3) Swales in parabolic dunes landwards of a partly vegetated frontal dune ridge**	**(4) Mainly vegetated dunes landwards of a partly vegetated frontal dune ridge with 25 to 50% cover**	**(5) No foredune. Eroded frontal dune with numerous mobile blowouts and sand sheets (>50% of the alongshore reach)**

KEY — **Combined estimate of vulnerability**

- Low
- Low-to-moderate
- Moderate
- Moderate-to-high
- High

Figure 2-10: Indicative Vulnerability Matrix for a Mixed Sandy and Rocky Coast Based on Combined Estimates of Risk for Susceptibility and Instability

Under the State Coastal Planning Policy (WAPC 2003) coastal planning is required to address potential hazards and risks associated with coastal erosion and landform instability. The risk to people and property arise from the hazards presented by coastal change, which in turn relates to the vulnerability of the coast. Interpretation of the vulnerability rank is indicated in Table 2-11 in which constraints indicated by the likelihood of coastal change are identified and the implications of vulnerability rankings for coastal management indicated.

Separating susceptibility and instability is a device to qualitatively examine overall coastal stability, herein defined for the purposes of the report as vulnerability. As they are applied in the report, the twin concepts identify disparate aspects of stability, both of which should be considered in coastal planning and management. Hence, the susceptibility of a geomorphic structure to change and its present instability condition should not be used separately in risk assessment. The various combinations of susceptibility and instability rankings to yield the five vulnerability ranks are listed in Table 2-12 together with their implications for coastal management and the degree of risk represented by each level of vulnerability.

Table 2-11: Implications and Recommendations for Vulnerability Rankings for Coastal Management

Vulnerability and Likelihood	Constraint	Site Specific Advice and Recommendations Relevant to Each Level of Vulnerability
Low Coastal risk is unlikely to be a constraint for coastal management.	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
Low-to-moderate Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate structural integrity or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
Moderate Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

Vulnerability and Likelihood	Constraint	Site Specific Advice and Recommendations Relevant to Each Level of Vulnerability
Moderate-to-high Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
High Coastal risk is a major constraint for coastal management.	The site has major constraints due to low integrity of natural structures, little natural resilience and high ongoing management requirements.	Development is not advised. It is recommended such land be set aside for the purpose of coastal protection and hazard mitigation. An exception to this recommendation is where large-scale infrastructure may require coastal access (eg. for marine-based industries, major harbours or port facilities). Detailed geotechnical investigation (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique), sediment budget analysis (approximate volumetric rates of sediment transport including sources and sinks) and numerical modelling (such as wave, current and sediment transport modelling to provide further context for the volumetric rates of sediment transport) are recommended as the basis for establishment of this infrastructure. A full hazard and risk assessment would be advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). It is recommended such development should not proceed without consideration of long-term management responsibility for coastal protection and stabilisation works, as well as for ongoing maintenance and management of the site. Required stabilisation works should be identified and costed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Where development proceeds outside of the recommendation, compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

Table 2-12: Combining the Coastal Rankings and Implications for Coastal Management

See Appendix E for Each Cell. Susceptibility and Instability Rankings should not be used Independently. Other combinations of Susceptibility and Instability may result in Moderate Vulnerability, but do not occur in the Study Area

No.	S	Susceptibility		Instability		Vulnerability			
			Implications		Implications		Constraint	Implications	Coastal Planning and Management Recommendations
32	Pumpkin Hollow	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough).	L	Coastal risk is unlikely to be a constraint to coastal management	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
31	Middle Head	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	L-M	Coastal risk may present a low constraint to coastal management	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate structural integrity or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
35	Sandy Point	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough).				
25	Hansen Head	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	M	Coastal risk may present a moderate constraint to coastal management	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
15	Lancelin Island	H	Natural structural features are extensively unsound. Major engineering works are likely to be required.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	M-H	Coastal risk is likely to be a significant constraint to coastal management	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
19	Wedge Island	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton).				
No cells were ranked as high vulnerability for the Gingin-Dandaragan coast.		H	Natural structural features are extensively unsound. Major engineering works are likely to be required.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton).	H	Coastal risk is a major constraint to coastal management	The site has major constraints due to low integrity of natural structures, little natural resilience and high ongoing management requirements.	Development is not advised. It is recommended such land be set aside for the purpose of coastal protection and hazard mitigation. An exception to this recommendation is where large-scale infrastructure may require coastal access (eg. for marine-based industries, major harbours or port facilities). Detailed geotechnical investigation (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique), sediment budget analysis (approximate volumetric rates of sediment transport including sources and sinks) and numerical modelling (such as wave, current and sediment transport modelling to provide further context for the volumetric rates of sediment transport) are recommended as the basis for establishment of this infrastructure. A full hazard and risk assessment would be advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). It is recommended such development should not proceed without consideration of long-term management responsibility for coastal protection and stabilisation works, as well as for ongoing maintenance and management of the site. Required stabilisation works should be identified and costed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Where development proceeds outside of the recommendation, compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

3. Regional Context: Land Systems and Landforms

The hierarchy of compartments used to identify planning units generally accords with the terrestrial land systems described by van Gool *et al.* (2005) for soils in the agricultural areas of Western Australia. In this report, provinces are approximately equivalent to WA coastal regions; zones to primary compartments; land systems to secondary compartments; landform to tertiary compartments and sediment cells; and landform elements to sediment cells (Figure 3-1). At each scale an individual compartment has landform associations and processes that distinguish it from its neighbouring compartments. However, within each of the three primary compartments the scales are dynamically linked by common morphology, processes and sediments and comprise a single morphodynamic system (Figure 3-2).

Impacts of environmental change at any level potentially may affect the whole system depending on the extent and intensity of change and the time over which it operates. Ramifications of this are that it is advisable to holistically consider potential impacts of a proposed development at a land system level first, scaling down to sediment cells and individual landforms as finer detail is required. Coastal susceptibility to environmental change is critical at a primary and secondary compartment scale. Conversely, the condition or stability of landforms is most relevant to investigation of tertiary compartments and sediment cells, the latter of which have been investigated here.

In both contexts, an objective of this report is to indicate the principal geologic, geomorphic and metocean factors contributing to the relative vulnerability of sediment cells along the coast and further develop the applications listed in Table 2-4 by integrating the marine and terrestrial components of the land system. This is the rationale underlying consideration of nearshore features in assessing coastal vulnerability (Table 2-6).

At a broad provincial scale, the temperate-zone coast of the shires of Gingin and Dandaragan is within the South West Coast Province and is subject to a Mediterranean to semi-arid climate (Figure 3-2). The province is affected by a variety of weather systems commonly including anticyclonic high pressure systems, extra-tropical cyclones, mid-latitude depressions and strong seabreezes (Section 4). It extends from Cape Leeuwin to the mouth of the Murchison River at Kalbarri and encompasses the Perth Basin (Playford *et al*. 1976).

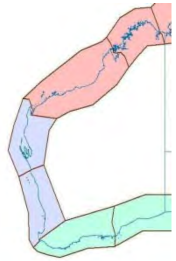
3.1. THE GEOLOGIC FRAMEWORK

At all scales, the geologic framework is a significant attribute of the Study Area. It is a primary determinant of the susceptibility of the coast to change through its interaction with marine processes and by provision of a foundation to the more recently formed Holocene landforms. At a secondary compartment level, or more detailed scale, tracts of coast may have landforms comprised of unconsolidated sandy sediments that overlie, or are perched, on a near continuous limestone surface well above present sea level. However the rock basement, particularly that formed by the coastal limestone, is uneven in planform, hardness, elevation and depth below the unconsolidated sands. There is considerable diversity in the limestone topography and hence diversity in the susceptibility of the coast to change due to metocean forcing. The variability can be addressed in the planning process by a requirement for geotechnical or geophysical investigations in areas where they are

1

Zones: Broad sectors of the Australian continent based on climate

2

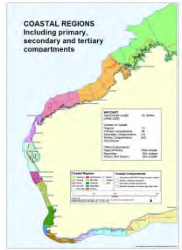


Divisions: Provides an overview of the whole state suitable for maps at scales of about 1:5,000,000

3

Provinces: Areas defined on geomorphologic or geological criteria suitable for regional perspectives at scales of about 1:1,000,000

4

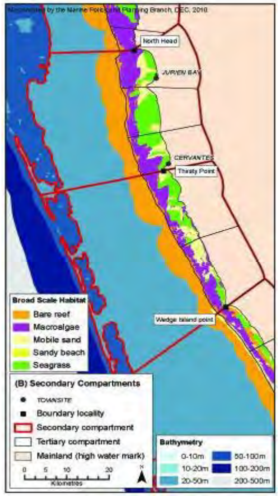


Regions: Areas with recurring patterns of landform and geology suitable for regional mapping at scales of approximately 1:250,000

5

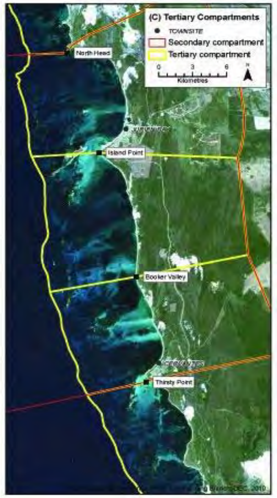
Land Systems (1):
Areas of characteristic landform patterns suitable for mapping at regional scales of 1:100,000 to 1:250,000.

6



Land Systems (2):
Areas of characteristic landform patterns suitable for mapping at regional scales of 1:50,000 to 1:100,000

7



Landforms (1): A local unit based on one or more definite landforms suitable for mapping at scales of about 1:25,000 to 1:50,000

8

Landforms (2): A local unit based on one or more definite landforms suitable for mapping at scales of about 1:10,000 to 1:25,000

Figure 3-1: Coastal Land Systems Hierarchy

justified by the value of proposed development or the need to protect existing infrastructure close to the shore.

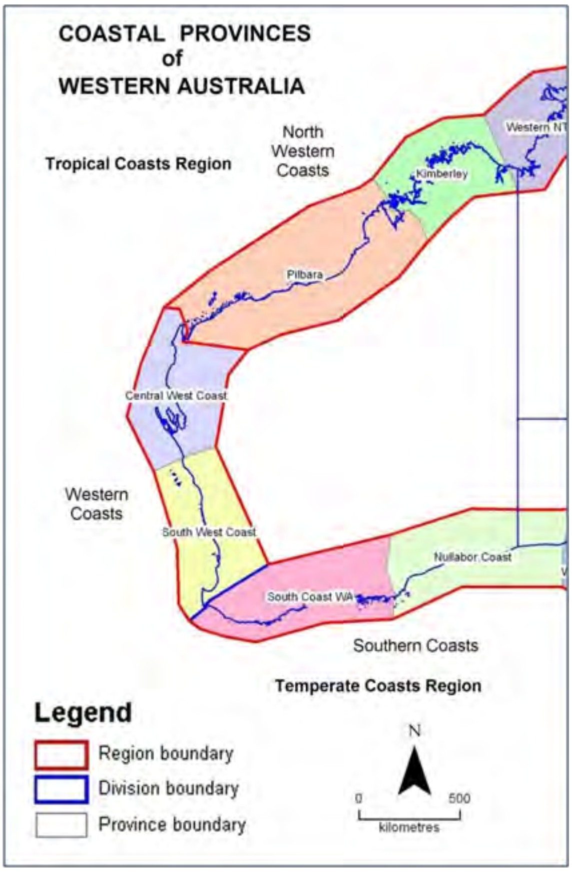


Figure 3-2: Coastal Provinces in Western Australia

Cleary *et al*. (1996: 250) stressed the role the inherited geologic framework plays in determining shoreface dynamics, dynamics of the area in which wave energy is mostly expended; the evolution of coastal sediment cells; and the development and morphology of unconsolidated accretionary landforms such as barriers and cuspate forelands. They pointed out that:

> *"…coastlines with limited sand supplies are also significantly influenced by the geological framework occurring underneath and seaward of the shoreface. For example, many US east coast barrier islands are perched on premodern sediments. The stratigraphic section underlying these perched barriers commonly controls the three-dimensional morphology of the shoreface and strongly influences modern beach dynamics, as well as sediment composition and sediment fluxes.*
>
> *First, perched barriers consist of thin and variable layers of surficial beach sands on top of older, eroding, stratigraphic units with highly variable compositions and geometries. Depending upon composition, the underlying platforms can act as a submarine headland forcing different responses to shoreface dynamics that will dictate the nature of the shoreface profile. Stratigraphically controlled shorefaces are often composed of compact muds, limestones, or sandstones.*

Such lithologies exhibit a greater effect upon both the planform of barriers and morphology of the shoreface than those composed of unconsolidated materials. Second, along many parts of the inner shelf, bathymetric features that occur modify incoming energy regimes, affecting the patterns of erosion, transport, and deposition on the adjacent shorelines."

Their observations are applicable to most of the coast of Western Australia. The observations are particularly relevant to the Gingin-Dandaragan coast because a large proportion of the coastal lands in the Study Area constitute Holocene dune barriers that overlie, or are perched on an irregular limestone platform of older Quaternary origin. The underlying limestone topography provides a topographic framework in which the coast is developing. Its interaction with sandy sediment and coastal processes is fundamental to the manner in which the coast has evolved and will continue to develop. It also determines the susceptibility of the coast to future environmental change.

At a local scale the nearshore ridges and depressions of the limestone on the shoreface, seaward to approximately 35metres below present sea level, extend under the modern beach and dunes and have a significant effect on beach responses to storms and inshore processes. Cleary *et al*. (1996) pointed out that limited data exists on the interrelationships between the underlying geological framework and the morphology, sediments and evolution of coastal systems, although the wave and current dynamics of the shoreface determine how the adjacent shoreline and beach will respond to storms, and ultimately to the effects of rising sea level. Since then McNinch & Drake (2001) have described the influences of underlying geology on nearshore and shoreline processes in the United States. Their observations have been supported by List *et al*. (2002) through evaluation of the persistence of shoreline change hotspots along the northern coast of North Carolina; and by Bender & Dean (2002) in a review of wave field modification by bathymetric anomalies and resulting shoreline changes.

Understanding the processes and three-dimensional geologic framework that govern the shoreface characteristics is vital to determining the behaviour of beaches. It is an especially important consideration in the context of this report for two reasons: Firstly, Clearly *et al*. (1996) and others (Pilkey *et al*. 1993; Cooper & Pilkey 2004) have argued it negates application of the Bruun Rule (Bruun 1983, 1988), which has been widely applied in the calculation of setback to development on mixed sandy and rocky coast in Western Australia (WAPC 2003). Secondly, Silvester (1974), Hsu & Evans (1989) and Sanderson (2000) have discussed the roles of shoreface topography in determining the plan shape of beaches and the development of cuspate forelands. Their observations indicate it may be useful to consider the probable responses of specific coastal landforms to changing metocean processes as a more appropriate means of assessing potential coastal responses to projected environmental change in sea level or climate given that Bruun (1983) stated similar reservations with the application of his model.

3.1.1. Geology

The geologic units of the Gingin-Dandaragan coast are part of a belt 6 to 15km wide, and have been assigned to the Safety Bay Sand (Quindalup Dune System) and Tamala Limestone

(Spearwood Dune System). The Tamala Limestone (Playford *et al.* 1976) consists of medium- to coarse-grained calcarenite and variable amounts of quartz sand. It was deposited in the middle to late Pleistocene as successive lines of coastal sand dunes. Extensive quartz sand covers the Tamala Limestone and is a residual deposit resulting from rain water solution of the calcarenite.

Along the Gingin-Dandaragan coast the inshore seabed, beaches and dunes are comprised mainly of unconsolidated sediments of the Quindalup geological system, principally carbonate sands of Holocene age. These abut and commonly overlie older marine and aeolian sediments including the Tamala Limestone of the Spearwood System (Geological Survey of Western Australia 2000) which forms the structural framework of the coast (Searle & Semeniuk 1985).

The Safety Bay Sand (Lowry 1974) comprises a series of parabolic dunes and relict foredune plains (cuspate forelands) in a belt adjacent to the coast and extends inland over the Tamala Limestone. The dunes are Holocene in age and derived entirely from a Holocene source with little, if any, carbonate derived from the underlying Tamala Limestone.

3.2. SEDIMENT SUPPLY

Regional coastal processes (Section 4.2) describe the potential for sediment transport to occur on the coast, without accounting for the availability of sediment and the connectivity of sediment pathways between landforms. The concept of sediment supply and availability is included in the assessment of vulnerability through the four categories for Instability (Table 2-6). There is alongshore variability within a sediment cell, with localised sources and sinks that fluctuate in capacity and function over time, including pulsational sediment supply from rivers (Section 4.2.5). The volume of available sediment is constrained by the geologic inheritance, for example, the restricted freely available sediment on beaches underlay by rock (perched beaches–Section 4.3.5) and cliffed coasts. The primary sources and sinks of sediment to the coastal landforms are listed in Table 3-1.

Table 3-1: Sediment Sources and Sinks
(After: Bowen & Inman 1966; van Rijn 1998)

Source	Sink
Biogenic deposition (e.g. from seagrass banks)	River mouth bars, deltas and alluvial landforms
Reworking of cliffs, beach rock, ridges and reefs	Dunes and sand sheets via aeolian transport
Longshore transport into the area from beaches and inshore areas	Offshore transport into inshore areas
Wind transport onto the beach offshore from the foredunes and transport along the beach	Offshore transport into lagoons and gaps within the reef structure; and submarine canyons.
River floods (including mobilisation of bar, alluvial and inshore sediments)	Longshore transport out of the area
Onshore transport	Solution and abrasion
Beach nourishment	All the above categories

Landforms are connected by sediment transport pathways, and any modification to sediment transport or sediment availability is likely to have an impact on the coast. The future stability of a landform is often dependent on any updrift interference with sediment transport and stabilisation approaches, along with natural variability and changes to metocean processes. Sediment transport interference, such as the installation of a harbour facility, could result in updrift sediment starvation of the beach and inshore, which in turn starves the frontal dune, primary dune and barrier. If an eroding dune is stabilised with revegetation; or as a dune grows or forms a blowout, this can result in sediment loss for the downdrift coast. The instability of the coast is considered with regard to the available sediment, including the vegetation coverage of the dune and barrier, with considerations of landform connectivity required when assessing future instability.

Much of the unconsolidated sediment of the Gingin-Dandaragan coast is calcareous Quindalup sand, but it includes quartzose sediment from erosion of sand banks and dunes as well as weathering and erosion of the Tamala Limestone. The calcareous component is largely skeletal, shell material recently produced in seagrass meadows and algal communities of reefs. To a lesser extent, some sediment is derived from terrestrial sources and transported to the coast intermittently by the two streams discharging onto the coast; the Moore River and Hill River. Sediment movement in the micro-tidal environment is affected by prevailing SW swell and seas driven by the major weather systems, particularly by strong sea breezes. Sandy sediments form the active sand lens of the shoreface, the area in which waves move sediment, extends in a thickening wedge from its seaward limit in waters over 30m deep to the frontal dunes along the landward margin of the beach. There it abuts a rocky coast or, more commonly, merges with the dunes to form a barrier, a ridge of dunes, between marine and terrestrial processes.

3.3. MAJOR LANDFORM ASSOCIATIONS

At all scales the structure and formation of landform is tied to the nearshore reef systems of the Gingin-Dandaragan coast. The bedrock outcrops of the nearshore waters and coast comprise a geologic framework consisting of a series of Pleistocene limestone features of marine and terrestrial origin which outcrop as islands, approximately shore-parallel reefs, rock platforms and cliffs. The alongshore variability of the reef structure of the Gingin-Dandaragan coast is summarised at a secondary compartment scale in Table 3-2, described in further detail in Appendix D and classified in the vulnerability assessment in Section 5. It is demonstrated visually in Figure 1-1 and in the Department of Transport and Australian Navy Navigation Charts, Geoscience Australia bathymetry and survey records.

3.3.1. Nearshore Morphology: Reefs and Sand Banks

The influence of changing metocean conditions on coastal sheltering provides an over-riding control on coastal landform change. Hence, the influence of reef structure on inshore metocean processes is included in the assessment of vulnerability through the *Nearshore Morphology* category for Susceptibility and *Inshore Substrate* category for Instability (Table 2-6). *Nearshore Morphology* classes the highest susceptibility rate for coastlines without reef and the lowest susceptibility for a continuous reef and lagoon. The three rankings in between incorporate concepts of varying reef continuity and structure (Figure 3-3). *Inshore Substrate* classes the most unstable inshore areas as those without any rock outcropping and the most stable as those with almost continuous rock cover or hard rock that has a high resistance to erosion (Figure 3-4).

The proximity of rock to the coast and its surface structure (width, depth, roughness and gaps) modify the local metocean processes in the lee of the reefs and islands (McNinch 2004; Silvester & Hsu 1993). Along the Gingin-Dandaragan coast water level, waves and currents interact with outcrops of coastal limestone to modify the inshore processes, including sediment transport and water circulation patterns (D'Adamo & Monty 1997). The coastal processes are discussed in Section 4.

Sediment availability and transport, and therefore the stability of the coast, is affected by the nature of the inshore substrate. Hence the morphology of the inshore substrate is included in the assessment of vulnerability largely through the *Inshore Substrate* category for Instability (Table 2-6). A hard rock substrate close to the surface of the seabed is unlikely to carry much available sediment for transport and is therefore the most stable. However, sediment is likely to be transported across such surfaces. Conversely bare sand surfaces are unstable and commonly show evidence of active transport, such as sand ripples.

Table 3-2: General Reef Structure of the Secondary Compartments

Boundaries	General reef structure
North Head to Fisherman Islands (Northern Boundary is Green Head)	The seabed of the inshore waters comprises intermittent reef, inshore pavement and platforms and unconsolidated sediments. Coastal limestone outcrops as platform and pavement at the shore around a number of headlands. A narrow reef chain widens northwards from North Head. The reef structure changes north of Fisherman Islands, to the north of the study area.
Thirsty Point to North Head	Discontinuous approximately N-S aligned reefs outcrop off Thirsty Point. The coast has a general N-S alignment north of Coffins rock outcrop, partially due to a change in the seaward facing trend of the 20m isobath from SW to W. Intermittent limestone reef is present, with deepening in areas potentially associated with marine extensions of historic Hill River flows. Large sedimentary accumulation forms are present in the lee of islands.
Wedge Island to Thirsty Point	Outcrops of coastal limestone are present along much of this coast. An initially continuous limestone ridge diverges from the coast with distance north to Thirsty Point, with superimposed N-S ridges of increased dominance with distance north.
Ledge Point to Wedge Island	Discontinuous nearshore reefs, lumps and islands are the dominant geological control, with a decrease in influence of the offshore ridge system compared to adjacent compartments.
Moore River to Ledge Point	Two discontinuous reefs outcrop offshore. The two largest breaks in the reef are associated with the nearshore marine extension of Moore River (S) and the outcrop of the groundwater discharge of the Moore River flow into Lake Karrakin (N).
Wreck Point to Moore River (Southern Boundary is Pinnaroo Point)	Continuous nearshore reef extends north of Wreck Point running approximately parallel to the N-S trend of the shore.

3.3.2. The Shore: Shoreline Shape, Beaches and Rocky Coasts

The vulnerability of landforms along the shore, including the frontal dune complex (foredunes and frontal dunes) and barrier system, to changes in metocean forcing is dependent on sediment supply, shoreline configuration and orientation, beach type and presence of rock (Table 2-6). Their susceptibility is related to coastal aspect and shoreline configuration; and instability to the type of beach and frontal dune characteristics.

Coastal aspect, or the direction to seaward the coast faces, determines the prevailing and dominant metocean processes to which it is susceptible. In the present analysis coastal aspect is included in the assessment of vulnerability through the *Coastal Orientation* category for Susceptibility (Table 2-6). It is considered in relation to the exposure to major storms. *Coastal Orientation* has the highest susceptibility ranking for cells exposed to the west and lowest susceptibility for cells exposed to the south (Figure 3-3). However, this is a classification of the aspect of the majority of the sediment cell and neglects localised variability within a cell. Additionally, large shifts in aspect generally coincide with coastal compartment boundaries.

Susceptibility of the barrier and shoreline configuration increases with reduced geological control. This has been included in the assessment of vulnerability through the *Shoreline Configuration* and *Barrier* categories for Susceptibility (Table 2-6). Cuspate forelands and tombolos have the highest susceptibility of any shoreline configuration, followed by salients (Figure 3-3). Conversely, the least susceptible shoreline configuration is a straight, uninterrupted coast; however, this can be the most unstable. The vulnerability ranking for a cell may not account for the cuspate foreland or salient as these landforms are often located on the cell boundaries and do not represent the majority of the shoreline configuration within the cell. Each cuspate foreland or tombolo should be considered separately to the adjacent cells as it will often be more vulnerable to future environmental change.

Several different types of beach are recognised in the literature including sheltered and estuarine beaches (Nordstrom 1992; Jackson *et al.* 2002) and exposed, wave-dominated beaches (Wright & Short 1984; Short 2005). Beach stability has been included in the assessment of vulnerability through the *Beachface Morphology and Profile* category for Instability (Table 2-6). Instability rankings for these types have been ordered according to the degree of wave exposure, with the most unstable beaches exposed to the highest wave energy (Figure 3-4).

Perched beaches are common features of the Gingin-Dandaragan coast, as they are for much of the shore of the Swan Coastal Plain, but are not widely described in the literature (Green 2008; Doucette 2009). They are included in the assessment of vulnerability partly through the *Nearshore* and *Barrier* categories for Susceptibility and partly though the *Inshore Substrate* and *Frontal Dune* categories for Instability (Table 2-6). Susceptibility of the barrier and inshore increases with reduced geological control. However, perched beaches can occur on a smaller spatial scale than the sediment cell and should be considered in any local assessment.

3.3.3. Onshore Landforms: Barriers, Dunes and Rivers

Formation of a barrier is a response to large-scale, long-term processes associated with changes in sea level sweeping the inner continental shelf during a rise in sea level over the Holocene, the past 6 to 8,000 years. The response is continuing at present. Rogers (1996) recognised three phases of barrier development from the Mid-West coast of WA and this may be similar for the Gingin-Dandaragan coast. The phases are likely to be related to inter-decadal fluctuations in storminess, sea level and the wave regime, as well as pulsational sediment supply along the coast as well as an intermittent supply from the rivers. Such low-frequency changes are difficult to determine from the comparatively short, available historical records of coastal change although they may be apparent in the stratigraphic record.

Processes underlying barrier formation and the diversity of landforms associated with them have been widely discussed; for example see reviews by Roy *et al.* (1994), Hesp & Short (1999a) and Masetti *et al.* (2008). In a seaward sequence the main barrier features match those of a retrograding coastal sand barrier comprising active and inactive parabolic dunes and/or foredune ridges as well as the beach and shoreface as described by Cowell & Thom (1994) and Hesp & Short (1999a). The barrier systems of the study area include the large episodic transgressive dune fields between Ledge Point and Kangaroo Point that forms the major onshore sediment sink in the province. Other barrier systems include foredunes plains that have developed landwards of calcarenite reef and islets as cuspate forelands and tombolos (Sanderson & Eliot 1996) or as narrow plains adjoining eroded dunes and infilling an embayment between headlands; for example the cuspate foreland at Island Point, Jurien Bay (Woods 1983b; Sanderson 2000) and the narrow foredune plain on the southern flank of Kangaroo Point.

The susceptibility of barriers to change is a function of barrier type and size. Following the nomenclature of Roy *et al.* (1994), the largest and least susceptible to change are episodic transgressive barriers which have undergone phases of dune activity leading to development of a dune ridge through the formation of foredunes, blowouts and nested parabolic sand dunes as the ridge migrates landwards. The most susceptible to change due to metocean forcing are mainland barriers where a thin wedge of sand abuts rocky coast. However, there are differences between the Australian East and West Coasts. The principal distinction is that dunes forming the WA barriers commonly overlie the coastal limestone and therefore are comparatively less susceptible to structural change due to metocean forcing. Hence Roy *et al.* (1994)'s model is combined with the degree to which the barrier system is affected by the geological framework to determine its susceptibility to change through the *Barrier or Sand Body* category for Susceptibility (Table 2-6; Figure 2-7). In the Study Area the least susceptible barriers are either large episodic transgressive barriers or barriers perched on high rock surfaces (Figure 2-7; Figure 3-3). The most susceptible to change are mainland beaches or unconsolidated spits and cheniers.

The stability of barriers and dunes is included through the *Frontal Dune Complex* and *Barrier Vegetation Cover* categories for Instability (Table 2-6; Figure 2-8 & Figure 2-9). Under extreme onshore wind conditions barriers migrate landwards. The proportion of vegetation cover on the barrier, as a whole, is an indication of its surface stability. Similarly, vegetation cover on the foredunes and frontal dunes is also an indication of their stability. Additionally, scarping of the foredunes and frontal dunes is evidence of shoreline movement and possibly erosion. Hence, the degree to which a foredune is developed or the seaward margin of the frontal dune is cliffed provides an indication of the stability of the frontal dune complex (Figure 2-8 & Figure 3-4).

Rivers are associated with mobile landforms and modify the supply of sediment to the coast. The most unstable coasts are identified as those with barred river mouths in the *Beachface Morphology and Profile* category for Instability (Table 2-6). The Hill and Moore Rivers have barred mouths which may alternately trap or release sediment at the coast. During significant runoff flooding, sediment may be released from the bar, beach and inshore areas in the path of the river flow. In addition sediment can also be supplied to the coastal system from the banks and bed of the alluvial channel. After a scour event, the scoured channel and inshore area will act to trap sediment until the bar has reformed, then becoming a feature that can be bypassed by alongshore sediment transport. While the bar is acting as a trap, it can potentially starve the downdrift coast until the bar is reformed and fully bypassing.

3.3.4. Ranking Susceptibility and Instability for Different Beach Zones

The ranked likelihood of susceptibility and instability for the nearshore, beachface, frontal dune complex and backshore zones are illustrated for barrier systems on a mixed sandy and rocky coast (Figure 3-3 & Figure 3-4).

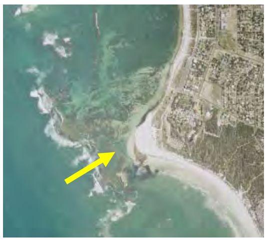
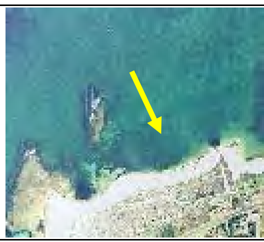
LAND SYSTEM	SUSCEPTIBILITY TO CHANGE		
Component	**Low**	**Moderate**	**High**
Nearshore Topography			
	Continuous offshore reef OR Shallow lagoon, rock platform or sand bank	Shallow intermittent reef OR Broken pavement (Depth <10m).	Unconsolidated sediments in bare sand OR Seagrass banks
Shoreline Configuration			
	Straight or seawardly convex rocky coast OR Made beaches	Arcuate or zeta form, deeply indented	Cuspate forelands and tombolos
Coastal Orientation			
	Coast faces southerly quadrant (SSE to SSW) and is subject to prevailing swell and sea breezes	Coast faces northerly quadrant (NNW to NNE) and is subject to NW storms and refracted storm waves	Coast faces westerly quadrant (WSW to WNW) and is subject to dominant storms
Barrier Type and/or Sand Body			
	Episodic transgressive barrier OR Perched dunes on a supratidal or higher rock surface	Stationary barrier OR Tombolo	Mainland beach adjacent cliff OR Narrow spit or chenier

Figure 3-3: Landform Associations and their Susceptibility to Changing Metocean Conditions

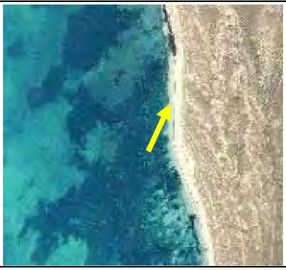
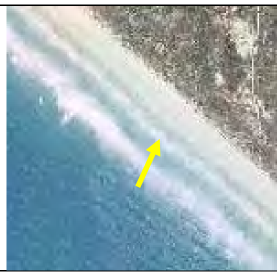
LANDFORM	**RELATIVE INSTABILITY**		
	Low	**Moderate**	**High**
Inshore Substrate			
	A high proportion (>75%) of shallow reef OR Pavement outcrops close to shore	Moderate (25 to 50%) proportion of reef OR Pavement near shore	Bare sand in water depths less than 5m close to shore
Beachface and/or Profile			
	Narrow, sheltered beach with a planar (flat) OR Segmented profile	Exposed beach with a wide berm and steep, reflective profile	Exposed, dissipative beach with multiple lines of breakers and rip currents
Frontal Dune Complex			
	A continuous, well-vegetated foredune ridge is located along the backshore of the beach.	The foredune ridge is discontinuous and comprised of a series of dune hummocks.	The foredune is absent and cliffing of the frontal dune is apparent along the beach backshore
Barrier Vegetation Cover			
	Broad, well-vegetated barrier in the lee of offshore structures and shallow inshore reefs	Moderately-wide and high dune field. Unknown depth to the limestone basement away from headlands	Narrow barrier with active dunes and/or sparse vegetation cover. Unknown depth to the limestone basement

Figure 3-4: Landform Associations and their Relative Instability

4. Coastal Processes

This section documents the available information on metocean forcing and some of the key factors which should be considered in further site-specific coastal processes investigations

Coastal processes are active over all time scales simultaneously. Care is required to ensure the process of change is not inappropriately identified due to confined use of one or two concepts of change (refer to Section 4.4). Hence the hierarchy of geomorphic features, from landscape elements to mega-landforms and based upon spatial and temporal variability (Figure 2-6) has been used as an aid to identify active processes likely to determine the stability of the coast for the Shires of Gingin and Dandaragan.

The metocean forcing is reviewed using wind, water level, wave, rainfall and discharge datasets (Figure 4-1). The variability and influence of these processes are described at a regional scale in Section 4.2 with local scale influences on sediment transport in Section 4.3.

- Meteorologic conditions contributing to the wind, wave and nearshore current regimes have been considered from stations at Rottnest, Lancelin, Jurien Bay and Geraldton (Table 4-4). Particular reference is made to extreme weather events likely to generate storm surge or significant aeolian transport for dune formation;
- Tides and surges are described from water level records from Fremantle and Geraldton (Table 4-5). Water level records have not been presented for Two Rocks, Lancelin and Jurien Bay, as there is limited alongshore variation in the water level record between Fremantle and Geraldton;
- Descriptions of offshore wave conditions have been derived from waverider buoys off Rottnest, Jurien Bay and Geraldton (Table 4-8). Further information on the transformation of waves across reef systems is included using two simultaneous deployments offshore and inshore of the reef at Moore River in 1988 to 1989; and four deployments of an acoustic wave and current meter at Ledge Point in 2003 to 2004, coinciding with an offshore waverider buoy from 2002 to 2004; and
- The influence of the two main river systems of the area on the coast is described using rainfall and discharge datasets for the Moore and Hill Rivers (Table 4-10).

The specific information used has been detailed in each section.

4.1. IDENTIFYING KEY METOCEAN PROCESSES

Coastal and landform instability may result from a range or combination of multiple processes, over differing time and spatial scales (Komar & Enfield 1987; de Vriend *et al*. 1993; Masetti *et al*. 2008). The sensitivity to different processes varies between landforms, such that consideration of a limited set of processes may yield highly variable performance when projecting possible change. Consequently, it is necessary to consider a full range of active processes and identify those which most significantly influence the landforms of interest. Such an evaluation may need to consider how processes may interact. An example is provided by dune development, which requires coincidence of sediment supply, onshore winds and vegetation growth (Hesp & Short 1999b).

The National Committee on Coastal and Ocean Engineering (NCCOE 2004) has suggested climate change assessment should be undertaken using a sensitivity framework to reduce the likelihood that poorly understood or modelled processes are neglected (NCCOE 2004; Abuodha & Woodroffe 2006). The framework suggests examining the sensitivity of the existing system to a suite of possible mechanisms, listed according to environmental (K1-K6) and process (S1-S13) variables (Table 4-1). By identifying the processes which are large amplitude or frequent, and to which the local system is most responsive, the focus for management may be highlighted.

It is noted that the aspect being evaluated (coastal and landform stability) includes the secondary variable foreshore stability (S9), which has therefore been neglected. Other parameters of ocean currents/ temperatures (K2), air temperature (K6), effects on structures (S5), estuary hydraulics (S11), quality of coastal waters (S12) and ecology (S13) have been neglected due to their limited relevance to the site.

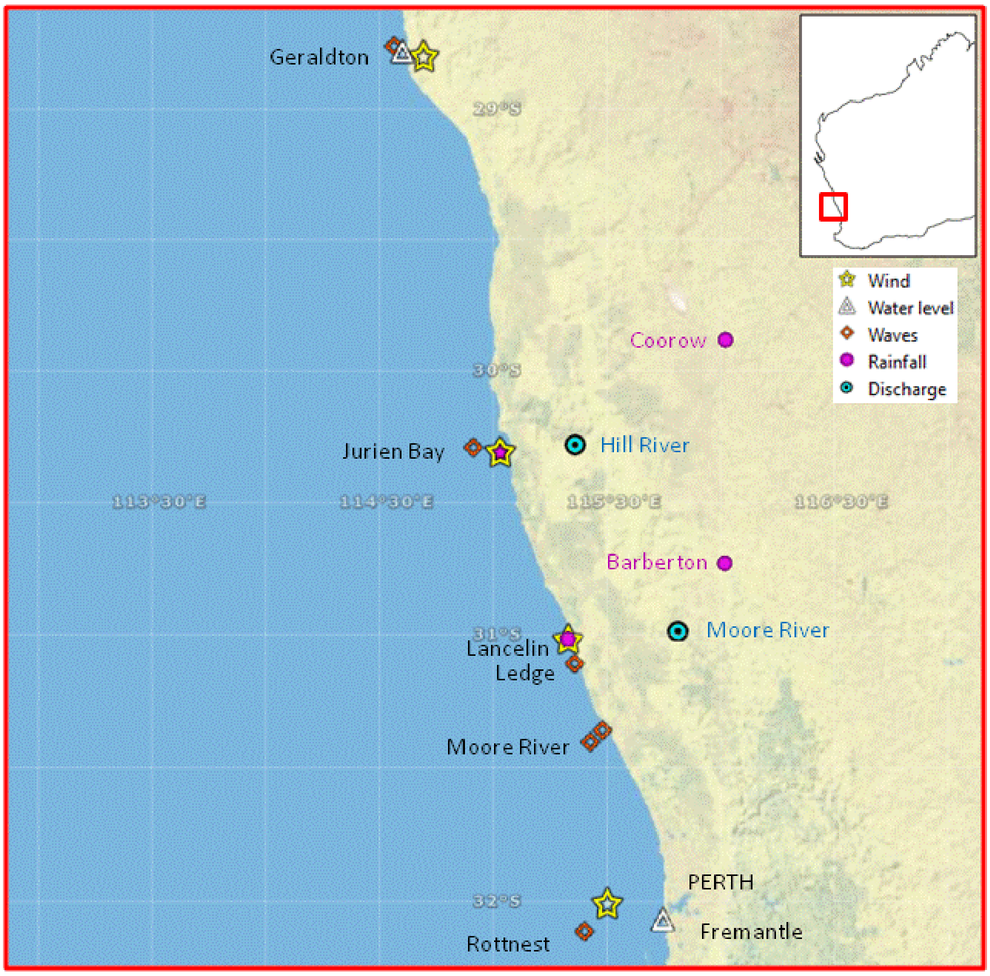


Figure 4-1: Monitoring Stations
(Image Source: esri World Physical Map)

Within the Gingin-Dandaragan coast, the structure and formation of landform units (beaches, dunes and coastal barriers) are strongly tied to the presence and formation of nearshore reef systems. Specifically, the presence or absence of such reefs provides wave sheltering or exposure that controls the development of cuspate forelands, tombolos and embayments (Sanderson & Eliot 1996). The over-riding control on coastal landform change is the influence of coastal sheltering combined with changing environmental conditions

(Box 4-1), and therefore an assessment of nearshore reef structure has been applied as a primary indicator of coastal sensitivity.

Table 4-1: Primary and Secondary Coastal Variables (NCCOE 2004)

Primary Variables	Secondary Variables		
K1 – Mean Sea Level	S1 – Local Sea Level	S8 – Beach Response	
K2 – Ocean Currents/ Temperatures	S2 – Local Currents	S9 – Foreshore Stability	
	S3 – Local Winds	S10 – Sediment Transport	
K3 – Wind Climate	S4 – Local Waves	S11 – Hydraulics of Estuaries	
K4 – Wave Climate	S5 – Effects on Structures	S12 – Quality of Coastal Waters	
K5 – Rainfall / Runoff	S6 – Groundwater	S13 – Ecology	
K6 – Air Temperature	S7 – Coastal Flooding		= Limited Relevance

In addition to the coastal sensitivity caused by shelf structure, reef sheltering or exposure, there is considerable further variation within the sequence of landform units progressing shoreward (Table 4-2). The examples of a sandy coast are included in Table 4-2.

Table 4-2: Sensitivity of Landform Units to Environmental Parameters

Zone / Parameter	Beach	Foredune	Primary Dune	Barrier System
K1 – Mean Sea Level	High	High	Medium	Low
K3 – Wind Climate	Low	Medium	High	Medium
K4 – Wave Climate	High	Medium	Low	Low
K5 – Rainfall / Runoff	N/A	Medium	Medium	Low
S1 – Local Sea Level	High	High	Medium	Low
S2 – Local Currents	Medium	Low	N/A	N/A
S3 – Local Winds	Low	High	High	Medium
S4 – Local Waves	High	Medium	Low	Low
S6 – Groundwater	Medium	Low	Medium	Medium
S7 – Coastal Flooding	High	Medium	Medium	Low
S8 – Beach Response	High	Medium	Low	Low
S9 – Foreshore Stability	High	High	High	Medium
S10 – Sediment Transport	High	High	Medium	Low

For this study, the relative importance of different processes has been considered with respect to the landform units described in Section 2.3. In general terms, there is a progression in time scales from rapid response at the beach scale, through to gradual, slow change for the barrier system as a whole (de Vriend *et al*. 1993; Cowell & Thom 1994).

Box 4-1: Nearshore Sheltering

The present-day influence of nearshore reef and island systems upon the coast is indicated by the convoluted natural structure of the coast that has evolved over the late Holocene (Sanderson 2000). However, these features are not anticipated to respond uniformly to changing environmental conditions (Semeniuk 1996b). Complex swell diffraction and refraction patterns through the discontinuous and degrading reef system and around islands is superimposed on wind-driven circulation in the lagoons and locally generated wind waves, causing sediment accumulation skewed to the direction of longshore transport (Sanderson 2000).

Islands sustain a variety of landforms in their lee, including tombolos, with the landforms susceptible to changes in water level and wave climate. Islands provide a barrier to wave transmission, with a wave shadow formed in the lee, compared to the adjacent coast. Shore perpendicular sand banks have formed in the lee of islands and some shallow reefs, with waves refracting across shallow features.

The reefs and associated lagoons of the Gingin-Dandaragan coast provide varied sheltering of the adjacent coast. The degree of shelter is largely dependent on the surface structure of the rock, including the degree of reef continuity, width and depths, along with the offshore distance of the reef structures (Sanderson & Eliot 1996).

Potential response of the coast to future changes in water level and wave climate, including direction, will not be uniform due to the varied reef, island and lagoon structures; and may include landform migration and retreat.

This general and simplified sensitivity assessment has been developed by Damara WA on the basis of geology and geomorphology in the region, and does not represent a comprehensive analysis of the coast.

When defining development constraints and opportunities, it is essential that planners and foreshore managers comprehend and make allowance for the combined effects of geomorphic evolution, natural climate fluctuations, Greenhouse-induced climate change and other anthropogenic changes that may affect foreshores, including active coastal management, or land use change. In many cases, it is pressures introduced by multiple sources of change that create ongoing management issues.

The frequency of coastal flooding, tidal cycles, inter-annual sea level fluctuations and vertical land movements must be considered when evaluating relative change in sea level. Increases in mean sea level due to El Nino / La Nina phase, plus a 19-year tidal cycle, have caused a dramatic increase in the number of coastal flooding events over the period 1993 to 2003. These are not directly related to Greenhouse-induced climate change (Pattiaratchi & Eliot 2008; Eliot 2011).

4.2. REGIONAL SCALE

The Gingin-Dandaragan coast is located approximately between latitudes 30^{o} 07' S and 31^{o} 30'S on the west-facing coast of Australia. It experiences a variable, sometimes high-energy, wave climate as measured offshore from Rottnest (Department of Transport: DoT 2009) with a similar climate recorded, but unreported at Jurien Bay. Wave generation occurs principally over the extended fetch of the southern Indian Ocean, providing a background swell that is comparatively slowly varying, which combines with highly variable locally generated wind waves. Prevailing swell is south to southwest, generated from mid-latitude synoptic systems, with increased west through northwest activity during winter months (Roncevich *et al.* 2009).

Elevated wave conditions are associated with a range of synoptic events, which may vary in latitude, intensity, frequency and mobility (Karelsky 1961; Steedman & Craig 1983; Trenberth 1991). The aspect common to these events is the occurrence of onshore winds, although direction may vary from southwest to northwest (Panizza 1983). Applying this characteristic, a measure of storminess has previously been established for the period 1962-1980 using winds from Fremantle (Steedman & Associates 1982).

4.2.1. Meteorology

The Gingin-Dandaragan coast region, including Jurien Bay and Lancelin, experiences a Mediterranean climate (Gentilli 1971, 1972), with mild wet winters and hot, dry summers. The region lies within the southern half of the extra-tropical ridge and is dominated in summer by eastward travelling high pressure systems, within 26^{o}S to 45^{o}S, which cross the coast every 3 to 10 days (Gentilli 1972). During winter, a northward movement of the pressure belts allows the impact of mid-latitude low-pressure systems from latitudes 35^{o}S to 50^{o}S to increase, through fronts or more direct synoptic winds systems. The influence of tropical systems is rare, although it may be significant, as amply illustrated by the impact of TC Alby in April 1978 and the 'storm of the century' in 1956 (Henfrey 1968).

Climate summaries from the Bureau of Meteorology for Rottnest, Lancelin, Jurien Bay and Geraldton describe the seasonal ambient variations (Figure 4-2; station information in Figure 4-1 and Table 4-4). The land-sea breeze cycle dominates the prevailing winds of the region, particularly over summer, with moderate easterly winds in the morning and stronger (up to 15 m/s) southerly sea breezes commencing around noon and weakening during the night. The sea breeze formation is similar to that reported for the Perth region (Pattiaratchi *et al.* 1997; Masselink & Pattiaratchi 1998): these southerly sea breezes blow almost sub-parallel to the northerly trend of the coastline; their onset is rapid, initial velocities are relatively high, and surface currents respond almost instantaneously. The sea breeze may occur in all seasons, although it is most frequent and intense during summer months.

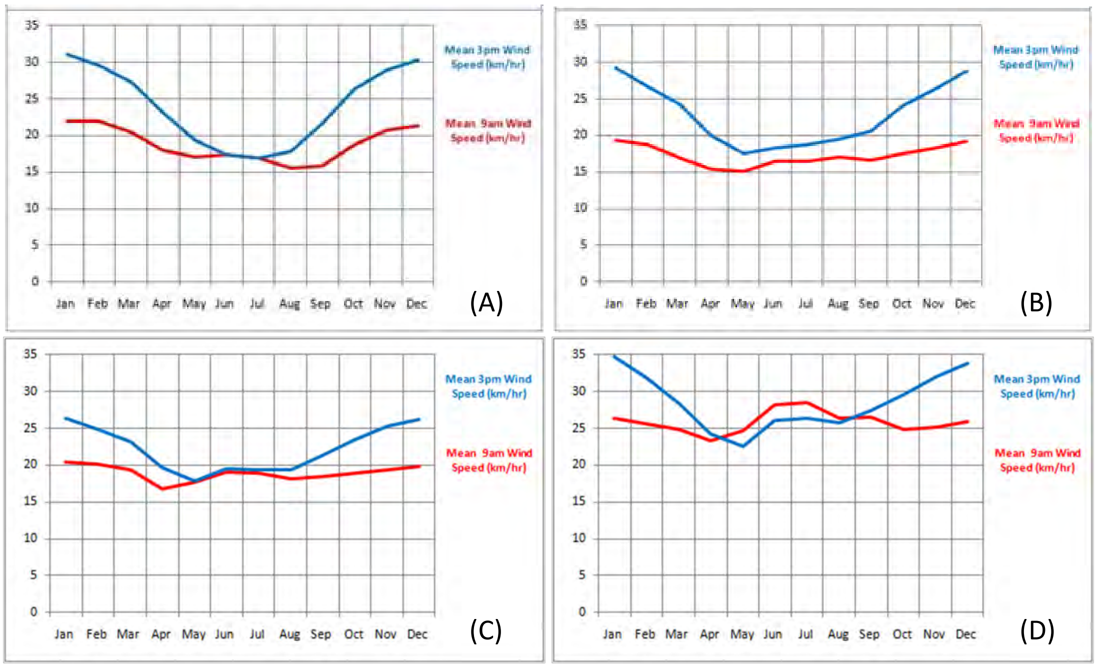


Figure 4-2: Mean Monthly 9am and 3pm Wind Speeds (A) Geraldton, (B) Jurien Bay, (C) Lancelin and (D) Rottnest (Source: Bureau of Meteorology)

4.2.1.1. Weather systems

The average wind speed, direction, duration, extremes and event frequency for the major weather systems experienced on the Perth Metropolitan Coast have been summarised by Stul (2005) and are listed in Table 4-3. It is expected that these will be similar for the Gingin-Dandaragan coast, although with marginal deviations in strength and direction of winds. An example of this is the shift in the prevailing seabreeze wind direction from SSW at Rottnest and Lancelin to S at Jurien Bay and Geraldton; however, this is a potential artefact of topographic and geographic influences on meteorologic stations (Section 4.2.1.3).

Table 4-3: Major Local Weather Systems

Weather System	**Anticyclones**	**Squalls**	**Mid-latitude Depressions**	**Dissipating Tropical Cyclones**	**Sea Breezes**
Occurrence	Annual	Dec – Apr	May – Oct	Oct – Mar	Oct – Mar (mainly)
Average Wind Speed	Light	15-20 m/s	15-29 m/s	15-25 m/s	10 m/s
Average Duration	Unknown	2-4 hours	10-55 hours	5-15 hours	~7 hours
Average Wind Direction	All	All	N to NW to W to SW	Depends on path	180-200^{o}
Frequency	3-10 days	13 days	3-8 / year	1 in 10 years	>15 days/month
References	Gentilli 1972	Steedman 1982	Gentilli 1972; Steedman 1982	Gentilli 1972; Steedman 1982	Pattiaratchi *et al*. 1997

4.2.1.2. *Storm events*

Sustained high winds in the Gingin-Dandaragan coast have similar synoptic origins to those experienced in the southwest. Consequently, the same nomenclature may be applied, (following Steedman & Associates 1982; Steedman & Craig 1983) which distinguishes between five sources:

1. Dissipating Tropical Cyclones
2. Sea Breezes
3. Extra-tropical Cyclones
4. Pre-frontal Troughs
5. Cold Fronts

Notably the last three sources of sustained high winds above are all caused by mid-latitude depressions, although the mechanism for wind generation is different, due to the relative dominance of radial geostrophic winds, pressure gradient intensification (generally longitudinal) and thermal gradients.

For the Gingin-Dandaragan coast, sea breezes provide a significant baseline of moderate strength, but not extreme winds. Consequently, they are recognised to play a significant role in ambient coastal forcing (Pattiaratchi *et al.* 1997). The intensity and direction of the sea breeze is influenced by the shape and orientation of the coast, surface friction and synoptic pressure patterns, including the location of the approximately north-south aligned trough (Figure 4-3; Pattiaratchi *et al.* 1997; Bureau of Meteorology 1998). The summer sea breeze pattern may be suppressed when the trough is located offshore.

Mid-latitude storm events are the most common source of extreme winds, generally occurring between May and September. A typical storm event is associated with an intense low pressure system location southwest of Australia, such that its clockwise rotation provides onshore winds (Figure 4-4). These storm systems commonly provide winds from the westerly half, often swinging from the northwest through to the southwest, with the peak winds speeds dependent upon the system location, path and thermal structure.

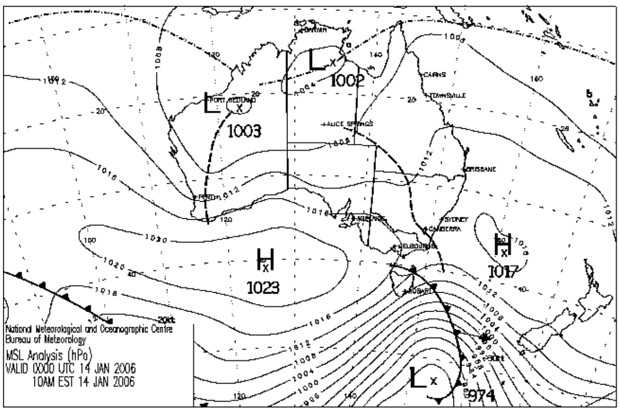


Figure 4-3: Common Summer Synoptic Conditions with Trough

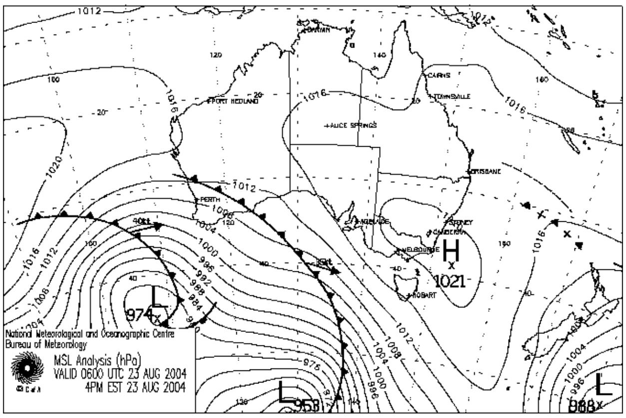


Figure 4-4: Common Winter Synoptic Conditions

The greatest observed wind conditions are associated with tropical cyclones, which represent very occasional extreme wind conditions, affecting the Central Coast Region approximately once every five to ten years. These may produce strong winds in any direction due to their intense radial structure, but most commonly are passing southwards offshore, and hence produce northeast winds, swinging through to northwest, westerly and southwest winds.

The most well-known storm events are the most unusual, or those in recent memory. These include storms in April 1978 (TC Alby), June 1996, May 2003, August 2005 (Coastal Engineering Solutions: CES 2005) and March 2011 (TC Bianca).

4.2.1.3. Winds

Four long-term wind observation stations near to the Gingin-Dandaragan coast are at Rottnest Island, Lancelin, Jurien Bay and Geraldton (Figure 4-1; Table 4-4). The longest set of observations is at Geraldton Port, since 1907, with automated recording of wind data only occurring from 1965 through the Bureau of Meteorology. The location of the Geraldton station moved inland to the airport from the port in 1953 and Rottnest Island station was relocated in 1987. The records contain a velocity scale change in 1960 at Geraldton and 1970 at Lancelin with increasing directional accuracy from 22.5° bands to the nearest degree.

Recorded winds are affected by geography, topography and instrument height, and need to be interpreted with these factors in mind. Of the stations considered here, Rottnest is on an island (43.1m elevation), Lancelin is on a southwest facing coast (4m), Jurien Bay is within northwest facing dunes (1.6m) and Geraldton is located 7.5km inland (33m). Variation of median and strong wind speeds suggest that site location is significant with Rottnest Island higher than the other three stations considered at Lancelin, Jurien Bay and Geraldton (Table 4-4). Maximum observed wind speeds do not show the same pattern, but this is typical for extreme conditions (Table 4-4).

Across all stations the dominant wind directions are NE in the morning and S to SSW in the afternoon, the latter indicating the significance of sea breezes in the region (Figure 4-5). The 3pm wind speed distribution plots demonstrate an apparent shift in the prevailing sea breeze direction from SSW at Rottnest and Lancelin to S at Jurien Bay and Geraldton (Figure 4-5). The signal of the shift in the prevailing sea breeze direction is dampened by the station locations, with a shift from an island to inland with distance from south to north. The shift in the sea breeze direction and dominance is demonstrated by the landforms with a shift to a more N-S alignment of the dunes, blowouts and sandsheets to the north of Wedge Island (between Lancelin and Jurien Bay), compared to the NW-SE alignment further south (Appendix C).

The direction shift in the sea breeze modifies the: local wind-wave climate (sea); longshore rates of sediment transport; aeolian (wind-driven) transport of sediment from beaches to the dunes; orientation and likelihood of dune blowouts; and landform alignment. This southerly shift in the winds with distance northwards should be considered in the alignment of coastal access and the proximity of development to migrating sandsheets.

Table 4-4: Wind Observations for the Gingin-Dandaragan Coast (Source: Bureau of Meteorology) Note change in velocity scale in 1960 at Geraldton and in 1970 at Lancelin

Station	Location	Lat. (S)	Long. (E)	Height (m)	Dates	50% Wind (km/hr)	90% Wind (km/hr)	Max Obs. (km/hr)
8051	Geraldton Airport	28.795°	114.698°	33	1941-2010	16.6	33.5	101.9
8050	Geraldton Port (not included herein)	N/A	N/A	3	1907-1953	15.5	24.1	117.7
9131	Jurien Bay	30.308°	115.031°	1.6	1969-2010	14.8	33.5	140.8
9114	Lancelin	31.016°	115.330°	4	1965-2010	18.4	31.7	87.1
9193	Rottnest Island	32.007°	115.502°	43.1	1987-2010	25.9	42.5	114.8
9038	Rottnest Is. Lighthouse (not included herein)	N/A	N/A	46	1965-1995	25.9	37.1	83.5

Wind observations at Rottnest, Jurien Bay and Geraldton over the period of record have shown considerable interannual variability, in keeping with assessments of storminess for the Perth metropolitan region (Steedman & Associates 1982; Panizza 1983). Annual summations of the 9am wind speed cardinal components (E-W and N-S) have been used to examine whether there are any apparent patterns of change or standout years (Figure 4-6). The 9am wind indicates the prevailing winds with limited influence of the seabreeze.

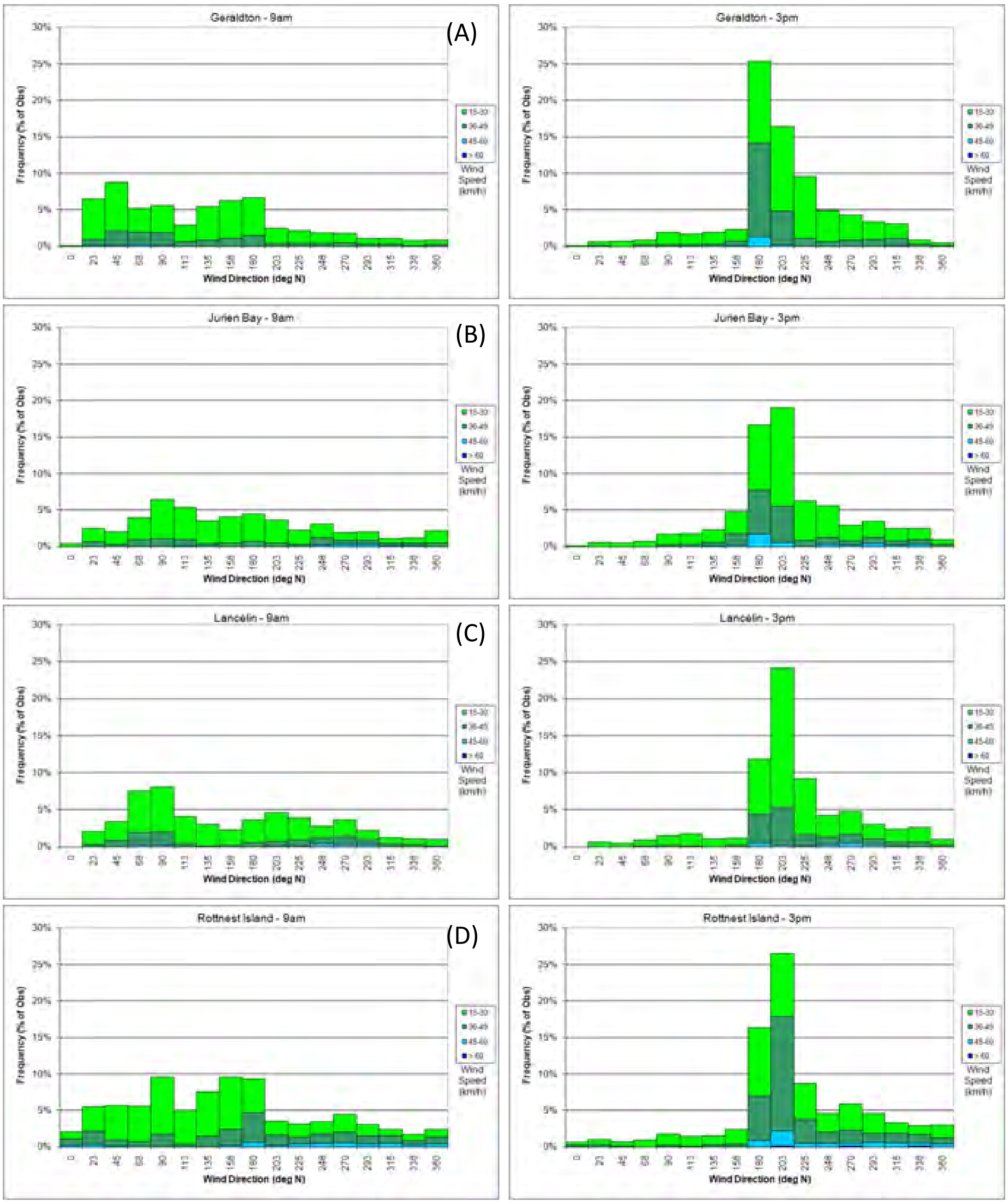


Figure 4-5: Wind speed and direction frequencies for 9am and 3pm (A) Geraldton; (B) Jurien Bay, (C) Lancelin and (D) Rottnest (Source: Bureau of Meteorology)

Figure 4-6 shows the nett annual easterly and northerly drifts at Rottnest, Jurien Bay and Geraldton stations. Periods where different weather stations have been used at Rottnest are marked by a vertical line. The Rottnest observations are partitioned by this break, suggesting a difference between sites. There are limited patterns of change apparent in the record. The inland Geraldton station didn't record the same variability in easterlies as Jurien Bay or the recent Rottnest recordings, which showed some years with a stronger westerly component and weaker southerly components. Winds at Geraldton have had an increased southerly dominance since the 1960s, not reflected in the Jurien Bay record since the mid 1990s. Jurien Bay demonstrated a period of stronger southerlies from the mid 1970s to mid 1990s.

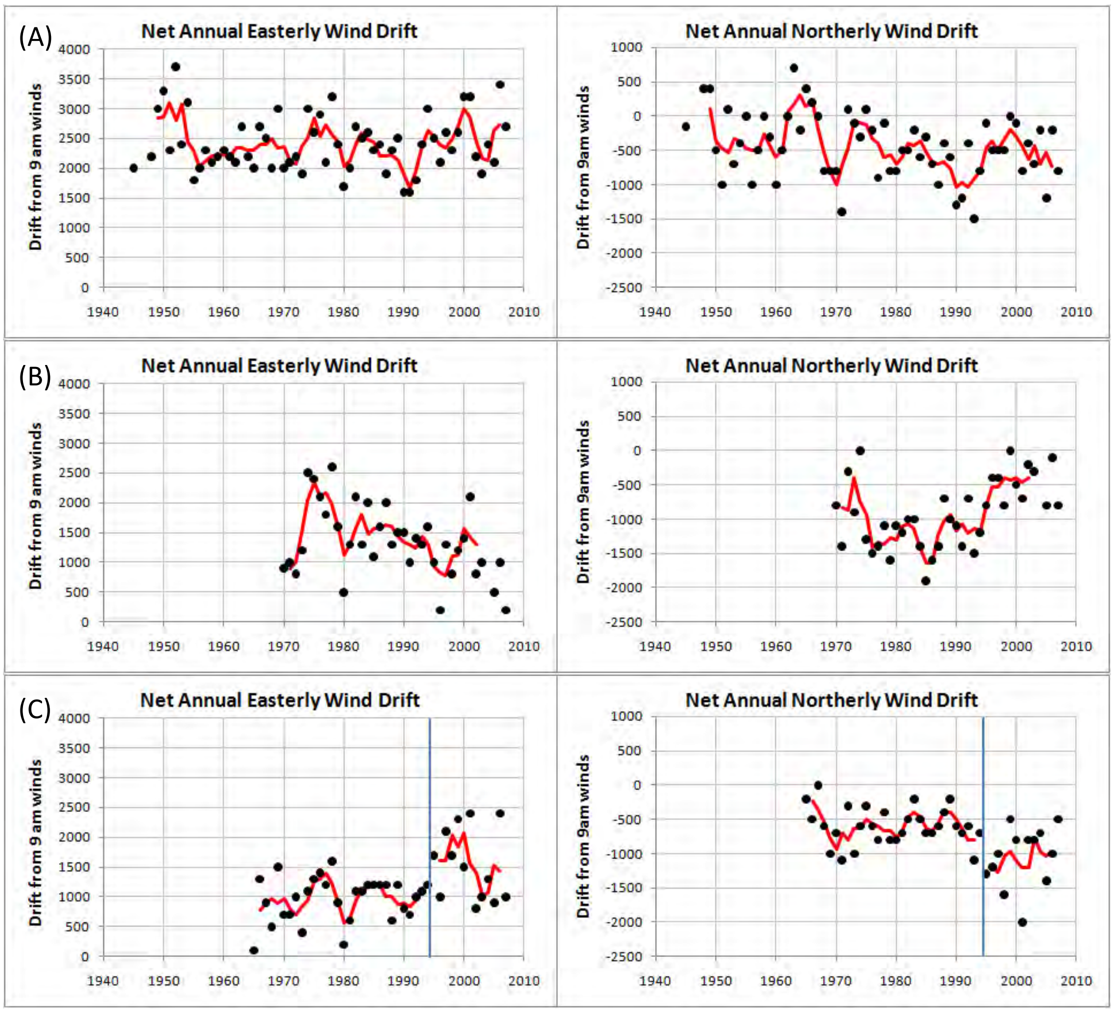


Figure 4-6: Annual Easterly and Northerly Wind Drift
(A) Geraldton, (B) Jurien Bay and (C) Rottnest
Different weather stations for Rottnest delineated by blue line

4.2.2. Water Levels

Sustained water level measuring stations near the Gingin-Dandaragan coast are at Fremantle and Geraldton (Figure 4-1; Table 4-5). Both datasets have reliable recordings since 1966, after the Australia Height Datum was established from 1965 (Easton 1970; Wallace 1988). There was a datum shift for Geraldton in 2005 (Damara WA 2008). The water level records for Fremantle and Geraldton are shown in Figure 4-7 and Figure 4-8 respectively. The shorter 10 year dataset for Jurien Bay is not considered in detail.

Table 4-5: Water Level Observations for the Gingin-Dandaragan Coast
(Source: Royal Australian Navy Hydrographic Office)

Station	Location	Lat. (S)	Long. (E)	Year Commenced
62290	Geraldton	28°46’34”	114°36’07”	1966
62270	Jurien Bay (not included herein)	30°17’14”	115°02’34”	1995
62230	Fremantle	32°03’56”	115°44’53”	1896

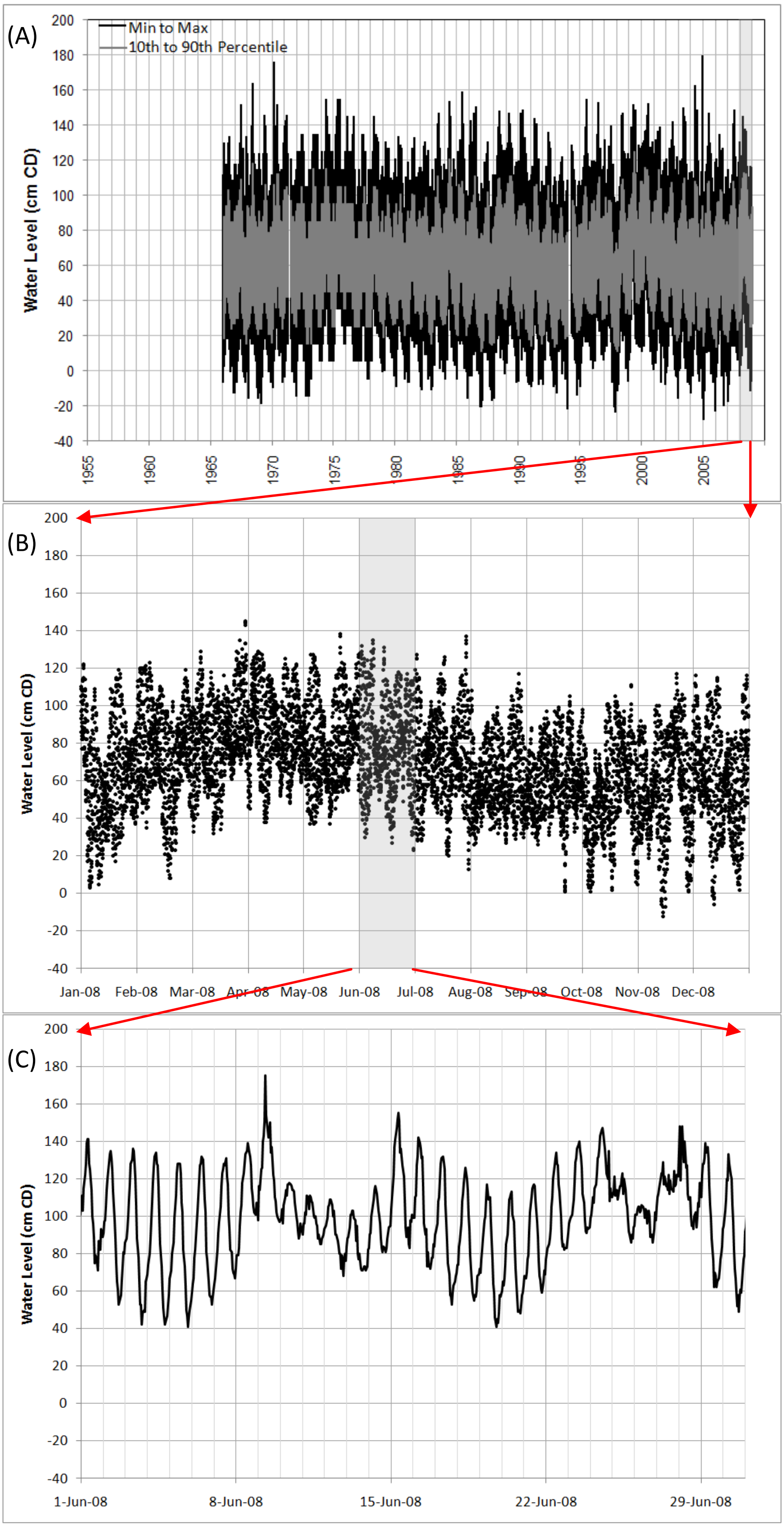


Figure 4-7: Water Levels (1966-2008) for Geraldton
(A) Total Record, (B) 2008 and (C) June 2008
(Source: Royal Australian Navy Hydrographic Office and Geraldton Port Authority)

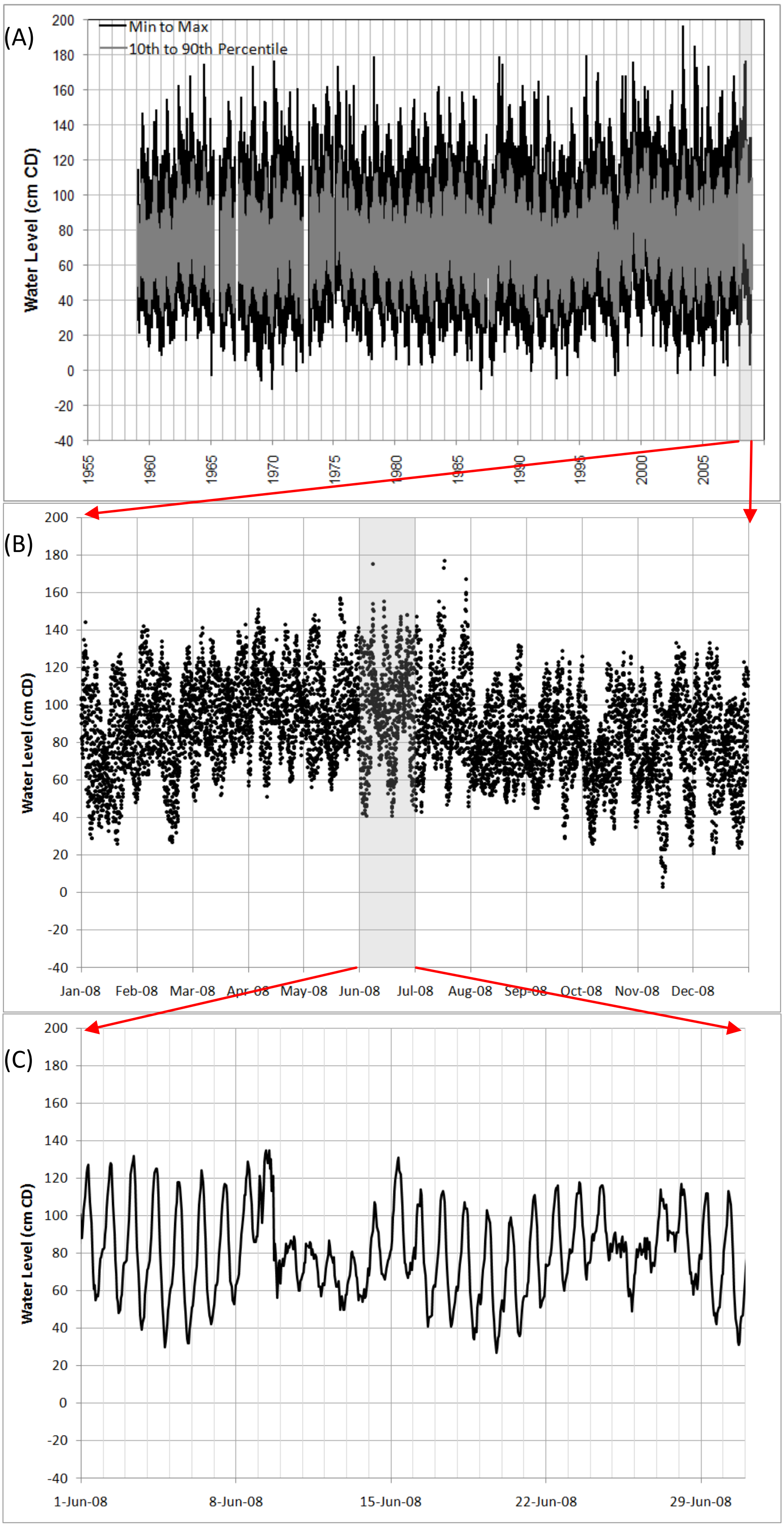


Figure 4-8: Water Levels (1966-2008) for Fremantle
(A) Total Record, (B) 2008 and (C) June 2008
(Source: Royal Australian Navy Hydrographic Office and Geraldton Port Authority)

Key water level processes affecting the Gingin-Dandaragan coast include tides, atmospheric surges, resonant phenomena, seasonal and inter-annual mean sea level variations. An analysis of the range and standard deviations of hourly water levels at Fremantle and Geraldton has been included to describe the relative influence of tidal and non-tidal water level signals (National Tidal Facility 2000; Eliot 2010). The water level time series was decomposed into approximations for mean sea level (30 day running mean), tide (Doodson-x_o filter) and surge (residual), with some overlap between the approximations (Table 4-6). Here the surge signal is likely to include resonant phenomena. The relative standard deviations indicate that tides are the major water level process, with mean sea level and surge providing a similar contribution. However, the relative ranges show a different pattern, with the non-tidal components having a larger ratio to tide, suggesting that they can intermittently overwhelm the tidal signal for the micro-tidal Gingin-Dandaragan coast.

Water levels can modify the attenuation of wave energy across the reefs of the Gingin-Dandaragan coast, the breaking wave angle and the zone of breaking waves on the shoreface.

Table 4-6: Mean Sea Level, Surge and Tide Approximations

	Geraldton (1966-2008)		Fremantle (1959-2008)	
	Range	Standard deviation	Range	Standard deviation
Water Level (cm CD)	-28 to 180 (228)	24	-11 to 197 (208)	23
Mean Sea Level (cm)	36 to 97 (61)	11	49 to 107 (58)	10
Surge (cm)	-35 to 50 (85)	10	-38 to 50 (88)	10
Tide (cm)	-37 to 41 (78)	18	-35 to 39 (74)	17

4.2.2.1. Tides

Fremantle and Geraldton are two of the Standard Ports defined by the Royal Australian Navy Hydrographic Office, with annual tidal predictions published in the Australian National Tide Tables (Department of Defence 2010). Jurien Bay is a secondary port within the Study Area, with tidal levels derived from harmonic constituents. The mainly diurnal tides are microtidal with a tidal range of 1.2-1.4 m from LAT to HAT (Table 4-7).

Table 4-7: Tidal planes for Geraldton, Jurien Bay and Fremantle (Source: Department of Defence 2010)

Tidal Level		**Water Level (mCD)**		
		Geraldton	**Jurien Bay**	**Fremantle**
Highest Astronomical Tide	HAT	1.2	1.2	1.4
Mean Higher High Water	MHHW	1.0	0.8	1.1
Mean Lower High Water	MLHW	0.8	0.6	1.0
Mean Sea Level	MSL	0.6	0.5	0.8
Mean Higher Low Water	MHLW	0.4	0.5	0.5
Mean Lower Low Water	MLLW	0.2	0.3	0.4
Lowest Astronomical Tide	LAT	0.0	0.0	0.0

The tidal sequence is affected by monthly spring-neap cycles, bi-annual and inter-annual signals (Figure 4-7 and Figure 4-8). The tidal range varies on a bi-annual cycle, with solstitial peaks in June and December. The tidal sequence is further modulated by the 8.85-year lunar perigee and 18.6-year lunar nodal cycles (Damara WA 2008; Eliot 2010). The lunar nodal cycle is dominant, with apparent peaks in 1987 and 2006, resulting in a 20% variation in maximum daily tide range between low and high years (Damara WA 2008). The seasonal range of water level is approximately 0.3m (Pariwono *et al.* 1986), mainly a non-tidal phenomenon, although commonly attributed to the S_a (solar annual) tidal constituent.

4.2.2.2. Atmospheric Surges

The contribution of surges to the water level record is high relative to the small tidal signal in the Gingin-Dandaragan coast area. The atmospheric surge can be of a similar order of magnitude to the tide at Fremantle (Pattiaratchi & Eliot 2008). Dependence of water level upon weather conditions was noted by Provis & Radok (1979) and suggests that the majority of surge is atmospheric in origin, a combination of barometric effect, wind and wave setup, related to mid-latitude storms. The track of the weather system will result in variation in surge levels across the region, as demonstrated by differences in surge peaks between Fremantle and Geraldton (Figure 4-7C and Figure 4-8C). The peak in the extra-tropical surge occurs in June to July in Fremantle and May to June in Geraldton (Damara WA 2008). Surges may also occur due to more unusual meteorological events, such as Tropical Cyclone Glynis in 1970, and are often combined with resonant phenomena, such as shelf waves. High surge conditions may induce substantial, albeit commonly short-lived, beach responses.

4.2.2.3. Resonant Phenomena

The water level record includes a number of resonant phenomena which are developed through the interaction of atmospheric-induced water level movements with coastal configuration (bathymetry and plan form). These phenomena include harbour and bay seiches, continental shelf waves, edge waves and tsunamis (Allison & Grassia 1979; Pattiaratchi & Eliot 2008; Eliot & Pattiaratchi 2010; Wijeratne *et al.* 2011).

Resonant phenomena play a significant role in the persistence of water level variations after an environmental perturbation (Rabinovich 2008). Resonance within the Gingin-Dandaragan region, including seiching, has been specifically identified as a result of coastal lagoon structure (Allison & Grassia 1979; Petrusevics *et al.* 1979). Forcing mechanisms may include storm systems, pressure jumps or thunderstorms, the latter of which are more common in summer than winter (Wijeratne *et al*. 2011).

Continental shelf waves, often remotely generated by tropical cyclones, can positively interact with atmospheric surge (Figure 4-9; Eliot & Pattiaratchi 2010). A continental shelf wave of 0.75m, generated by Tropical Cyclone Bianca, was recorded at Fremantle and Geraldton in March 2011.

Tsunamis generated in the Indian Ocean can result in high water levels associated with the leading waves, as well as local seiches on the shelf, with the highest water level residual at Geraldton occurring during the 2004 Boxing Day Tsunami (Pattiaratchi & Eliot 2008).

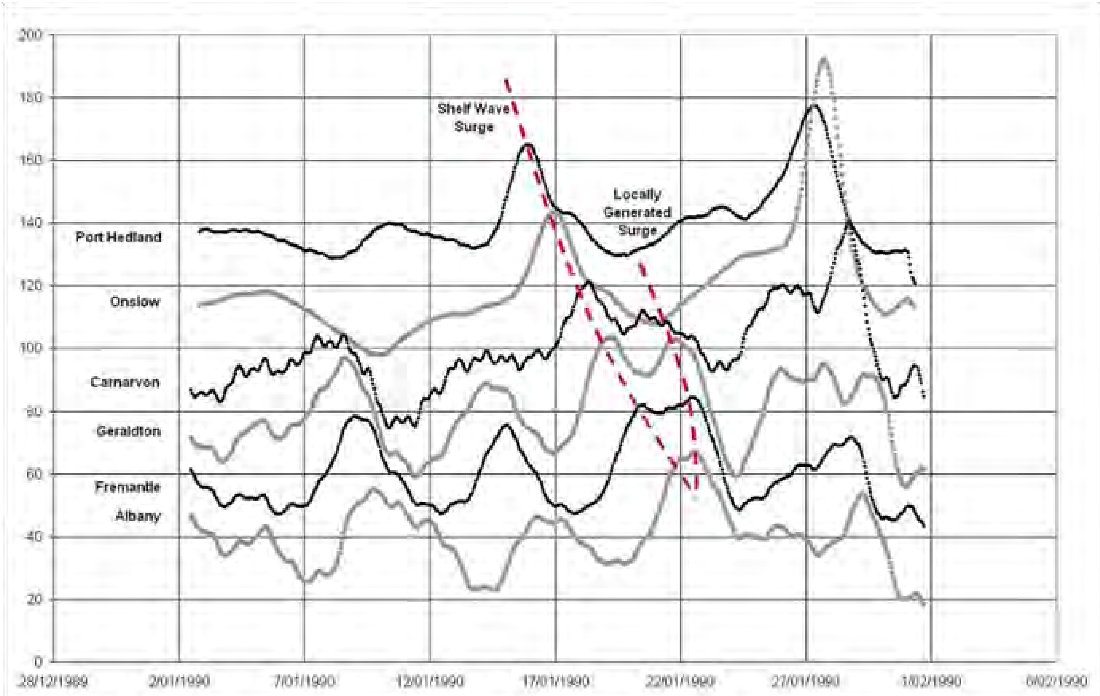


Figure 4-9: Shelf Wave Interaction with Locally Generated Surge

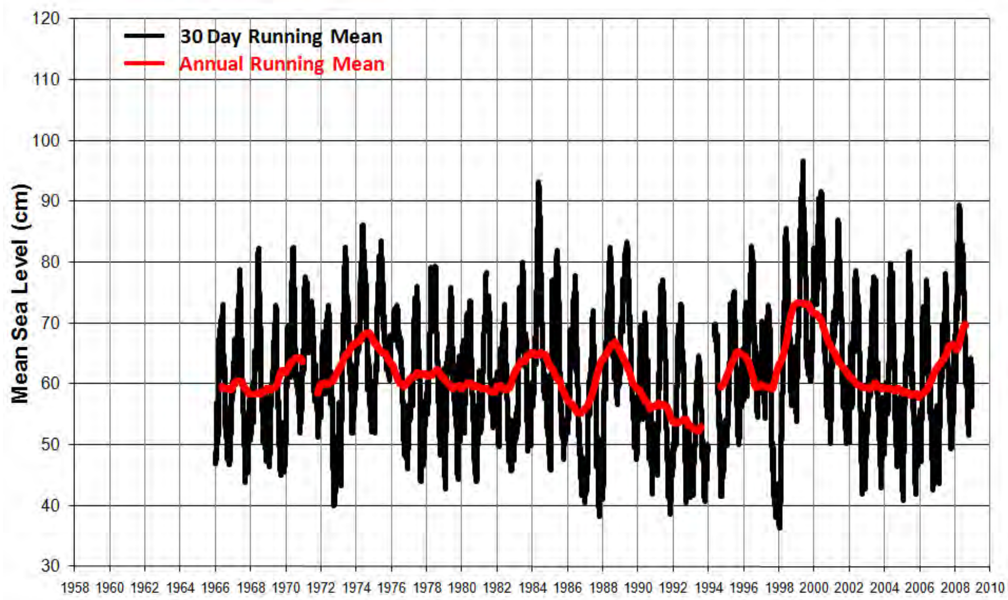
4.2.2.4. Mean Sea Level Variations

The 30-day and annual running means of water levels indicates two significant sources of slowly varying sea level fluctuations, at seasonal and inter-annual time scales (Figure 4-10). Comparison of the long-term record for Fremantle (1966-2004) and Geraldton (1966-2003) suggest a mean sea level rise of 1.4 mm/year and 0.5 mm/year, respectively, although the trend for any time period is strongly affected by inter-annual fluctuations, and therefore should be interpreted with caution (Damara WA 2008). Also, the tide gauge location in Geraldton was shifted in 1977, which may provide some uncertainty in the estimate of relative sea level rise.

The seasonal variation at Fremantle averages 0.22m with a maximum in May to June and minimum in October to November largely attributed to changes in the strength of the Leeuwin Current (Pattiaratchi & Buchan 1991; Pattiaratchi & Eliot 2008).

The inter-annual relationship between mean sea level and climate fluctuations is suggested by a strong correlation between annual average water level and SOI - the Southern Oscillation Index (Pattiaratchi & Buchan 1991). The SOI is determined by the barometric pressure difference between Darwin and Hawaii, and has been demonstrated as a reasonable indicator of El Nino or La Nina climatic conditions. The sea level relationship to SOI indicated by Figure 4-11 occurs along the entire Western Australian coast (Pariwono *et al.* 1986; Pattiaratchi & Buchan 1991; Feng *et al.* 2004).

(A)



(B)

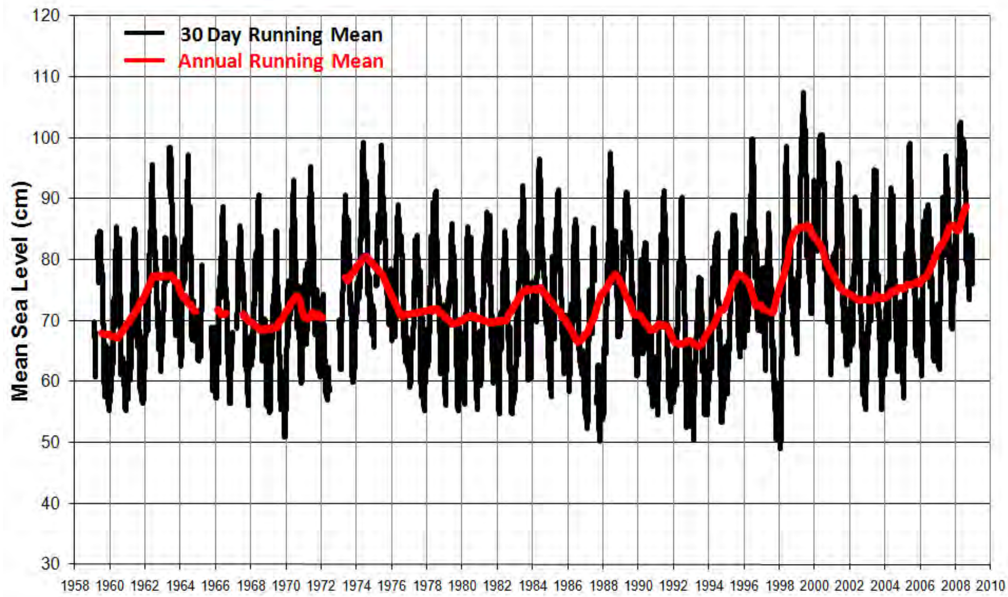


Figure 4-10: 30-Day Running Mean and Annual Mean Sea Level (A) Geraldton (1966-2008) and (B) Fremantle (1959-2008)

4.2.2.5. Extreme Water Levels

The relative timing of tide, mean water level and extra-tropical surge controls the potential for high water levels which occurs in June in Fremantle and May-June in Geraldton. The timing of high water levels in this region is generally out of phase with the tropical cyclone season. An exception is the high water level at Geraldton associated with TC Glynis (1970). The highest water level at Fremantle occurred during a mid-latitude depression (May 2003). The extreme water level distributions have excluded the 2004 Boxing Day Tsunami which generated a water level at Geraldton 0.9 m higher than TC Glynis.

Inter-annual cycles of tidal potential and mean sea level modify the likelihood of high or low water level events (Eliot 2011).

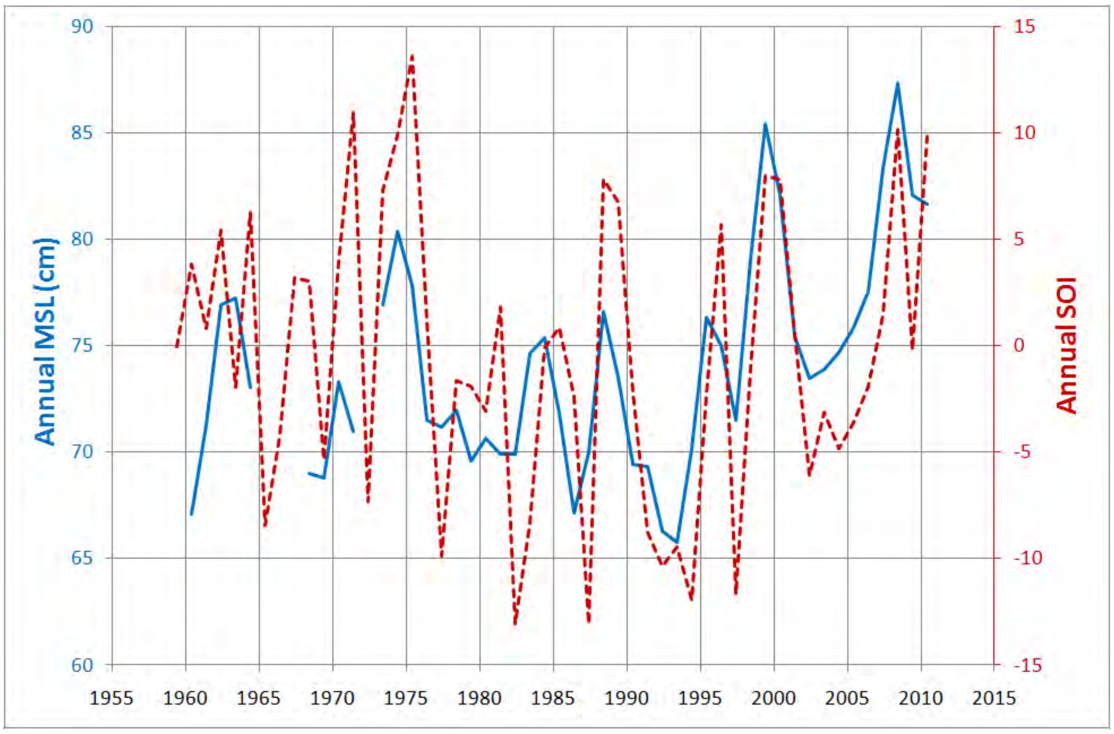


Figure 4-11: Correspondence between the Annual Means of Fremantle Mean Sea Level and SOI (1960 to 2010)

4.2.3. Waves

Wave measurements around southwest Australia have been historically collected by Federal and State government agencies, including observations at the major ports and other locations where major coastal facilities were planned. From 1971 to 1994, these measurements were sporadic in nature, with comparatively short term deployments of one to four years.

From 1993, a series of permanent offshore waverider buoy installations have been progressively undertaken to provide a regional description of the wave climate throughout the southwest. The three buoys most relevant to the Gingin-Dandaragan coast are those at Rottnest (south of the Study Area), Jurien Bay and Geraldton (north of the Study Area) since 1994, 1998 and 1999 respectively (Figure 4-1; Table 4-8). The Rottnest and Jurien Bay buoys were upgraded to directional buoys in 2004 and 2009 respectively. The Geraldton waverider buoy was removed in 2006, with an AWAC meter used since 2005 in a location 7.5km south of the waverider (Grant Ryan *pers. comm.*). Observations from the waverider buoys off Geraldton Harbour, at Jurien Bay and southwest of Rottnest are illustrated in Figure 4-12, Figure 4-13 and Figure 4-15.

Wave conditions are strongly modulated by water levels due to depth limited wave breaking. A short two-year record of non-directional waverider buoy data is included for investigation of reef influence on inshore waves at Ledge (Figure 4-14; discussed in Section 4.3.3). The buoy location is shown in Figure 4-1 and Table 4-8. A nine month deployment of two non-directional waverider buoys (1988 to 1989) also considered the influence of reef on inshore wave climate at Moore River (McCance 1991; Department of Marine and Harbours: DMH 1991; discussed in Section 4.3.3).

Table 4-8: Wave Observations Incorporated for the Gingin-Dandaragan Coast (Source: Department of Transport; McCance 1991; DMH 1991; Damara WA 2005; Grant Ryan *pers comm.*)

Station	Location	Lat. (S)	Long. (E)	Depth (m)	Installed	Removed
	Geraldton – Channel	28°45’24”	114°33’56”	12	1/3/1999	31/12/2006
	Geraldton–AWAC Directional	28°45’28”	114°33’56”	13	1/3/2004 3/3/2005	15/8/2004 Current
40	Jurien Bay	30°17’30”	114°54’52”	42	27/10/1997	Current
45	Ledge Point – Offshore	31°08’05”	115°18’52”	26	6/6/2002	18/4/2004
28	Moore River – Offshore	31°24’17”	115°25’40”	33	7/4/1988	4/1/1989
29	Moore River – Inshore	31°21’35”	115°28’55”	10	7/4/1988	4/1/1989
33	Rottnest Is.–Non-directional	32°06’41”	115°24’07”	48	25/07/1991	14/9/2004
47	Rottnest Is.-Directional	32°05’39”	115°24’28”	48	14/9/2004	Current

This study neglected the short deployments adjacent to the Jurien Bay Boat Harbour in 1981 to 1982 (PWD 1984) as it was not compared to any measured offshore datasets; at Geraldton prior to 1988 (Steedman & Associates 1983, 1985; DMH 1988) and Port Denison in 1974-1976 (PWD 1976) as the two sites are beyond the Study Area. The Department of Transport is the custodian of these datasets.

Spatial variation of the wave climate is suggested by wave modelling from 1997 to 2004 (Figure 4-16; Richardson *et al.* 2005). This shows a mild decrease in wave height from south to north, with major variation occurring across the shelf boundary, in depths less than 50m. There is a general decrease in wave heights towards shore due to depth effects, along with increasing shelter from reefs and islands (Table 4-9). This cross-shelf variation in wave climate limits direct comparison of waverider buoy observations, as these are generally obtained from sites on the shelf (Figure 4-1; Table 4-8). Measurements from Geraldton are significantly damped due to the shallow depth of observation (12m) and the shelter provided by the Houtman Abrolhos. Rottnest (48m) and Jurien (42m) are likely to provide a closer representation to offshore wave conditions for the Study Area.

Table 4-9: Median and 1% Significant Wave Heights

Location	Depth	Period	Median H_s (m)	1% H_s (m)
Geraldton	12m	March 1999 to December 2006	0.88	2.0
Jurien Bay	42m	January 1998 to December 2009	2.2	4.9
Rottnest	48m	January 1994 to December 2009	2.0	5.3

The time series of observations for the four wave rider buoys is relatively consistent, albeit with significantly lower wave heights at Geraldton (Figure 4-12 to Figure 4-15). The Ledge offshore waverider buoy shows a similar trend to Jurien Bay, with lower extreme wave heights partially attributed to the shallower depth of 26m at Ledge compared to 42m at Jurien Bay (Figure 4-13; Figure 4-14).

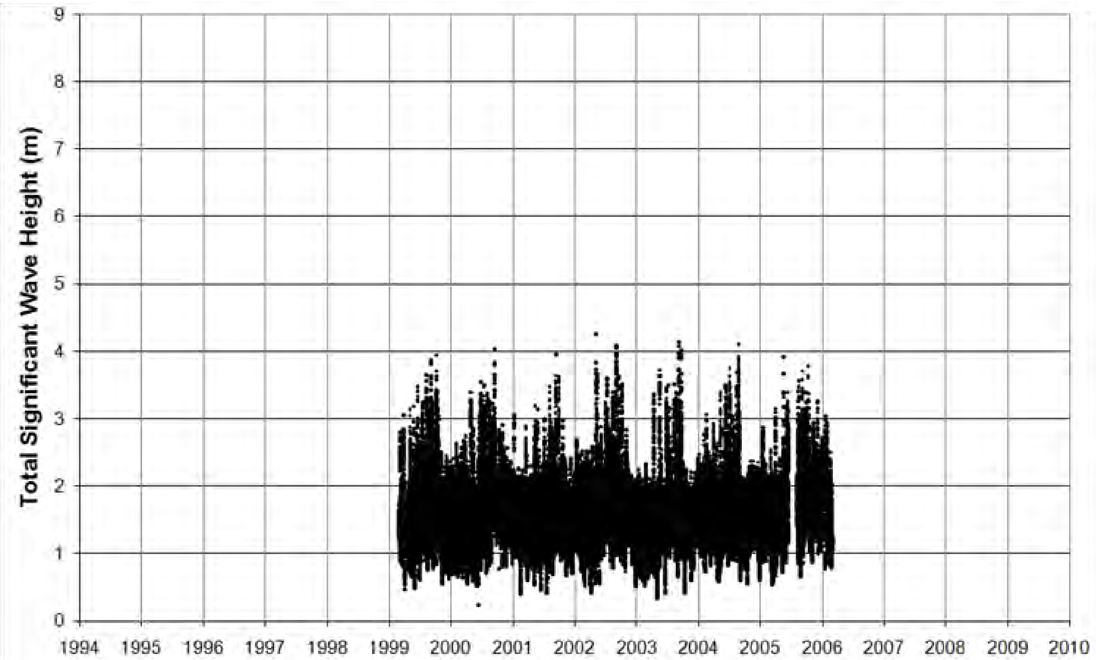


Figure 4-12: Geraldton Outer Channel Buoy Wave Heights (1999-2006)
(Source: Geraldton Port Authority)

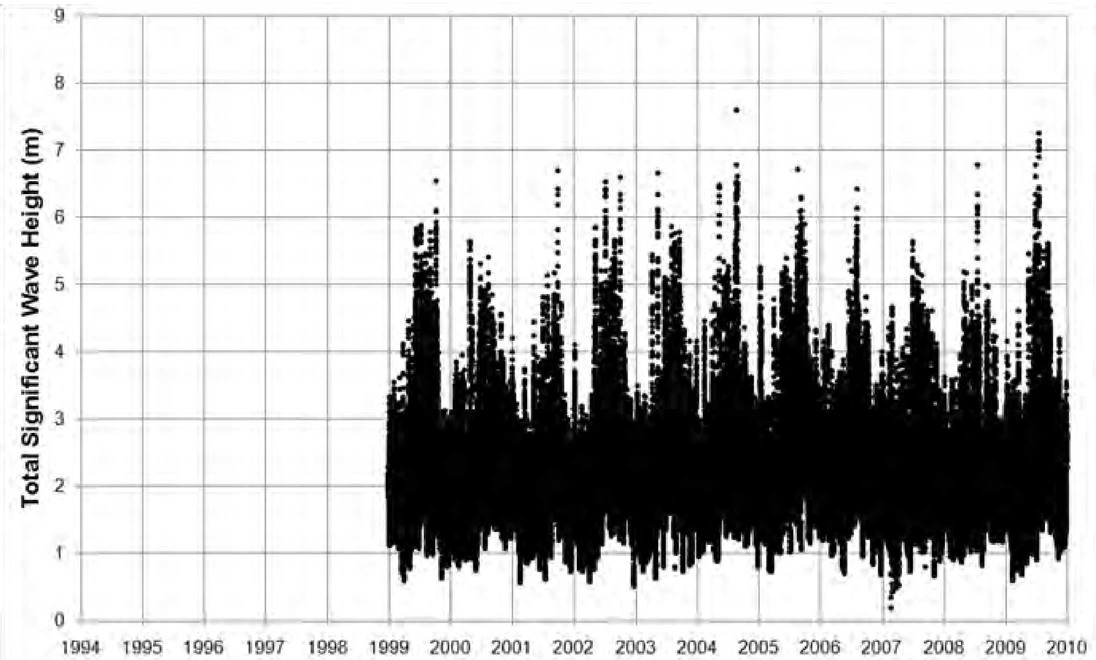


Figure 4-13: Jurien Bay Offshore Wave Heights (1998-2009)
(Source: Department of Transport)

The discrepancy of wave climate descriptions between sites may also partially be explained by the different occasions over which the waves were observed, noting that a high level of inter-annual variability has been identified at sites with more than one or two years of record (Riedel & Trajer 1978; Li *et al.* 2009). Consequently, it is suggested that an extended period of record needs to be used when interpreting wave conditions. Recent wave modelling has been conducted at UWA to extend the wave record, using modelled information, from 1970 to 2009 across the south west (Bosserelle *et al.* In Press). The results could be used in future to compare the alongshore variation in the wave climate at the approximate depths of the buoys (≈40m).

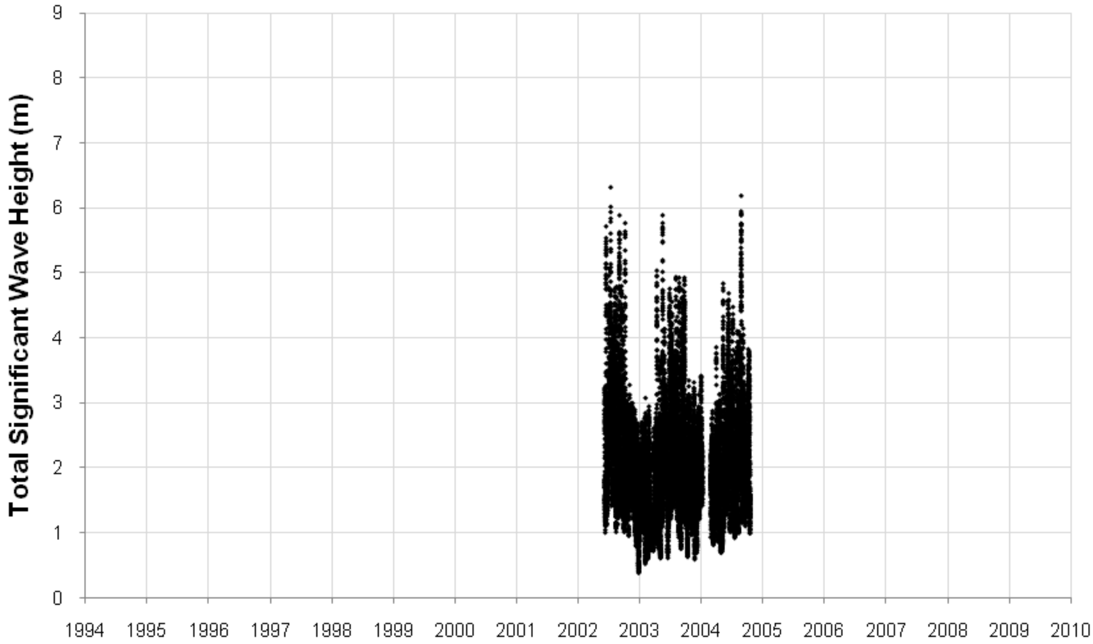


Figure 4-14: Ledge Offshore Wave Heights (2002-2004)
(Source: Department of Transport)

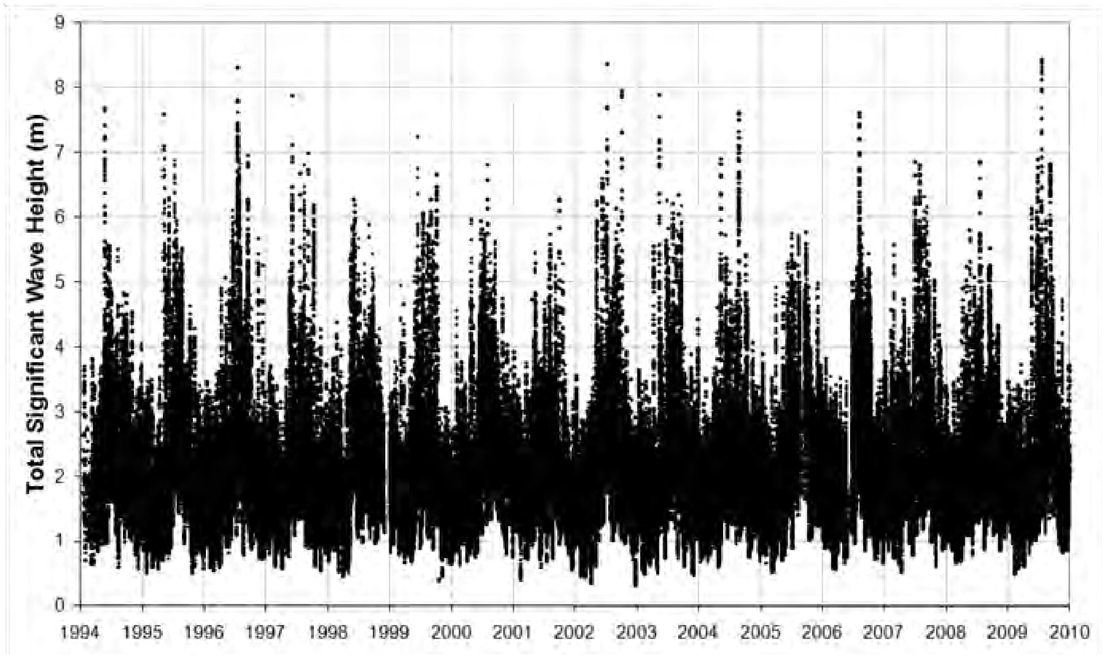


Figure 4-15: Rottnest Offshore Wave Heights (1994-2009)
(Source: Department of Transport)

At Rottnest, analysis of the first three years of records from 1994 to 1996 showed an ambient wave climate of approximately 1.5 m significant wave height and 7 seconds (T_{01} statistic) during summer, increasing to approximately 2.0 m significant wave height and 9 seconds period during winter (Lemm 1996; Lemm *et al.* 1999). The longer record from 1994 to 2009 shows high inter-annual variability of extreme waves, but the ambient summer-winter cycle remains relatively consistent from year to year (Figure 4-15; Li *et al.* 2009). The peak winter wave energy occurred in 1996 and the lowest recorded occurred in 2001.

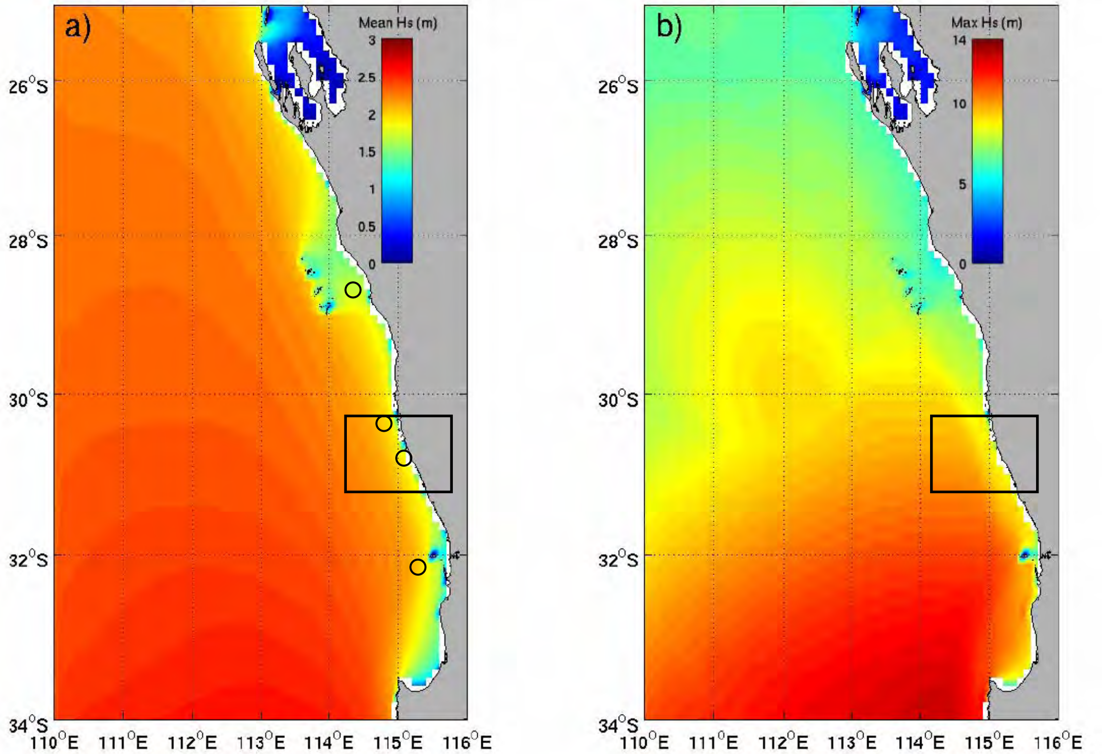


Figure 4-16: Indicative Variation of Significant Wave Heights for Geographe Bay to Cape Inscription (February 1997 – February 2004)
(a) Mean and (b) Maximum
(After: Richardson *et al.* 2005)
Note: Study Area Shown in Black Box and Wave Buoys as Black Circles

Plots of the joint distribution of significant wave height and peak wave period for the period of 1999 to 2006 for Rottnest, Jurien Bay and Geraldton demonstrate a similarity in the shorter period locally-generated waves, with the largest discrepancy between sites for the higher energy storm waves and longer period swell (Figure 4-17). This variation between sites is considered further using the directional wave record for 2006 only for Rottnest and Geraldton (Figure 4-18). The main discrepancies between the sites are: location of the Rottnest buoy farther offshore allowing sufficient fetch for wind waves to be generated by the land breeze with sea waves in the 70-130° direction range; a narrower band of directions where swell is observed at Geraldton due to refraction and a reduction in westerly swell by the Houtman Abrolhos (Figure 4-16); and the reduced fetch for NW to N locally generated waves at Geraldton due to the Houtman Abrolhos.

The Rottnest buoy demonstrates a broad directional range of high swell energy from 240 to 280° with prevailing swell from the south to southwest, with enhanced west to northwest activity during winter months (Figure 4-18; Roncevich *et al.* 2009). Approximately 6% of the swell wave energy during 2006 arrived from north of west, but this only arrives during winter months, or extremely rarely in summer during southwards tracking tropical cyclones such as occurred in 2011. This confirms a nett seasonal shift in swell direction described for the Perth coastline qualitatively (Masselink & Pattiaratchi 1998) and quantitatively for 2004 to 2009 (Roncevich *et al.* 2009). However, analysis of synoptic system variability suggests that the quantity of change may vary significantly between years (Steedman & Associates 1982; Panizza 1983). This synoptic variability has been translated to wave variability by Bosserelle *et al.* (In Press) through a 40 year modelling investigation of track and intensity of large wave events in the Southern Indian Ocean that affect the south-west WA Coast.

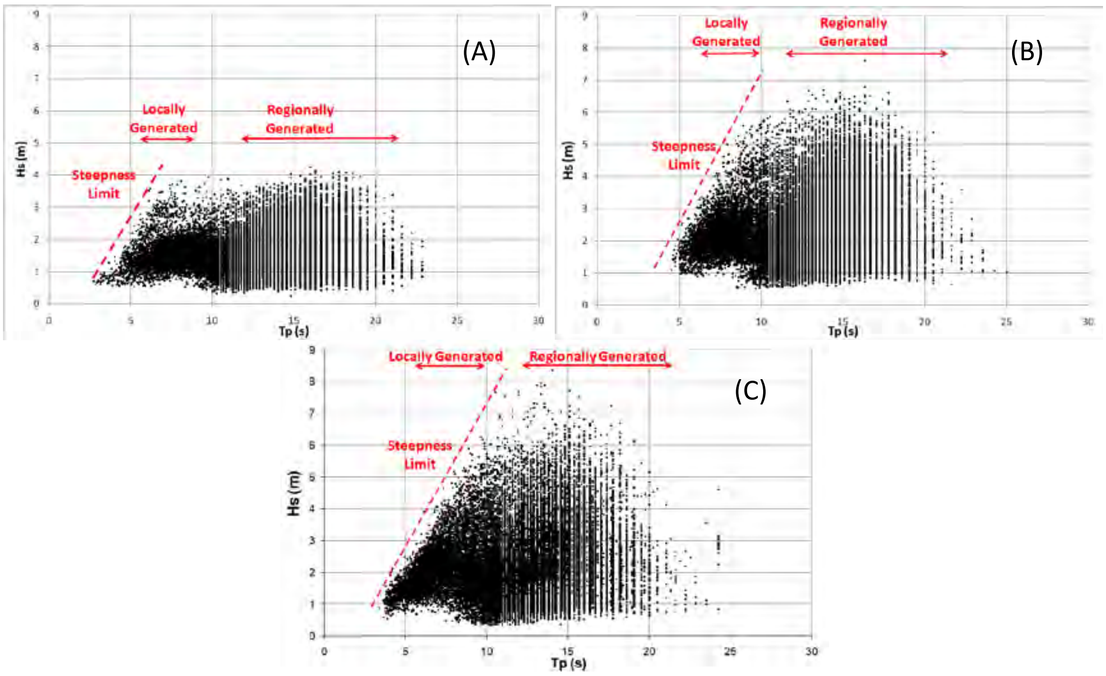


Figure 4-17: Wave Height and Period Crossplots (1999-2006)
(A) Geraldton, (B) Jurien Bay and (C) Rottnest

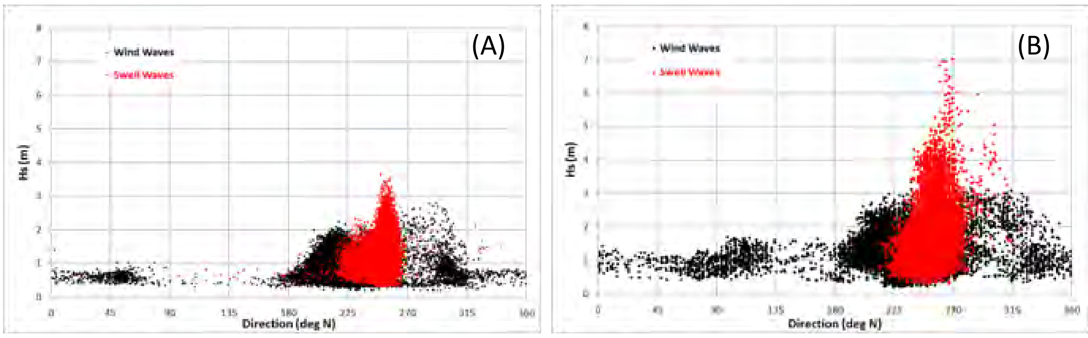


Figure 4-18: Wave Height and Direction for 2006 for (A) Geraldton and (B) Rottnest

The seasonal distribution of wave heights shows a peak from May to September across the region (Figure 4-19). Variability between sites may be attributed to a combination of factors including weather system type and track, along with local intensification of winds.

Extreme events are shown by the peak in the 99th percentile (Figure 4-19). Extreme wave heights, particularly associated with high water level events, can result in acute storm erosion. It is appropriate to note that the preparation of any extreme distribution curves strongly reflects stormy periods and therefore is highly affected by inter-annual variability of the wave conditions. Any extreme distribution curves should be interpreted with caution due to the short length of the datasets.

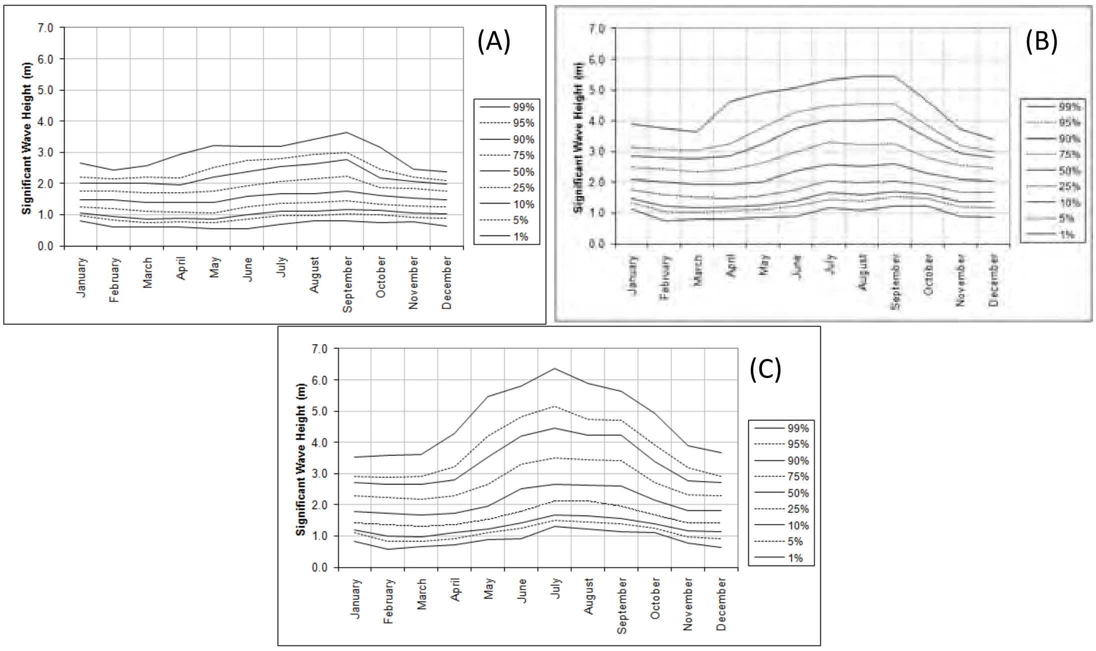


Figure 4-19: Seasonal Distributions of Wave Height
(A) Geraldton (1999-2006), (B) Jurien Bay (1999-2009) and (C) Rottnest (1994-2009)

The perception of trends and variability in the Western Australian extreme wave climate is limited by the relative availability of environmental data sets. Observational data from permanent monitoring stations are available from 1994, with inferred wave conditions via altimetry from 1985 or by modelled wave hindcast from 1970. Early data are recognised as having lower quality, and cannot be independently validated. The measured wave record at Rottnest (1994 to present) shows a natural inter-annual variability in larger waves of approximately 22% (Figure 4-15).

The investigation of variability has been extended through the use of satellite altimetry, with accuracy and sampling frequency limitations. Young *et al.* (2011) used 23 years (1985-2003) of satellite altimetry inferred wave heights to determine a trend of approximately +0.5% per annum in 90% occurrence significant wave heights offshore of SW WA over the period. This corresponds to an approximate increase from 5 m wave height to 5.6 m over the 23 years.

A wave modelling investigation of the Southern Indian Ocean over the last 40 years (1970 to 2009) extends the wave record to consider the natural variability, with a 30-50% annual variability of significant wave height (Bosserelle *et al.* In Press), which is greater than the 22% determined from the measured buoy record at Fremantle. Bosserelle *et al.* (In Press) have attempted to account for this variability over the 40 year record, determining there is no statistically significant trend in extremes (90% occurrence significant wave height), with a +0.006m/yr change in mean wave height over the 40 year modelled record. There is no discernable trend in extreme wave heights, including large swell events, when considering the longer record. An increased number of large wave events in the southern Indian Ocean have been observed, offset by tendency for storm systems to track further southwards relative to WA (Bosserelle *et al.* In Press).

Local effects of reef, island and bank structures on the inshore wave climate is discussed in Section 4.3.3.

4.2.4. Nearshore Currents

Limited information has been collected regarding nearshore currents in the Gingin-Dandaragan area, with the majority of available information relevant to describing regional offshore currents.

In theory, four principal current drivers are oceanographic (steric gradients and weather systems), tidal, wind-driven (local winds) and wave driven processes, each of which is likely to be dominant in a different zone relative to the coast and lagoons. Consequently, there is a theoretical sequence of currents moving seawards that relates to the relative strength of the forcing mechanisms (Figure 4-20; Damara WA 2010).

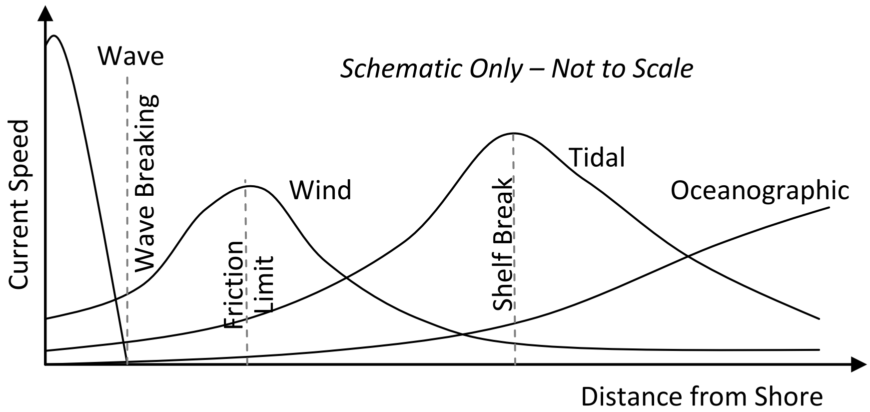


Figure 4-20: Schematic Spatial Distribution of Currents (Source: Damara WA 2010)

Regional currents have been examined using satellite imagery, drifters, gliders, boat based measurements and long-term current metering deployment at the Abrolhos (Cresswell *et al.* 1989; Pearce & Pattiaratchi 1997). These investigations provide a general focus on surface currents, the Leeuwin Current and weather system forcing, including eddy formation and influences of islands (Zaker *et al*. 2007).

In general, the boundary effect of the coast causes most surface currents in the nearshore to run nearly shore parallel. This pattern can be modified by the influence of reef and islands, discussed in Section 4.3.3. Further offshore the surface current direction becomes more responsive to the direction of forcing. Tidal currents become more shore-normal near the shelf break (Damara WA 2010).

The majority of available nearshore current measurements and modelling in the Study Area is focused on the circulation within the lagoon and around Island Point at Jurien Bay (Sanderson 1997, 2000; Chua 2002; Holloway 2008) or as part of the wider Jurien Bay

Marine Park (D'Adamo & Monty 1997). Surface and bed currents responded to weather systems, with current measurements also responding to continental shelf waves and seiches.

4.2.5. Hydrology

Rivers influence the coast by increasing landform mobility and modifying the supply of sediment (Section 3.3.3). River influences on the coast are increasingly dominant north of the Gingin-Dandaragan coast, but is still considered a locally significant factor for some of the Areas of Planning Interest (Section 6). The two main rivers of the Gingin-Dandaragan coast that discharge to the coast are the Moore and Hill Rivers (Figure 1-1; Figure 4-21). Other river systems (such as the Nambung) discharge into coastal lakes or submerge into the groundwater system, some outcropping on the inner shelf. A summary of the surface drainage and wetland behaviour of the area is provided in the *Central Coast Regional Profile* (DPUD 1994).

The hydrologic network is gauged and monitored by the Department of Water, with rainfall monitored by the Bureau of Meteorology. The gauging stations used herein are listed in Table 4-10 and labelled in Figure 4-1.

The flooding regime of the Moore and Hill Rivers is associated with rainfall runoff, flood routing and residual groundwater levels. The likelihood of flooding is often calculated statistically from hydrological data of known flood events to determine a statistical floodplain. A further approach for determining areas that may be inundated by floodwaters might be to consider the natural floodplain as a whole based on landforms, which can be identified from the mapping of alluvial and estuarine landforms (Gozzard 2011c; Appendix C).

Figure 4-21: Hill and Moore River Catchments (Source: Department of Water)

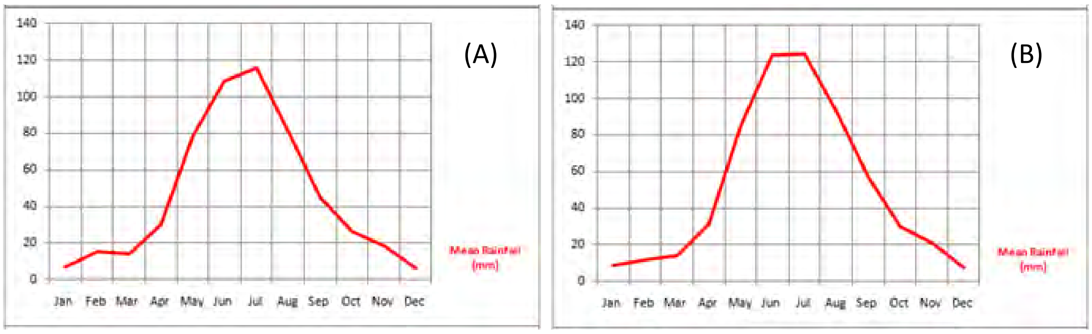


Figure 4-22: Mean Monthly Rainfall at (A) Jurien Bay and (B) Lancelin (Source: Bureau of Meteorology)

Table 4-10: Rainfall and River Discharge Observations Incorporated for the Gingin-Dandaragan Coast (Source: Bureau of Meteorology and Department of Water)

Location	Station	Lat. (S)	Long. (E)	Data	Installed	Distance Upstream from mouth
Hill River						
Jurien Bay	9131	30.308°	115.031°	Rainfall	1968	N/A
Coorow	8037	29.882°	116.023°	Rainfall	1912	N/A
Hill River Springs	617002	30.277°	115.367°	Streamflow	1971	45km
Moore River						
Lancelin	9114	31.016°	115.330°	Rainfall	1965	N/A
Barberton	8005	30.729°	116.020°	Rainfall	1911	N/A
Quinns Ford	617001	30.982°	115.819°	Streamflow	1969	70km

4.2.5.1. Moore River

The Moore River catchment is 9,829 km^2 above the Quinns Ford gauging station, located approximately 70 km upstream of the Moore River mouth. The total catchment area of 13,557 km^2 extends 230 km northeast of the mouth (Cousins 2003; Figure 4-21). The river mouth is strongly topographically controlled. Alluvial terraces are present upstream of the mouth with the river meanders migrating in response to large flow events. The river has a barred mouth that is intermittently open, multiple times a year. Investigations of the bar have been conducted to assess water quality within the estuary, including documentation of the artificial opening of the bar (e.g. Grimes & Eliot 1998; Cousins 2003).

A hydrologic study to estimate 10, 25 and 100 year Average Recurrence Interval (ARI) flood levels for the Moore River at Moora (90km upstream of the mouth) was prepared by Gutteridge Haskins & Davey (GHD 1991) and revised by Water Studies (2000) based on flood level datasets for the two 1999 flood events. A prior study in 1967 by Timmermans, Hold and Associates investigated causes of flooding at Moora (Water Studies 2000).

The coastal (Lancelin) and inland (Barberton) monthly rainfall is presented in Figure 4-23, along with the peak monthly discharge for Quinns Ford. Station locations are listed in Table 4-10 and labelled in Figure 4-1. The ten maximum recorded flows at the Quinns Ford gauging station are presented in Table 4-11, with the maximum recorded event of 446.4 m^3s^{-1} in March 1999 associated with TC Vance. The rainfall record at Barberton extends 58 years longer than the streamflow gauge at Quinns Ford. This suggests the potential for greater floods to occur than have been recorded since 1969, with at least seven individual months between 1911 and 1969 receiving monthly rainfalls in excess of the maximum monthly rainfall for the period of streamflow record (1969-2008). Major floods were reported in 1872, 1904, 1917, 1955, 1963, 1968 and 1999 (Grimes & Eliot 1998; GHD 1991; Water Studies 2000).

Flow through the river mouth is seasonal, with the bar intermittently open (Stelfox 2001; Cousins 2003). Surface water levels are sustained in the lower reaches in dry months by local groundwater discharge to the river (Cousins 2003). The river flows in flood events, which most commonly occur during the higher rainfall period May to September (Figure 4-22B), with the ten maximum discharge events occurring during these months or associated with infrequent summer tropical cyclones (Figure 4-23C; Table 4-11). Winter flow peaks in the order of 30 to 89 million cubic metres discharge (DPUD 1994).

Table 4-11: Ten Largest Peak Events for Moore River (1969-2010)

Year	Month	Peak Discharge (m^3/s)
1999	March	446.4 (TC Vance)
1995	July	318.0
1983	July	270.2
1999	May	193.6
1974	August	141.5
2006	January	133.4 (TC Daryl)
1988	July	125.9
1974	July	115.0
1975	July	110.3
2003	August	109.1

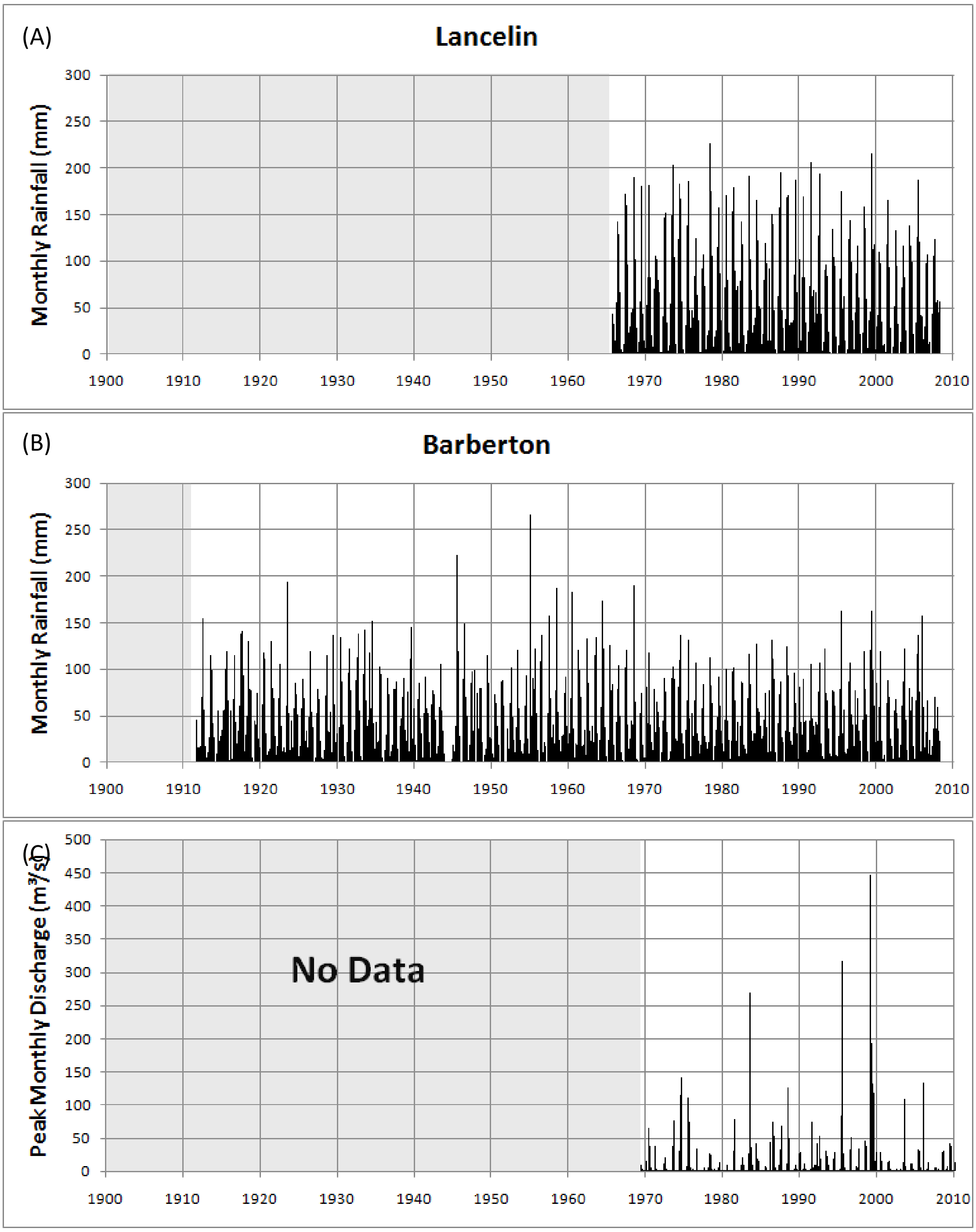


Figure 4-23: Rainfall at Selected Locations and Discharge for the Moore River (A) Coastal Station at Lancelin, (B) Inland Station at Barberton and (C) Peak Monthly Discharge at Quinns Ford approximately 70 km upstream of the Moore River mouth (Source: Bureau of Meteorology and Department of Water)

4.2.5.2. *Hill River*

The Hill River catchment is 626 km^2 above the Hill River Springs gauging station located approximately 45 km upstream of the Hill River mouth. The river descends off the scarp into a deltaic lowland (MPRA 2000; Figure 4-21). The river occasionally discharges to the ocean during significant flow events, but it generally has a barred entrance. No hydrologic studies on flood levels have been conducted for the Hill River by the Department of Water (or its predecessors), likely attributed to the low recorded flood flows and the sparse settlement in the floodplain.

The coastal (Jurien Bay station 9131) and inland (Coorow station 8037) monthly rainfall is presented in Figure 4-24, along with the peak monthly discharge for Hill River Springs (Station 617002). Station locations are listed in Table 4-10 and labelled in Figure 4-1. The ten largest recorded peak flows at the Hill River Springs gauging station are presented in Table 4-12, with the maximum recorded event of 50.6 m^3s^{-1} in August 1974. This flow rate is an order of magnitude smaller than the maximum at Moore River. The rainfall record at Coorow extends 59 years longer than the streamflow gauge at Hill River Springs. This suggests the potential for greater floods to occur than have been recorded since 1971, with at least six individual months between 1912 and 1971 receiving monthly rainfalls in excess of the maximum monthly rainfall for the period of streamflow record (1971-2008).

Flow is discontinuous, with water levels sustained in dry months by local groundwater discharge to the river (Rutherford *et al.* 2005). The river flows in flood events, which most commonly occur during the higher rainfall months of winter (Figure 4-22A), with the ten largest peak discharge events occurring in July and August (Figure 4-24C; Table 4-12). Winter flow peaks in the order of 3 to 7 million cubic metres discharge (DPUD 1994).

Table 4-12: Ten Largest Peak Discharge Events for Hill River (1971-2008)

Year	Month	Peak Discharge (m^3/s)
1974	August	50.6
1981	August	46.2
1983	July	45.1
1974	July	37.0
1988	July	36.2
1995	July	25.0
1999	July	24.1
1983	August	20.8
1975	July	20.2

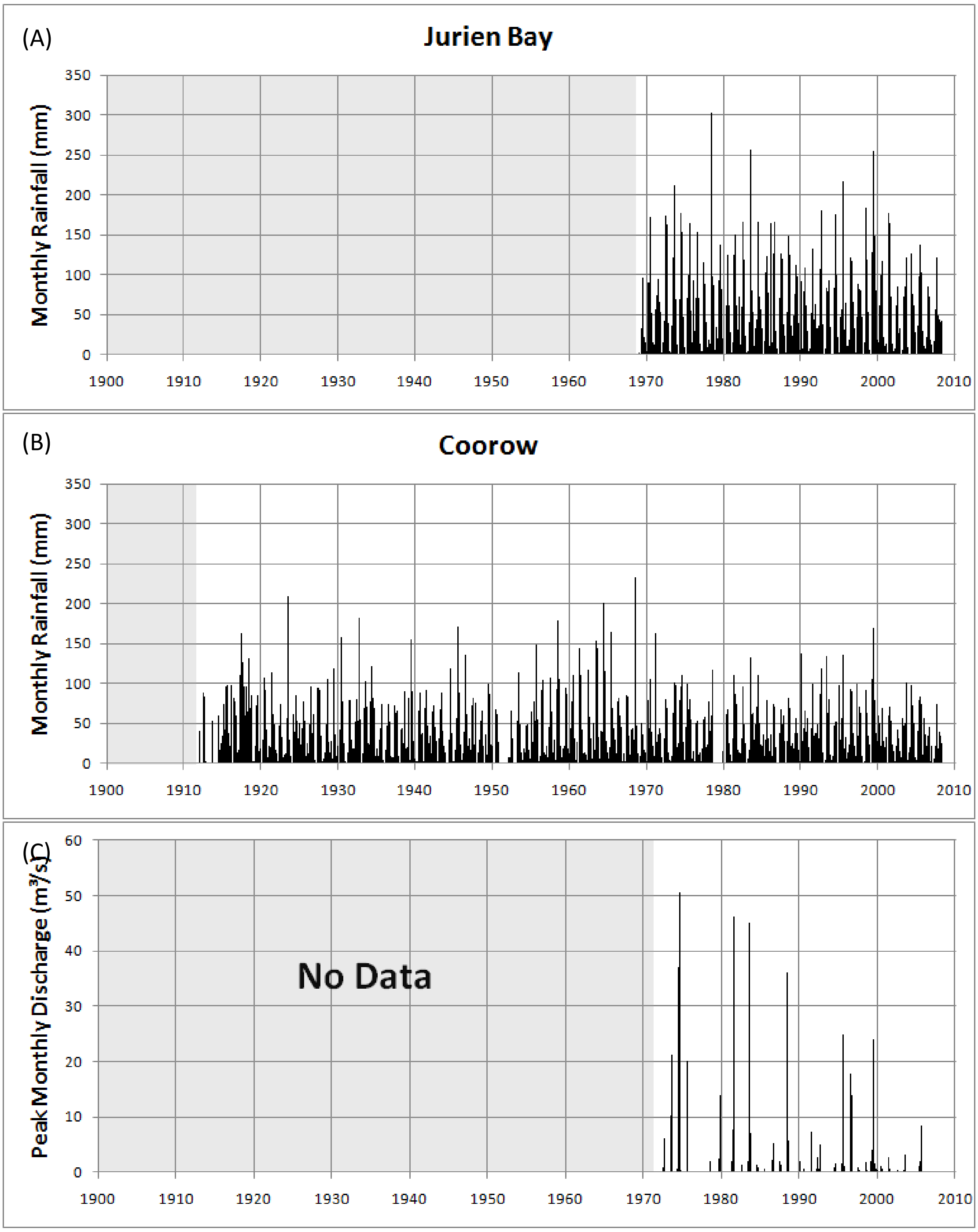


Figure 4-24: Rainfall at Selected Locations and Discharge for the Hill River (A) Coastal Station at Jurien Bay, (B) Inland Station at Coorow and (C) Peak Monthly Discharge at Hill River Springs approximately 45 km upstream of the Hill River mouth (Source: Bureau of Meteorology and Department of Water)

4.2.6. Groundwater

Beaches with elevated groundwater generally have greater instability as saturated sediments are more prone to entrainment by waves. Lower groundwater levels enhance deposition and the unsaturated sediments are increasingly available for aeolian transport along the beach and into the dunes. Low frequency shoreline fluctuations with recurrence intervals of 0.5-10 years can occur due to varying groundwater conditions (Clarke & Eliot 1987).

Regional groundwater behaviour is summarised in the *Central Coast Regional Profile* (DPUD 1994). Many of the groundwater investigations in the area relate to groundwater management for use in town and resource water supplies, regional park management and for management and environmental water requirements of wetlands and the Hill and Moore Rivers (Kern 1993, 1997; MPRA 2000; Stelfox 2001; Rutherford *et al.* 2005; Wetland Research & Management 2005). There are both deep and shallow aquifers in the region. Many of these are fed by the creeks that drain off the scarp and accumulate in coastal wetlands. Flow is generally west and south west, with the surficial aquifer discharging groundwater at the shoreline over a saltwater interface. Flow occurs towards the rivers in the vicinity of Hill and Moore Rivers (Stelfox 2001; Wetland Research and Management 2005). There is a low hydraulic gradient at the coastal interface due to the high hydraulic conductivity of the tamala limestone (Wetland Research & Management 2005).

Groundwater levels vary spatially and temporally. The groundwater level is higher closer to the coast from Wedge Island to south of Cervantes (Kern 1997; Rutherford *et al.* 2005) resulting in increased likelihood of beach saturation and mobility. North of Jurien Bay, from North Head to Coolimba, the creeks and groundwater flow from the scarp to accumulate in a series of coastal wetlands (Kern 1997). Groundwater levels are highest following winter in September-October and lowest following summer in March-April (Wetland Research and Management 2005), with inter-annual variability related to rainfall (Clarke & Eliot 1987). Higher groundwater levels can correspond with depletion of beach width (Clarke & Eliot 1987). During periods of lower groundwater levels the unsaturated sediments are more easily transported by wind, increasing the potential mobility of blowouts and sandsheets.

4.3. LOCAL MODIFICATIONS

Meteorologic and oceanic drivers of coastal processes on the Mid-West coast are described at a broad scale in Sections 4.2.1 through 4.2.6. However, the coastal response is a more complex function of the coastal morphodynamic system: which relates to the interaction of metocean forcing, the geological (sedimentological) framework and the landforms (Wright & Thom 1977). Interpretation of the landforms and geological structure may be used as a proxy to describe local scale variations in coastal processes that arise due to morphodynamic interactions.

4.3.1. Coastal Aspect

Coastal aspect determines the prevailing and dominant metocean processes to which the coast is susceptible (Section 3.3.2). The Gingin-Dandaragan coastal aspect is largely controlled by the geologic framework, including the aspect and form of the ridges and reefs. The average aspect changes north of Thirsty Point from west-southwest to west; with local aspect varying from south to west to north owing to the presence of tombolos, salients, cuspate forelands and embayments. The shift in general aspect north of Thirsty Point, along with a north-south reef alignment, contributes to the nett deposition of sediment in this area in inshore sand banks and in dune blowouts and sandsheets. The shift in aspect coincides with an increased N-S alignment of landforms and of the seabreeze.

The majority of the Gingin-Dandaragan coast is partly sheltered from dominant northwesterly storms by the coastal alignment and reef structure, but is more exposed to dominant southwesterly fronts and prevailing southerly to south-southwesterly seabreeze systems. The coastal response to seasonal, interannual and interdecadal variability in winds, swell and water levels will vary with aspect.

4.3.2. Sediment Sources

The influence of local variability in sediment supply and landform connectivity is discussed in Section 3.2. The alongshore variability in the supply of sediment from nearshore sources is significant for the landforms of the Gingin-Dandaragan coast. The rate of onshore transport of sediment from banks, formed in the lee of reefs and islands, and seagrass meadows could undergo long-term change due to altered metocean forcing as it does with short-term changes in weather conditions such as those described by D'Adamo (1997) and Sanderson (1997).

Seagrass meadows are present largely seaward of the first reef between Moore River and Wedge Island, within the landward lagoon between Wedge Island and North Head, with other localised patches in more sheltered areas close to cuspate forelands (DPUD 1994; MPRA 2000). The sediment produced in seagrass beds is often transported onshore across shallow banks (Figure 4-25). The largest onshore feeds from banks are likely to occur at Thirsty Point, north of Cervantes (Appendix C; Figure C - 9), at Twin Bank at Black Point (Appendix C; Figure C - 7), in the lee of Booker Rocks (south of Hill River) (Appendix C; Figure C - 7), within Jurien Bay at Island Point and north of Jurien Small Boat Harbour (Appendix C; Figure C - 5).

4.3.3. Reef Structure

The structure and formation of landforms is strongly tied to the nearshore reef systems of the Gingin-Dandaragan coast (Section 3.3; Table 3-2). The water level, waves and currents interact with the rock to modify the inshore processes, including sediment transport.

The degree of protection provided by reef is strongly affected by the wave conditions and the still water level (GEMS 2005). However, there is further variability associated with wave period, wave direction and the reef structure. There is often greater effectiveness of reef sheltering on the inshore wave climate during lower water levels. For low water conditions, where the reef is emergent or partially emergent, waves break at the outer edge and may possibly spill across the platform. The change in wave angle across the reef is likely to be greater for lower water level conditions. Under high water conditions lower friction is experienced. Storm erosion in many sections of the Gingin-Dandaragan coast will be most significant when high water levels coincide with high wave energy events, as the wave energy will transmit across the reef (Coastal Zone Management & Damara WA 2008).

Potential future changes in amplitude and duration of water level fluctuations could alter the inshore wave climate and sediment transport, along with migratory secondary and tertiary sediment cell boundaries.

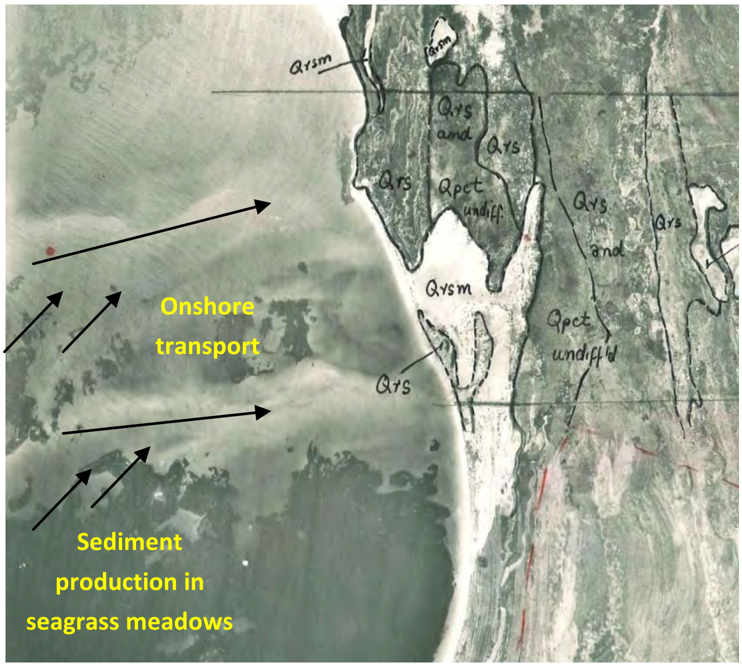


Figure 4-25: Illustration of Sediment Supply by Seagrass Meadows and Banks (Image source: Twin Banks, north of Cervantes from 1960)

Reefs have influence on the inshore wave climate and landforms via:

- The reduction of wave energy through friction and wave-breaking. The reduction in wave transmission is dependent on reef structure, with an exponential decay in wave energy with increasing shelf width (Fredsoe & Deigaard 1992). Greater wave energy can be transmitted during higher water levels. Local wind waves will have more influence in areas where the reef protects the coast from incoming swell;
- Refraction and diffraction (islands or lumps) which alters the wave direction;
- Creating a differential in water level at the coast owing to the discontinuous structure of the reefs. Higher water levels will occur in areas with greater wave transmission, such as gaps in the reef or lower reef sections, as a result of greater wave setup. This generates alongshore currents, with sediment transported away from the areas of highest wave transmission. This mechanism contributes to the presence of sedimentary accumulation landforms adjacent to gaps in the reef (Hearn *et al.* 1986; Sanderson 2000);
- Islands which reflect and break waves with a wave shadow formed in the lee, in addition to the primary influence of wave diffraction. This produces a relatively lower water level behind the island, generating alongshore currents with sediment transported to the wave shadow area; and
- Altering the sediment transport dynamics and sediment holding capacity of beaches perched on rock (see Section 4.3.5).

Reefs and islands also contribute to the formation and amplification of currents, which influence local sediment transport rates and pathways. Wave-generated rips are repeatedly developed in gaps through relatively continuous reef sections, providing potential to transport sediment offshore (Hearn *et al.* 1986). Wind-driven flows can be accelerated through a constrained gap in the reef, or vertically over a broad reef platform. Current amplification between reefs or islands and the land (e.g. cuspate forelands) can result in locally enhanced alongshore sediment transport, contributing to the northward skewness of sedimentary accumulation landforms on the Gingin-Dandaragan coast (Sanderson 2000; Section 4.3.4).

Potential response of the coast to future changes in water level and wave climate (including direction) will not be uniform due to the varied reef and lagoon structures. For example, at the sub-decadal timescale the most susceptible reaches are likely to be in close proximity to salients (Section 4.3.4) and extensive rock outcrops (Section 4.3.5). Any future response to changing environmental conditions should also be superimposed on the potential for reef collapse as the Gingin-Dandaragan coast reef is degrading (Sanderson 2000).

Any local coastal processes investigations for the Gingin-Dandaragan coast require consideration of reef influence on the inshore wave climate, currents and local patterns of sediment transport in response to reef variability. The inshore non-directional wave climate has been compared to offshore non-directional wave climates for short durations for two locations of the Gingin-Dandaragan coast: Moore River (1988-1989) and Ledge Point (2002-2004). The relationships interpreted from short datasets are dependent on the monitoring period in relation to the natural variability of the wave, wind and water level climates and do not necessarily capture the full range of conditions occurring at the inshore sites.

4.3.3.1. Moore River/Guilderton

Two non-directional waverider buoys were installed offshore and inshore of the reef near the entrance to Moore River as part of a Port feasibility study as recommended by Steedman & Associates (1976) and reported by McCance (1991). The significant wave height (H_s) and zero crossing wave period (T_z) were recorded at six hourly intervals for nine months at both locations (Table 4-8).

The potential influence of the reef complexity was discussed by both Steedman & Associates (1976) and McCance (1991). There is both an inner and outer reef line, with the reef crest at the outer reef line exposed at low tide level, and up to 150m wide. The reef is not continuous, with many outcrops and channels. This results in complex wave trains of transmitted, reflected, diffracted and refracted waves, combined with standing waves formed between the reefs.

McCance (1991) derived an approximation for inshore wave height as a function of offshore wave height. For swell with offshore wave heights of 1.5 to 5 m range, this theoretical approximation would equate to the inshore wave height being 40%-50% of the offshore wave height. This is a similar result to the Ledge and Mullaloo studies (Section 4.3.3.2; Steedman 1977). The wave period was variable, with no clear trend, other than the inshore wave period irregularity increased as the offshore wave period increased. This would partially be attributed to the structure of the reef and local wind influences acting across the 4km fetch between the two sites.

McCance (1991) acknowledged the limitations of this approach as there was no account for the approaching wave direction, directional spread, wave reflection, water level or weather systems such as squalls. Steedman & Associates (1976) provide some discussion on these factors. Also, instrument error, the short dataset and time for the wave to travel between buoys would have affected the relationship between the two buoys.

4.3.3.2. Ledge Point

A wave study in the vicinity of Ledge Point in 2002-2004 investigated the influence of reef structure on the inshore wave climate (Damara WA 2005). Relatively short periods of measurement were undertaken at four inshore locations using an AWAC meter (Table 4-13), to be compared with an offshore data set (Figure 4-14). Primary assessment of the data sets showed a very high correspondence of inshore and offshore wave measurements, with the inshore significant wave height typically 30-40% of that recorded offshore (Table 4-13). These results are similar to the findings of Steedman (1977) that suggested the multiple lines of reef and the beach at Mullaloo attenuated a mean 39% (range 23-71%) of the wave energy, with a standard deviation of 10%.

The inshore total wave height averaged 34% of the offshore total wave height, reaching up to 55%. There did not appear to be any clear dependence of these ratios with offshore wave height, with influence of wave period, wave direction, water level and reef structure having varied impact on the ratios.

The AWAC wave measurements showed a slightly higher level of variability between consecutive measurements compared with the waverider buoy observations. The relative contribution of instrumentation effects or inshore wave character is uncertain. However, this variability needs to be considered when comparing singular observations of offshore and inshore waves.

Table 4-13: Summary of Four AWAC Deployments at Ledge Point (Source: Damara WA 2005)

Location	Location 1	Location 3	Location 4	Location 5
Observation Period	Late Summer to Early Autumn	Late Winter to Early Spring	Late Spring to Summer	Late Summer to Autumn
Observation Dates	31/1/2003-2/4/2003	7/8/2003-2/10/2003	7/9/2003-13/2/2004	25/2/2004-19/5/2004
Storm Characteristics	No Strong Storms	4 Winter Storms	No Strong Storms	3 Autumn Storms
Water Level Effects	Weakly apparent	Apparent	Not Apparent	Apparent during storm
Mean Inshore vs Offshore (maximum)	41% (65%)	32% (50%)	28% (50%)	34% (55%)
Apparent Relationship		Depth Limited	Sensitive to Direction	

4.3.4. Cuspate Forelands

Salients, cuspate forelands and tombolos are common sedimentary accumulation features of the coast along the Swan Coastal Plain (Searle & Semeniuk 1985; Sanderson & Eliot 1996). Salients are low-amplitude, seawardly convex reaches of coast. As do cuspate forelands, salients occur in the lee of different reef structures. However, cuspate forelands are promontories that project well seaward from the general trend of the shoreline, often at a point of convergence of waves and currents. In this report they are commonly used to identify the boundaries of sediment cells. Tombolos extend seaward to attach to an island or reef. The initial formation of these features largely occurred during periods of different mean sea levels within the Holocene (Woods & Searle 1983; Searle *et al*. 1988), with extensive modification by contemporary metocean forcing. Cuspate forelands are included in the assessment of vulnerability for their susceptibility (Section 3.3.2) to changing metocean conditions; however, each cuspate foreland should be considered independently of the adjacent cells as each will often be more vulnerable to future environmental change.

The varied development of sedimentary accumulation landforms on the Gingin-Dandaragan coast is attributed to the complex reef structure, localised nearshore processes and sediment availability. Five types of sedimentary accumulation forms on the Central West Coast have been identified by Sanderson & Eliot (1996) and are shown schematically in Figure 4-26, together with their alongshore distribution. Some of the landforms are migratory. Nearly all cuspate forelands are skewed in the prevailing wind-direction. They are influenced by wind-driven, circulation and local enhancement of currents between the landform and the reef or island and alongshore sediment transport by breaking wind waves, wind-driven currents and aeolian transport.

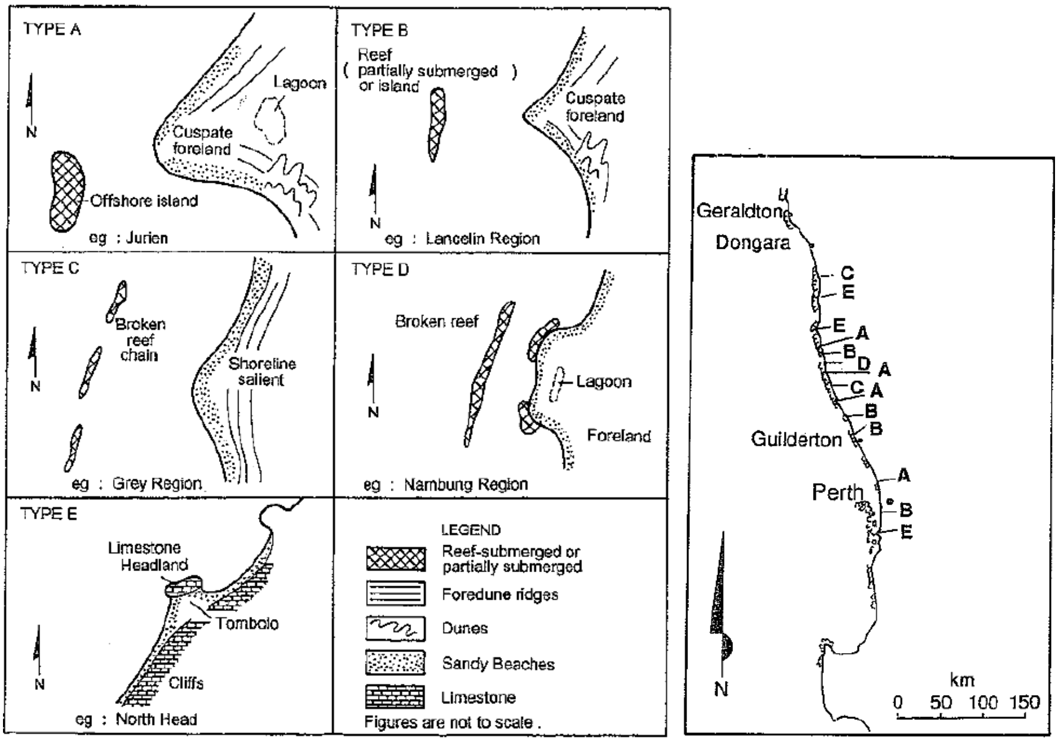


Figure 4-26: Reef Protected Features on the Central West Coast
(Source: Sanderson & Eliot 1996)

The formation and migration of salients, cuspate forelands and tombolos is potentially reversible under changing metocean and sediment supply conditions. There may be a tipping point of landform erosion that results in rapid retreat that is likely to be irreversible across the planning timeframe of 100 years. This could occur as a result of a loss of reef control (e.g. partial collapse), as has occurred at Post Office Beach in South Australia (Fotheringham 2009) and/or a significant reduction in sediment supply. There is evidence of wholescale retreat of cuspate forelands, larger in size than Island Point at Jurien Bay, in the vicinity of the Beagle Islands.

4.3.5. Perched Beaches

A perched beach may be defined as an accumulation of unconsolidated sediment atop rocky coastal topography (Larson & Kraus 2000; Doucette 2009; Gallop *et al*. 2011). Semeniuk and Johnson (1985: 233) described such beaches as '*rocky shore with sandy beach*' and noted they permanently have '*a wedge, pockets or continuous ribbon of beach-dune sand overlying inner parts of the platform, notch, high tidal seacliff, supratidal seacliff and bench*'. At the broadest scale they may form the mainland barriers described by Roy *et al*. (1994). The beaches are geologically controlled, with the interaction between the local metocean processes, available sediment and underlying rock structure governing the beach response. They can undergo rapid changes in width and elevation, as occurs at Seabird, partially due to the restricted volume of sediment available for transport. Perched beaches are included in the assessment of vulnerability (Sections 3.3.2 and 3.3.3) but also should be considered n further detail in any local assessment.

An understanding of the perched beach system is required for assessing vulnerability on a local scale. The behaviour of perched beaches is not well described in available literature (Green 2008); however, there are some conceptual models available that describe the behaviour of certain types of perched beaches (Green 2008; Gallop *et al.* 2011). Many of these models consider cross-shore processes, such as those shown in Figure 4-27. Sediment can be contributed to the beach during low water levels when waves overtop the offshore limit of the rock platform, depositing sediment on the platform. Erosion of the beachface occurs owing to lower wave energy attenuation during high water levels, with sediment deposited seaward of the platform. These beach systems are sensitive to inter-decadal variability in metocean processes, such as periods of higher water levels removing sediment from the beachface.

The elevation of the rock surface underlying unconsolidated coastal sediments in relation to sea level is a critical factor in determining the effects of natural fluctuations in sea level on overlying sand deposits 'perched' above the rock. In some circumstances coincidence of periods of higher than average sea level with storm surge and high waves may erode and trigger instability of frontal dunes. The diversity of possible coastal response warrants consideration of the coastal susceptibility to changing environmental conditions as well as identification of landform elements which are inherently unstable. The two are clearly related. Susceptibility which identifies *potential* landform change is the primary factor, given the form of the rocky topography. The stability of the unconsolidated sandy landforms perched on the rocky topography essentially describes the present condition of the barrier surface and is a secondary consideration. It describes landform change that is *presently* taking place.

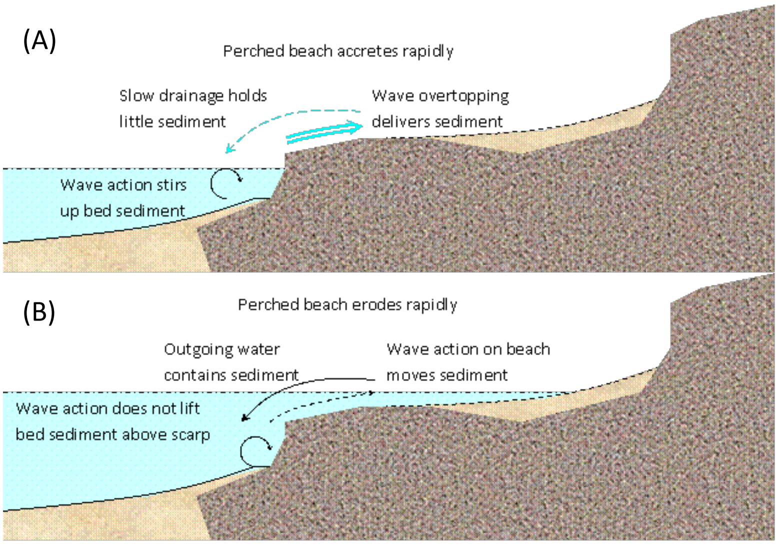


Figure 4-27: Perched Beach (A) Accretion Process and (B) Erosion Process

Further consideration is required into other factors controlling the beach presence and variability, particularly the role of alongshore transport. This includes the planform behaviour of the area, such as any local currents transporting sediment beyond the platform through gaps in reefs or rips and limits to sediment availability by headlands, cliffs and engineered structures. Investigations are required into the sediment transport patterns at the site including: pathways for sediment supply and loss; the episodic erosion patterns (e.g. there may be a storm threshold for erosion); and the disjunction between the erosion and recovery processes (Figure 4-27).

A relatively unstable and migratory perched beach system could have relatively stable landforms further landward.

4.4. COASTAL CHANGE

Coastal change occurs over a wide range of temporal and spatial scales. More slowly varying metocean processes provide extrinsic forcing and affect the physical structure of the coast, whereas more rapidly varying processes cause fluctuations that have a reduced residual effect on structure when considered over an extended period but may have significant local affects on surficial landforms. The conceptual framework under which observed changes have been assessed commonly uses the assumption that different spatial scales will be dominated by processes acting over corresponding time scales (de Vriend *et al*. 1993; Cowell & Thom 1994). This framework is often used to justify four distinct scalar concepts when describing coastal change:

1. At the largest (geological) scales, coastal change is dominated by eustasy (sea level movements), isostasy, tectonics, lithification and occasionally vulcanology (van de Plassche 1986). These processes determine the presence of rock, and through movement of relative sea level, may relate to large movements of the coast;

2. At moderate (geomorphic) scales, coastal evolution is determined by the production of mobile sediments, transfer via metocean forcing and accumulation in zones of relative shelter. This suggests simulation of coastal change using sediment budgets tied to identification of large-scale sources, transport paths and sinks (Komar 1996; Rosati 2005) prompting the concept of equilibrium coastal alignment (van Rijn 1998);
3. Over short (planning) scales, large scale sinks and sources of material may be considered constant and the shoreline fluctuations caused by storm erosion-recovery cycles may be considered almost in balance. Coastal change may be described largely by alongshore sediment transport and its variability, including spatial variation developed through changes in coastal aspect, and year-to-year metocean variations;
4. Over very short (coastal management) scales, dramatic coastal change occurs in response to weather cycles. This is most commonly represented as cross-shore transport associated with storm events and subsequent recovery during lower energy conditions (van der Meer 1988).

It is relevant to note that change may be active over all time scales simultaneously. Hence, when assessing change, care is required to ensure that the process of change is not inappropriately identified due to confined use of one or two concepts.

There is a lack of detailed morphostratigraphic description and historical information describing metocean processes for the region. The following general observations about coastal change and stability have been drawn from available information, site visits and interpretation of imagery. They are discussed at the scales of coastal change described above.

At a geological timescale, the rocky landforms of secondary coastal compartments have provided topographic control for formation of the modern dune barrier as the dune ridge evolved during the past 10,000 years. Albeit slowly, barrier evolution is continuing at present as sediment is moved along and across the shore. Phases of dune activity associated with variation in the intensity and duration of metocean processes will continue to contribute to development of the dune ridge through the formation and destruction of foredunes, blowout activity and the migration of nested parabolic sand dunes. At a similar geological timescale, the reef and headland provide topographic control for the formation of sedimentary accumulation landforms, such as sand banks, salients, cuspate forelands and tombolos. These coincide with tertiary coastal compartment and primary sediment cell boundaries.

Medium time scales are relevant to barrier changes occurring over decades and centuries. In this context, dune formation and migration on the barrier is ultimately dependent on sediment supply from offshore and alongshore, in the context of long-term variability in metocean processes. At present the alongshore component of littoral sediment transport (nett northerly), superimposed with circulation patterns influenced by the reef and lagoon structure, is critical to coastal stability and future evolution of the barrier. The ramifications of this are that the future medium-term stability of the coast will potentially be affected by rates of onshore sediment supply, any updrift interference with the coastal sediment transport, or modification to the reef or headland controls, as well as by natural variability and change to metocean processes. Changes in sediment supply and dominance of the southerly component of governing metocean processes are contributing to the northwards migration of some of the sedimentary accumulation landforms on the coast (Sanderson 2000).

Local changes are also active over medium time scales, as any future destabilisation and landward movement of the dunes results in a loss of sand from the adjacent shore. There has been a general reduction in dune blowouts, and increase in vegetation cover, in the Gingin-Dandaragan coast from the 1960s to early 2000s, with a minor increase in dune activity recently. Changes in beach width largely correspond with dune and blowout activity. Sandsheets have continued to rapidly migrate north (northeast to northwest dependent on the local wind climate and topography) at varied rates with investigations of rates presently in progress by the Geological Survey of Western Australia. Some sandsheets are revegetating on the southern flank.

At sub-decadal time scales, interaction of modern metocean processes with the inherited geologic framework has two ramifications. Firstly, alongshore variation in coastal alignment, beach erosion and deposition, foredune formation and dune development occurs as a result of this interaction. The reaches of coast most susceptible to environmental change are commonly in close proximity to shoreline salients and extensive rock outcrops. Secondly, it invalidates application of the Bruun Rule (Bruun 1962) that has been widely applied in the calculation of setback to development on mixed sandy and rocky coast in Western Australia (WAPC 2003); a point made by Bruun himself in his criticism of the application of the 'rule' (Bruun 1983, 1988). This implies that localised estimation of shoreline change is necessary and should be linked to geophysical determination of the distribution and elevation of the underlying limestone topography supporting the barrier.

On an event scale, the response of beaches, foredunes and primary dunes to storms is localised, with the sediment transport influenced by the broad scale metocean processes along with the local influences of groundwater, coastal aspect, sediment supply and connectivity, reef structure and the underlying rock structure (Section 4.3). The rate of recovery during lower energy periods varies along the Gingin-Dandaragan coast, largely influenced by the underlying rock structure.

4.4.1. Shoreline Movement

Shoreline change is typically described in terms of cross-shore and alongshore sediment movement (van Rijn 1998). This separation is fundamentally based upon geomorphic time scales, where cross-shore transport most commonly occurs under high frequency fluctuations associated with storms and water level variations; and nett alongshore transport is considered to represent slower changes, which may be evolutionary in nature. For example, from an analysis of 16 years of monthly data from Scarborough Beach, Clarke and Eliot (1983, 1987) attribute less than 5% of nett annual sediment movement to alongshore transport, despite being the major mechanism for long-term change. Although the distinction between cross-shore and alongshore transport is convenient, it is not altogether accurate. Significant alongshore transport also may occur pulsationally and over short times frames, particularly where the inshore bathymetry is complex and there is periodic supply of sediments along and offshore through reef gaps and from inshore banks and bars, as it is on the Gingin-Dandaragan coast. Similarly, cross-shore transport may not always have a nett zero change over years or even decades.

Cross-shore processes are evidenced by the presence of shore parallel bar and bedform features in the nearshore waters, scarped foredunes or frontal dunes and mobile frontal dunes where sediment is actively moving inland from the shore. The effect of alongshore transport is apparent through the geological structure of the barrier and its landform patterns as well as by the beach profile configuration in sheltered environments (Nordstrom 1992). The analysis applied to the Gingin-Dandaragan coast examined changes to the beach and coastal dune components discernable from available aerial photography as well as ground reconnaissance. It provided an indication of the areas susceptible to change as well as the relative stability of landforms within each sediment cell. In places the barrier is susceptible to becoming unstable and subsequently eroding, particularly where vegetation has been removed or the frontal dunes, those closest to the shore, have been activated by metocean processes.

More detailed analysis of coastal change was completed for eight Areas of Planning Interest (Section 6). Vertical aerial photographs were examined from 1960/1965 and 2009, with further years in between for certain sites. Although a more detailed, photogrammetric analysis is required to fully quantify shoreline and dune movement, comparison of the photographs indicates change in the shoreline position is localised to areas between rock outcrops or corresponds to a northern migration of many of the salients and cuspate forelands. Sand sheets continue to migrate north, with some revegetating on the southern flank. However, the photographic record is not sufficiently frequent to pinpoint the number of phases and when each occurred. Overall the historic record indicates a shoreline that is variable, particularly in the vicinity of sedimentary accumulation landforms and fluctuations in dune activity owing to changes in vegetation cover. There are localised reaches of sandy shore backed by unstable foredunes and frontal dunes that are prone to blowouts.

4.5. PROJECTED FUTURE CHANGE

Analysis of the broad-scale susceptibility and stability of the Gingin-Dandaragan coast has primarily been conducted with reference to its geological framework and the landforms present. However, it is relevant to recognise that the coastal climate is subject to considerable variability, both due to natural causes and anthropogenic factors, with the latter most strongly linked to those caused by increased greenhouse gas emissions (Intergovernmental Panel on Climate Change: IPCC 2007; Commonwealth Scientific and Industrial Research Organisation: CSIRO 2007). Both natural and anthropogenic climate variations are subject to uncertainty, with increasing significance when considered over longer time scales. Consequently, coastal management within the region should be undertaken within a framework that recognises this uncertainty. Additionally, the complexity of the coast with beaches and forelands tied to the limestone topography requires a detailed geophysical assessment of potential landform change at local and site scales for areas where development is proposed, similar to that recommended for Cottesloe by CZM & Damara WA (2008).

Potential variations of coastal parameters due to enhanced climate change have been examined through numerical modelling using a range of possible emission scenarios (IPCC 1990). From the 1980s and 1990s, modelling outputs were mainly focused upon ocean-atmosphere interactions, reflecting changes in temperature and water balance at a global scale (Titus *et al.* 1985; IPCC 1990). More recently, effort has been made to “downscale” the modelling to a level that provides projection of climate parameters with sufficient resolution to undertake regional climate change assessments (IPCC 2007; CSIRO 2007).

The best researched and reported components of projected change are temperature and mean sea level rise, associated with global warming, which are possibly the coastal parameters most amenable to downscaling. Mean global sea level rise is estimated to range from 0.3 to 0.9 m by 2090, with a smaller change of 0.1-0.5 m to 2040 (IPCC 2007; CSIRO 2007; DoT 2010). The well-espoused projected effect of a sea level rise is to cause a landward and upward translation of the shore profile (van Rijn 1998). However, for the Gingin-Dandaragan coast, such a movement is expected to be complicated through interaction with coastal rock features, including an increase in wave exposure due to reduced reef sheltering. The increased water level and wave exposure could cause inundation of some coastal lowlands; rotation or retreat of pocket beaches and barrier systems; alongshore migration of salients, forelands and tombolos; and increased influence of the underlying lithified basement. The complex nature of mixed sand and rock shoreline response to sea level variation has been demonstrated for the Swan Coastal Plain using palaeological evidence (Semeniuk 1996b).

Preliminary estimates of changes to the wind climate are consistent with a southwards latitudinal shift of the weather bands, with a mild weakening of median winter winds and a slight strengthening of median summer median winds (CSIRO 2007). These changes are small (<5%), and the range of uncertainty associated with the modelling is apparently larger than the trend. Projected changes to the southwest region wave climate have not presently been downscaled from global climate models (Hemer *et al*. 2008). Interpretation of the existing measured wave climate with the projected change to wind fields suggests that there would be a general decline of background swell, with a slight increase to summer winds. Section 4.2.3 contains further discussion on natural variability of wave heights. The effect on alongshore sediment transport and sediment budgets is uncertain.

Analysis of variability and secular trends of historic coastal data for south-west Western Australia has been undertaken for a range of coastal parameters, including rainfall. Findings of these analyses are relevant to the Gingin-Dandaragan coast, noting that there is an increasing contribution of sub-tropical and tropical forcing northwards. Studies include:

- Synoptic systems (Karelsky 1961; Steedman & Craig 1983; Trenberth 1991; Bosserelle *et al.* In Press; Haigh *et al.* In Press)
- Wind observations (Steedman & Associates 1982; Panizza 1983; Nicholls *et al*. 2000; Damara WA 2003)
- Rainfall (Indian Ocean Climate Initiative: IOCI 2002; CSIRO 2007)
- Wave conditions (Riedel & Trajer 1978; Lemm 1996; CZM & Damara WA 2008; DoT 2009; Bosserelle *et al.* In Press); and

- Water levels (National Tidal Facility 2000; Feng *et al*. 2004; Pattiaratchi & Eliot 2008; 2010; Eliot 2010; Eliot 2011; Haigh *et al.* In Press).

Typically, these analyses have shown considerable variability at seasonal and sub-decadal time scales. The most widely recognised variations are those linked to El Nino-La Nina climate oscillations. However, in most cases, comparatively short records (<30 years) or changes of instrumentation limit the capacity to identify inter-decadal fluctuations or to describe secular trends. Recent investigations into longer-term natural variability have incorporated reanalysis of modelled atmospheric pressure and winds to consider the variability of tracks of storm events that generated surge (largest 100 surge events) and swell (offshore H_s>7 m) in south-west Western Australia in the last 60 and 40 years respectively (Bosserelle *et al.* In Press; Haigh *et al.* In Press). Further discussion of variability is included for water levels in Section 4.2.2 and waves in Section 4.2.3.

Projected changes in rainfall are relevant for the influence of rivers and drains on the coast, coastal flooding as well as aeolian transport, dune stability and sandsheet migration. CSIRO (2007) projections for Perth coastal areas suggest decreasing rainfall, with an increase in summer rainfall and no anticipated change to the intensity of extreme rainfall events. These projections largely match local analyses of rainfall (IOCI 2002); however the highly variable regional rainfall could result in possible increases in frequency of high intensity precipitation events. Both projected rainfall and historic flood climates should be considered.

The influence of tropical and sub-tropical synoptic systems on the Gingin-Dandaragan coast is mainly developed through occasional southerly travelling tropical cyclones. These represent approximately 10% of cyclones within the Bureau of Meteorology tropical cyclone database, although they have been relatively under-represented since the 1980s. Historical variability of tropical cyclones is very high, and strongly biased through changes of instrumentation and observational techniques (Coleman 1972; Lourensz 1981; Landsea 2000; Damara WA 2008). There is evidence that cyclone behaviour is linked to climate variations over inter-annual time scales (Solow & Nicholls 1990; Nicholls 1992; Qi *et al*. 2008), which suggests a likely response to anthropogenic change (Knutson *et al*. 2001; Abbs *et al*. 2006). However, stark contrast between existing modelling studies (Abbs *et al*. 2006; Camargo *et al*. 2008; Leplastrier *et al*. 2008) suggests that the parameters controlling cyclone formation off Western Australia have not been fully resolved. This is consistent with the statement regarding global studies of cyclone behaviour:

> "*Current knowledge and available techniques are not able to provide robust quantitative indications of potential changes in tropical cyclone frequency*" (Henderson-Sellers *et al*. 1998; World Meteorological Organisation: WMO 2006).

In this situation, the effects of such uncertainty should be considered in the interpretation and projection of coastal change.

Coastal climate variation over the historic period is generally larger than the predicted anthropogenic forcing over the next 30 years (Eliot & Pattiaratchi 2007; CZM & Damara WA 2008; Bosserelle *et al.* In Press). Consequently, the natural variability may either mask or exacerbate the effects of climate-change induced trends, depending upon the active phase.

Due to the apparent sensitivity of the Gingin-Dandaragan coast to different coastal parameters, interpretation of the effects of climate variability, including anthropogenic change, should consider a range of possible scenarios, with variation of winds, wave conditions and water levels.

Further detailed consideration of the natural variability and potential future changes in metocean forcing at a local scale is advised for any detailed site investigations of coastal processes for planning and development purposes, including setback assessments. The information included on the natural variability at a regional and local scale (Sections 4.2 and 4.3) should be combined with projected future change in metocean forcing.

5. Landform Stability & Susceptibility to Change

The Gingin-Dandaragan coast comprises three primary, six secondary and thirteen tertiary compartments (Figure 1-2; Table 2-1). The Gingin Coast partly falls in the northern part of the Swan Primary Compartment and to the north of the Study Area the Dandaragan Coast overlaps with the southern part of the Beagle Primary Compartment. The two shires share the Hill Primary Compartment which extends between the mouth of the Moore River and North Head. Four secondary and ten tertiary compartments are included in the Hill Primary Compartment. At a more detailed scale, thirty six sediment cells have been identified between Wreck Point and Fisherman Islands (Figure 1-2; Table 2-1). Twenty nine of the sediment cells are within the Hill Primary Compartment.

The vulnerability of the three primary compartments has previously been considered by Eliot *et al.* (2011a) for strategic planning. The direct assessment of primary, secondary and tertiary compartments was not considered in this study, given the focus on local area planning. However, information is inferred on the compartments from the sediment cell assessments.

Sediment cells of the Gingin-Dandaragan coast are considered in detail at a landform scale appropriate to local area planning. The landforms for each sediment cell have been identified, mapped and described. The cell boundaries were identified and mapped in Figure 1-2 and Table 2-1. The landforms of each cell were mapped in Appendix C and described in Appendix D in relation to the susceptibility and instability criteria listed in Table 2-6.

5.1. LAND SYSTEM SUSCEPTIBILITY AND LANDFORM INSTABILITY

The major natural structural features of the cells as well as their present and potential future landform stability are discussed separately prior to addressing vulnerability.

5.1.1. Land System Susceptibility

The major natural structural features of each cell were described (Appendix D) and ranked (Table 5-1) according to their likely susceptibility to change. The overall results for the Gingin-Dandaragan coast reveal a substantial proportion (56%) of the 36 cells examined are moderately susceptible to change. Thirteen cells (36%) have a landform association with a low susceptibility; and three cells (8%) are highly susceptible. A summary of the three levels of susceptibility across primary and secondary compartments, the combined Gingin-Dandaragan coast and separately for each shire is shown in Table 5-2. A summary of the susceptibility across primary, secondary and tertiary compartments, and the sediment cells is included in Table 5-8.

Sediment cells have low susceptibility where the coast is protected by a nearly continuous offshore reef or a wide shelf, platform or bank; straight or seawardly convex rocky coast; the coast is sheltered from metocean forcing; beaches are perched on an intertidal rock surface; and/or the dune barrier is either perched on a rock surface above the highest astronomic tide or is an episodic, transgressive barrier. Tracts of land having low susceptibility occur between Wreck Point and the Moore River, Eagles Nest Bluff to South First Bluff, North Wedge to Grey and Middle Head to North Head (Table 5-1; Table 5-2). These are areas where the coast is protected by offshore reef, rock typically outcrops along the shore and the dune barrier is likely to be perched on a rock surface above High Water Level.

Table 5-1: Susceptibility Rankings for Each Cell

Cell	Southern Boundary of Cell	Nearshore Morphology	Shoreline Configuration	Orientation	Barrier	Susceptibility Score	Susceptibility Ranking
36	South Fisherman	2	1	5	1	9	L
35	Sandy Point	3	3	4	3	13	M
34	Sandland	2	3	5	4	14	M
33	North Head	2	3	5	2	12	M
32	Pumpkin Hollow	3	3	1	1	8	L
31	Middle Head	3	3	2	1	9	L
30	Island Point	2	3	4	4	13	M
29	South Booka Valley	5	3	5	4	17	H
28	South Hill River	4	3	4	2	13	M
27	Black Head	2	1	2	1	6	L
26	Thirsty Point	3	3	4	3	13	M
25	Hansen Head	2	3	2	4	11	M
24	Kangaroo Point	2	3	5	4	14	M
23	Boggy Bay	2	3	5	4	14	M
22	Grey	2	2	5	2	11	M
21	South Grey	1	1	2	1	5	L
20	North Wedge	1	1	2	1	5	L
19	Wedge Island	1	3	5	4	13	M
18	Magic Reef	3	5	5	3	16	H
17	Narrow Neck	2	3	2	3	10	M
16	Dide Point	2	3	2	2	9	L
15	Lancelin Island	4	4	5	4	17	H
14	Edward Island	1	3	5	4	13	M
13	South Pacific Reef	3	2	5	1	11	M
12	Ledge Point	2	3	2	3	10	M
11	Green Reef	1	3	5	2	11	M
10	Manakoora Sand Patch	4	1	5	3	13	M
9	South First Bluff	4	1	5	1	11	M
8	Second Bluff	2	1	5	1	9	L
7	Eagles Nest Bluff	1	1	5	1	8	L
6	Seabird	1	1	5	4	11	M
5	Moore River	1	3	2	4	10	M
4	South Moore River	1	2	2	2	7	L
3	North Two Rocks	1	1	2	2	6	L
2	Two Rocks	1	3	2	2	8	L
1	Wreck Point	1	3	2	2	8	L

Sediment cells considered highly susceptible to change due to metocean forcing are Lancelin to Dide Point, Magic Reef to Wedge Island and South Booka Valley to Island Point (Table 5-1). Combinations of some of the following factors indicate susceptibility of these parts of the coast to change due to metocean forcing: limited protection by offshore reefs; exposure to NW storms; cuspate forelands; and sandy barriers inset between rocky outcrops.

Adjustment of the susceptibility ranking occurs with the scale of investigation (Table 5-8) because the proportion of coast comprising particular natural structural features, land systems and landforms changes with scale. It also highlights the need for very detailed examination of landforms and processes at local planning scales. Some of the cells have a higher susceptibility ranking when considered at a finer spatial scale than secondary compartments because the more susceptible natural structural features, such as cuspate forelands comprise a higher proportion of the coast of interest.

At a broad strategic scale the Gingin-Dandaragan coast has moderate susceptibility.

Table 5-2: Summary of Cell Susceptibility for Coastal Segments Including Primary and Secondary Compartments, Total Study Area and the Shires Note this is a count of cells of unequal coastal extent

Compartment		No. Cells	Susceptibility - Count and Percentage of Cells			
			L	**M**	**H**	**Mode**
Primary	Moore River to North Head	28	8 29%	17 **60%**	3 11%	M
Secondary	Thirsty Point to North Head	7	3 **43%**	3 **43%**	1 14%	M
	Wedge Island to Thirsty Point	7	2 29%	5 **71%**	0 0%	M
	Ledge Point to Wedge Island	7	1 14%	4 **57%**	2 29%	M
	Moore River to Ledge Point	7	2 29%	5 **71%**	0 0%	M
	Wreck Point to Moore River (Tertiary)	4	4 **100%**	0 0%	0 0%	L
Total for Gingin-Dandaragan		36	13 36%	20 **56%**	3 8%	M
Shire of Dandaragan		18	5 28%	11 **61%**	2 11%	M
Shire of Gingin		14	5 36%	8 **57%**	1 7%	M

5.1.2. Landform Instability

Simplistically, rocky sections of coast are less susceptible to change due to metocean forcing than sandy reaches along the shore and, as a first approximation, superficial (surface) landforms of the Gingin-Dandaragan coast were assigned a ranking for their relative stability on a three point scale following the classification of Gozzard (2011a, b). They were classed as being relatively stable (Low Instability), moderately stable or unstable (High Instability) and the results indicated in Table 5-3. The procedure deals specifically with landform types but omits some composite forms, notably barriers and cuspate forelands, which are structurally significant and more apparent at a broad scale. It also neglects aspects of the coast which link morphology with coastal processes and sediments. For example unconsolidated sand dunes overlying a high bedrock surface are less prone to shore erosion but may be destabilised by other processes, and there is a close relationship between the rocky topography of the inshore waters and landforms along the shore in their lee. These aspects led to the adoption of a methodology that distinguishes the structural attributes of sediment cells along the Gingin-Dandaragan coast from landform instability (Table 2-6).

The present instability of landform features at a cell scale were described (Appendix D) and ranked according to their likely instability (Table 5-4). Difference between the rankings for susceptibility and instability assigned to the same cell highlight the significance of long-term versus short-term change. Overall, the estimated levels of instability for each of the cells along the Gingin-Dandaragan coast reveal a high proportion (78%) of the 36 cells examined are moderately stable. Five cells (14%) have a low instability ranking; and three cells (8%) are of high instability. A summary of the three levels of landform instability across primary and secondary compartments, the combined Gingin-Dandaragan coast and separately for each shire is shown in Table 5-5. A summary of the instability across primary, secondary and tertiary compartments, and the sediment cells is included in Table 5-8.

Sediment cells display low instability where the coast has a limited amount of sediment stored inshore with sheltering by inshore reefs and/or rocky pavement; sandy beachface is has a sheltered profile; the frontal dune complex is relatively intact; and/or the barrier dunes are well vegetated. Sediment cells with low instability occur between Wreck Point and Two Rocks, Eagles Nest Bluff to Second Bluff, Pumpkin Hollow to North Head and along the coast north of Sandy Point (Table 5-4; Table 5-5).

Cells considered to have high instability are Manakoora Sand Patch to Green Reef, Wedge Island to North Wedge and Hill River to South Booka Valley (Table 5-4). Combinations of some of the following factors indicate current levels of landform instability: the inshore seabed is bare sand; beaches are commonly subject to high wave conditions or part of a barred river mouth; there is no foredune and the frontal dune is scarped; and vegetation cover is low and /or mobile sand sheets are present on the barrier.

Adjustment of landform rankings, in this case instability rankings, again varies with the scale of investigation (Table 5-8) because the proportion of coast comprising particular unstable landforms changes with scale. Some of the cells have a higher instability ranking when considered at a finer spatial scale than secondary compartments because the more unstable landforms, such as active dunes and scarped foredunes, represent a higher proportion of the coast of interest.

At a broad strategic scale the Gingin-Dandaragan coast has moderate instability.

Table 5-3: Gingin-Dandaragan Coast Landforms and their Relative Instability (Source: Gozzard 2011a, b). See Table 2-10B for Explanation of Colour Codes

Landform	Description	Relative Instability
Beach	Unconsolidated marine sediments, commonly sand and shell debris, deposited at the shore through the interaction of water levels, waves and currents.	High (Unstable)
Foredune	A single ridge or line of small dunes at the landward margin of the beach. Foredunes are the first stage of dune formation and support pioneer vegetation communities.	High (Unstable)
Foredune Plain	Low lying plain comprising a series of relic foredune ridges aligned parallel to the coast and adjoining the active foredune; relief is commonly less than 5m.	Moderate
Active parabolic dunes and blowouts, Quindalup Dunes	U-shaped, transgressive lobes or sand sheets migrating landwards. They vary in relief from 5 to 15m close to shore with slopes of up to 50% on the advancing slip-faces.	High (Unstable)
Parabolic and nested parabolic dune complexes, Quindalup Dunes	Phases of dune development have resulted in the most recently formed dunes overriding older dunes to landward. This forms a field of nested forms with a relative relief of 20 to 40m, elevations of up to 70m and steep, unstable slopes to landward.	Moderate
Older dunes, Quindalup Dunes	Well vegetated parabolic and nested parabolic dune complexes, commonly with more subdued relief than the younger forms described above.	Moderate
Older deflated dunes, Quindalup Dunes	An area of low relief, commonly less than 2m, formed on Quindalup Sands.	Low (Stable)
Long walled parabolic dunes Quindalup Dunes	Parabolic or U-shaped dunes with long trailing arms. These are a subset of the parabolic dunes described above and are sometimes referred to as hairpin dunes. The advancing head of the dune may be an active sand sheet.	Moderate
Deflation basins	Level to gently undulating plain bounded by the trailing arms of long-walled parabolic dunes and blowouts. The deflation basin may contain low dunes, less than 5m high with subdued relief.	Low (Stable)
Deflation basins, calcarenite floor	Level to gently undulating plain bounded by the trailing arms of long-walled parabolic dunes and blowouts. The deflation basin may contain low dunes, less than 5m high with subdued relief. The basin floor is developed in calcarenite.	Low (Stable)
Alluvial flats	Flat, level floodplain immediately adjoining a river channel.	Moderate
Alluvial channel	Main channel of a river and associated tributaries.	High (Unstable)
Alluvial terrace	High level floodplain or remnant floodplain of a river.	Moderate
Estuarine flats	Small estuarine area at the junction of a river and the ocean where stream flow is modified by tides and waves.	High (Unstable)
Lagoons and swamps, younger	Circular to elongate, topographically low, closed depressions, often the sites of small brackish to saline lakes.	Moderate
Lagoons and swamps, older	Deposits of former inshore lagoons formed about 3000–6500 years ago when sea level was approximately 5m higher than today.	Moderate
Cliff-foot slope	Parallel slopes immediately below a cliff resulting from the deposition of collapsed material from the cliff admixed with colluvial material.	Moderate
Colluvial footslopes	Moderately to very gently inclined slopes resulting from the deposition of mass wasting deposits.	Moderate
Barrier complex: Spearwood Dune System - calcarenite	Marine and aeolian sediments lithified to form the coastal limestone which outcrops as inshore reefs, pavement, shore platforms, ramps underlying the Quindalup Sands.	Low (Stable)

Table 5-4: Instability Rankings for Each Cell

Cell	Southern Boundary of Cell	Inshore Substrate	Beachface Profile	Frontal Dune	Barrier Vegetation	Instability Score	Instability Ranking
36	South Fisherman	2	2	1	2	7	L
35	Sandy Point	2	3	3	1	9	L
34	Sandland	3	4	3	3	13	M
33	North Head	2	3	3	4	12	M
32	Pumpkin Hollow	3	2	2	2	9	L
31	Middle Head	2	3	4	3	12	M
30	Island Point	3	3	3	1	10	M
29	South Booka Valley	4	3	5	2	14	M
28	South Hill River	4	4	4	3	15	H
27	Black Head	2	3	4	3	12	M
26	Thirsty Point	3	2	3	2	10	M
25	Hansen Head	4	2	2	2	10	M
24	Kangaroo Point	2	2	3	3	10	M
23	Boggy Bay	3	3	3	4	13	M
22	Grey	3	3	3	2	11	M
21	South Grey	2	3	3	2	10	M
20	North Wedge	2	4	3	2	11	M
19	Wedge Island	3	4	4	4	15	H
18	Magic Reef	3	4	3	4	14	M
17	Narrow Neck	3	4	3	4	14	M
16	Dide Point	3	3	4	2	12	M
15	Lancelin Island	3	4	4	3	14	M
14	Edward Island	3	2	2	5	12	M
13	South Pacific Reef	3	4	4	3	14	M
12	Ledge Point	3	4	4	2	13	M
11	Green Reef	3	4	3	2	12	M
10	Manakoora Sand Patch	3	4	3	5	15	H
9	South First Bluff	3	3	3	2	11	M
8	Second Bluff	3	3	3	2	11	M
7	Eagles Nest Bluff	3	3	1	1	8	L
6	Seabird	3	3	4	2	12	M
5	Moore River	3	3	3	2	11	M
4	South Moore River	3	3	3	2	11	M
3	North Two Rocks	3	3	4	2	12	M
2	Two Rocks	3	3	4	3	13	M
1	Wreck Point	3	2	2	2	9	L

Table 5-5: Summary of Cell Instability for Coastal Segments Including Primary and Secondary Compartments, Total Study Area and the Shires Note this is a count of cells of unequal coastal extent

Compartment		No. Cells	Instability - Count and Percentage of Cells			
			L	M	H	Mode
Primary	Moore River to North Head	28	2	23	3	M
			7%	**82%**	11%	
Secondary	Thirsty Point to North Head	7	1	5	1	M
			14%	**72%**	14%	
	Wedge Island to Thirsty Point	7	0	6	1	M
			0%	**86%**	14%	
	Ledge Point to Wedge Island	7	0	7	0	M
			0%	**100%**	0%	
	Moore River to Ledge Point	7	1	5	1	M
			14%	**72%**	14%	
	Wreck Point to Moore River (Tertiary)	4	1	3	0	M
			25%	**75%**	0%	
Total for Gingin-Dandaragan		36	5	28	3	M
			14%	**78%**	8%	
Shire of Dandaragan		18	1	15	2	M
			6%	**83%**	11%	
Shire of Gingin		14	1	12	1	M
			7%	**86%**	7%	

5.2. VULNERABILITY

The vulnerability of the cells was estimated by combining the overall rankings for susceptibility and instability to identify the likelihood of geomorphic change, grouped into five categories (Table 5-6; Figure 5-1). Descriptions of the main natural structural features and landform instability for each cell are included in Appendix D. The overall results for the Gingin-Dandaragan coast indicate four (11%) of the 36 cells examined have a low level of vulnerability; 10 (28%) are of low-to-moderate vulnerability; 16 (44%) are moderately vulnerable; six cells (17%) have a moderate-to-high vulnerability ranking and none had a high vulnerability. A summary of the five levels of vulnerability across primary and secondary compartments, the combined Gingin-Dandaragan coast and separately for each shire is shown in Table 5-7. A summary of the susceptibility, instability and vulnerability across primary, secondary and tertiary compartments, and the sediment cells is included in Table 5-8.

At a broad, regional planning scale, distinct landform patterns are apparent in each of the secondary compartments occurring in the Study Area, each characterising the structural compartment in which it occurs. The compartments are described in the sequence of nett littoral sediment transport from south to north and the prevailing features of each are as follows:

1. The tertiary compartment between Wreck Point and the Moore River is the reach of coast most amenable for rural-urban development with the exception of the area immediately north of Two Rocks Marina. It has a low susceptibility to change due to metocean forcing, its landforms have a low instability ranking and three of the four cells have a low-to-moderate vulnerability ranking (Table 5-7). Continuous offshore reef shelters much of the SW facing shore. Low-energy reflective beaches are inset between outcrops of rocky shore. The frontal dune ridge is scarped along the shore and foredunes are either absent or discontinuous. Landward, the perched barrier is comprised of nested parabolic and blowout dunes. These are well vegetated away from the frontal dune ridge.

2. Coastal vulnerability rankings range from low to moderate-to-high in the secondary compartment between the Moore River and Ledge Point, but is mainly ranked as moderate (Table 5-7). Lower rankings have been ascribed to the rocky coast between Eagles Nest Bluff and South First Bluff, and a moderate-to-high ranking for Manakoora Sand Patch to Green Reef. The moderate rankings apply to both susceptibility and instability and are related to less protection of the coast by the offshore reefs, higher energy at the shore, salients at Seabird and North Breton Bay, and an episodic transgressive barrier intermittently overlying rocky coast. The moderate-to-high ranking accords with instability of the mobile sand sheet at Manakoora.

   Cell 5, between Moore River and Seabird, is ranked as having a moderate vulnerability although it includes the Moore River, its estuarine reaches and the more vulnerable stretch of coast at Seabird. This is a good example of the Cell having a lower ranking than would the individual landforms it contains. The estuarine system warrants separate, more detailed consideration in local area strategies and site plans.

3. The secondary compartment from Ledge Point to Wedge Island is the area of greatest variation in susceptibility, with the rankings ranging from low in areas of rocky coast, as in Cell 16 between Dide Point and Narrow Neck, to high in Cells 15 and 18 on the flanks of large cuspate forelands. The landforms are ranked as having moderate instability, with several areas close to the high category (Table 5-4). Overall 57% of cells examined were moderate, and 29% of moderate-to-high, vulnerability (Table 5-7).

4. The secondary compartment between Wedge Island and Thirsty Point mainly has a moderate susceptibility to change due to metocean forcing, apart from an area of low susceptibility to change along the rocky coast from North Wedge to Grey. Landform instability is also ranked as moderate, with the exception of Cell 19, Wedge Island, which has extensive tracts of mobile dune on the northern flank of the cuspate foreland. The vulnerability is moderate-to-high in Wedge (Cell 19), low-to-moderate along the rocky coast between North Wedge and Grey (Cells 20 and 21) and from Grey to Thirsty Point (Cells 22 to 25) (Table 5-7).

5. In the secondary compartment extending from Thirsty Point to North Head the coastal vulnerability ranges between low and moderate-to-high levels. The highest vulnerability is between South Hill River and Island Point in Cells 28 and 29 (Table 5-7), respectively associated with the instability of the coastal dunes between the Hill River mouth and South Booka Valley, and the susceptibility of the southern flank of the cuspate foreland at Island Point to changing metocean processes.
6. The three cells north of North Head form part of a secondary compartment extending into the Mid-West Coast. They include tombolos and cuspate forelands in Cells 33 to 35 (Table 5-7) with a moderate, verging on high susceptibility to structural change due to metocean forcing. The dune landforms on the tombolo and cuspate foreland features are of moderate instability with evidence of active blowouts. The coast is predominantly rocky north of Sandy Point and the dunes have a low instability ranking. The vulnerability scores for the part-compartment are moderate but become increasingly low towards the northern rocky limit of the Study Area.

The Gingin-Dandaragan coast falls almost entirely in a single primary compartment within the South West Coast Region, that is characterised by three land systems and has been attributed a moderate-to-high vulnerability based largely on its instability ranking (4) across the Hill primary compartment (southern of the two primary compartments labeled 'Mid-West' in Figure 5-2). For the planning purposes of this report the approach used in investigating coastal vulnerability has been extended to a finer spatial scale, to a primary sediment cell level. This has led to further consideration of the integrity of natural structures of land systems and landforms as well as their condition or stability. It results in adjustment of the vulnerability ranking because the proportion of coast comprising particular land systems and landforms changes with the scale of investigation. The overall vulnerability of the primary compartment forming most of Gingin-Dandaragan coast is rated as having moderate vulnerability to changing metocean processes (Table 5-7; Table 5-8).

Adjustment of the vulnerability rankings alter with the scale of investigation (Table 5-8) because the proportion of coast comprising susceptible natural structural features and/or particular unstable landforms changes with scale. Some of the cells have a higher vulnerability ranking when considered at a finer spatial scale than the secondary compartments because the areas of higher coastal risk represent a higher proportion of the coast of interest. Higher coastal risk could be attributed to a higher proportion of susceptible natural structural features, such as cuspate forelands, and/or more unstable landforms, such as active dunes and scarped foredunes.

Table 5-6: Susceptibility, Instability and Vulnerability Rankings for Each Cell

Cell	Southern Boundary of Cell	Susceptibility Rank	Instability Rank	Vulnerability Rank
36	South Fisherman	L	L	L
35	Sandy Point	M	L	L-M
34	Sandland	M	M	M
33	North Head	M	M	M
32	Pumpkin Hollow	L	L	L
31	Middle Head	L	M	L-M
30	Island Point	M	M	M
29	South Booka Valley	H	M	M-H
28	South Hill River	M	H	M-H
27	Black Head	L	M	L-M
26	Thirsty Point	M	M	M
25	Hansen Head	M	M	M
24	Kangaroo Point	M	M	M
23	Boggy Bay	M	M	M
22	Grey	M	M	M
21	South Grey	L	M	L-M
20	North Wedge	L	M	L-M
19	Wedge Island	M	H	M-H
18	Magic Reef	H	M	M-H
17	Narrow Neck	M	M	M
16	Dide Point	L	M	L-M
15	Lancelin Island	H	M	M-H
14	Edward Island	M	M	M
13	South Pacific Reef	M	M	M
12	Ledge Point	M	M	M
11	Green Reef	M	M	M
10	Manakoora Sand Patch	M	H	M-H
9	South First Bluff	M	M	M
8	Second Bluff	L	M	L-M
7	Eagles Nest Bluff	L	L	L
6	Seabird	M	M	M
5	Moore River	M	M	M
4	South Moore River	L	M	L-M
3	North Two Rocks	L	M	L-M
2	Two Rocks	L	M	L-M
1	Wreck Point	L	L	L

Key	Vulnerability of environmental change	Implications for development (see Table 2-11 for further description)
	Low	Coastal risk is unlikely to be a constraint to development
	Low-to-moderate	Coastal risk may present a low constraint to development
	Moderate	Coastal risk may present a moderate constraint to development
	Moderate-to-high	Coastal risk is likely to be a significant constraint to development
	High	Coastal risk is a highly significant constraint to development

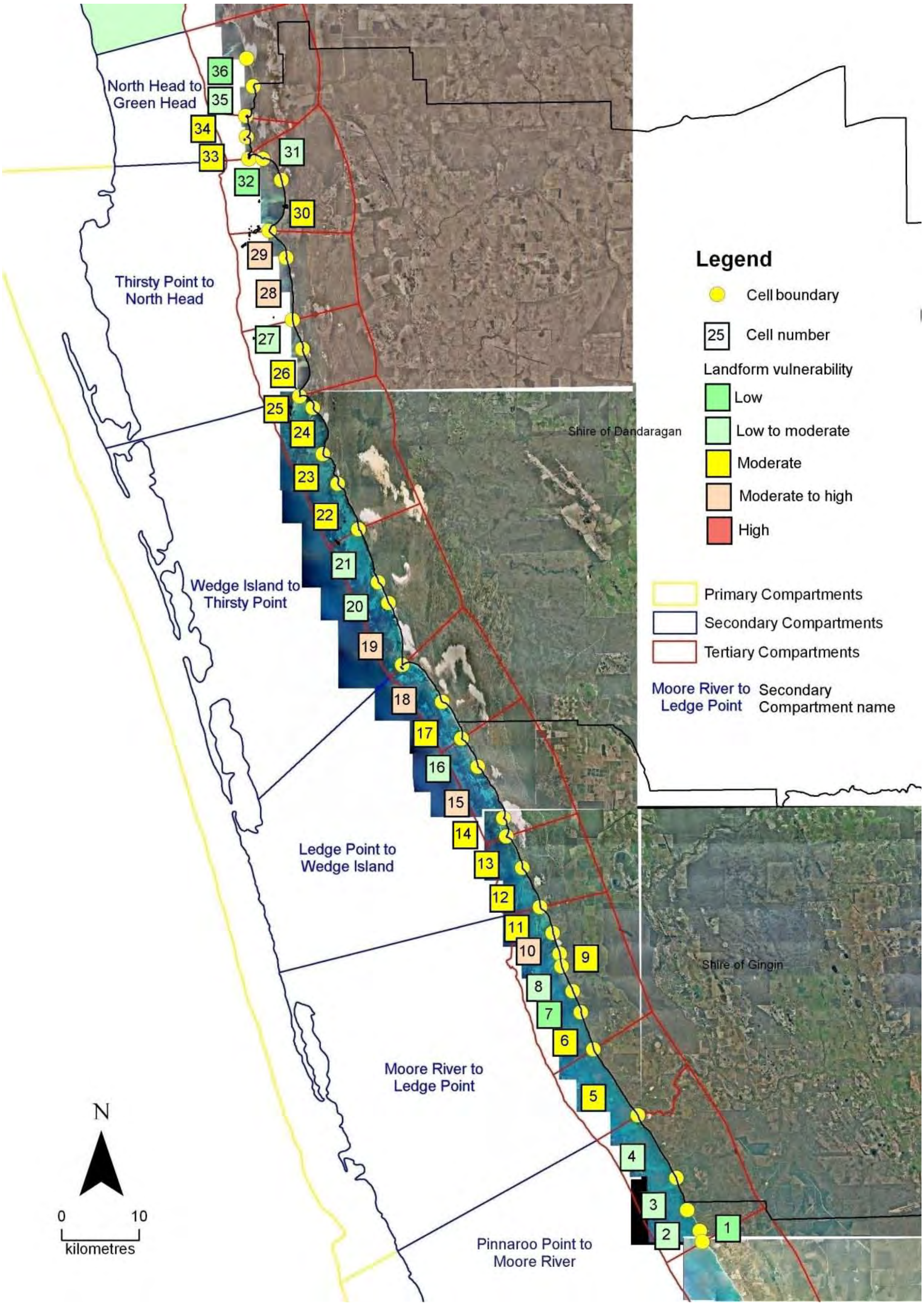


Figure 5-1: Vulnerability Rankings for the Gingin-Dandaragan Coast

Table 5-7: Summary of Cell Vulnerability for Coastal Segments Including Primary and Secondary Compartments, Total Study Area and the Shires Note this is a count of cells of unequal coastal extent

Compartment		No. Cells	Vulnerability - Count and Percentage of Cells					
			L	L-M	M	M-H	H	Mode
Primary	Moore River to North Head	28	2	6	14	6	0	M
			8%	21%	**50%**	21%	0%	
Secondary	Thirsty Point to North Head	7	1	2	2	2	0	M
			13%	**29%**	**29%**	**29%**	0%	
	Wedge Island to Thirsty Point	7	0	2	4	1	0	M
			0%	29%	**57%**	14%	0%	
	Ledge Point to Wedge Island	7	0	1	4	2	0	M
			0%	14%	**57%**	29%	0%	
	Moore River to Ledge Point	7	1	1	4	1	0	M
			14%	14%	**58%**	14%	0%	
	Wreck Point to Moore River (Tertiary)	4	1	3	0	0	0	L-M
			25%	**75%**	0%	0%	0%	
Total for Gingin-Dandaragan		36	4	10	16	6	0	M
			11%	28%	**44%**	17%	0%	
Shire of Dandaragan		18	1	4	9	4	0	M
			6%	22%	**50%**	22%	0%	
Shire of Gingin		14	1	4	7	2	0	M
			7%	29%	**50%**	14%	0%	

Table 5-8: Susceptibility, Instability and Vulnerability Rankings for Compartments and Cells Compartment ranks were allocated from the mean ranking of the component cells. Rankings from the Mid-west study (Eliot *et al.* 2011b) were used for compartments north of North Head.

Note the component cells are of unequal coastal extent and assessment of the primary compartments is based on an early version of the OSRA database.

<table>
<tr><th rowspan="3">Primary Sediment Cell</th><th colspan="4">Susceptibility</th><th colspan="4">Instability</th><th colspan="4">Vulnerability</th></tr>
<tr><th colspan="3">Compartment Rank</th><th>Cell</th><th colspan="3">Compartment Rank</th><th>Cell</th><th colspan="3">Compartment Rank</th><th>Cell</th></tr>
<tr><th>1°</th><th>2°</th><th>3°</th><th>Rank</th><th>1°</th><th>2°</th><th>3°</th><th>Rank</th><th>1°</th><th>2°</th><th>3°</th><th>Rank</th></tr>
<tr><td>36. South Fisherman to Fisherman</td><td rowspan="4">M</td><td rowspan="4">M</td><td rowspan="2">M</td><td>L</td><td rowspan="4">M</td><td rowspan="4">M</td><td rowspan="2">M</td><td>L</td><td rowspan="4">M</td><td rowspan="4">L-M</td><td rowspan="2">L-M</td><td>L</td></tr>
<tr><td>35. Sandy Point to South Fisherman</td><td>M</td><td>L</td><td>L-M</td></tr>
<tr><td>34. Sandland to Sandy Point</td><td rowspan="2">M</td><td>M</td><td rowspan="2">M</td><td>M</td><td rowspan="2">M</td><td>M</td></tr>
<tr><td>33. North Head to Sandland</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>32. Pumpkin Hollow to North Head</td><td rowspan="28">M</td><td rowspan="7">M</td><td rowspan="3">L</td><td>L</td><td rowspan="28">M</td><td rowspan="7">M</td><td rowspan="3">M</td><td>L</td><td rowspan="28">M</td><td rowspan="7">M</td><td rowspan="3">L-M</td><td>L</td></tr>
<tr><td>31. Middle Head to Pumpkin</td><td>L</td><td>M</td><td>L-M</td></tr>
<tr><td>30. Island Point to Middle Head</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>29. South Booka Valley to Island Point</td><td rowspan="2">H</td><td>H</td><td rowspan="2">H</td><td>M</td><td rowspan="2">M-H</td><td>M-H</td></tr>
<tr><td>28. South Hill River to South Booka</td><td>M</td><td>H</td><td>M-H</td></tr>
<tr><td>27. Black Head to South Hill River</td><td rowspan="2">M</td><td>L</td><td rowspan="2">M</td><td>M</td><td rowspan="2">M</td><td>L-M</td></tr>
<tr><td>26. Thirsty Point to Black Head</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>25. Hansen Head to Thirsty Point</td><td rowspan="7">M</td><td rowspan="4">M</td><td>M</td><td rowspan="7">M</td><td rowspan="4">M</td><td>M</td><td rowspan="7">M</td><td rowspan="4">M</td><td>M</td></tr>
<tr><td>24. Kangaroo Point to Hansen Head</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>23. Boggy Bay to Kangaroo Point</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>22. Grey to Boggy Bay</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>21. South Grey to Grey</td><td rowspan="3">L</td><td>L</td><td rowspan="3">M</td><td>M</td><td rowspan="3">L-M</td><td>L-M</td></tr>
<tr><td>20. North Wedge to South Grey</td><td>L</td><td>M</td><td>L-M</td></tr>
<tr><td>19. Wedge Island to North Wedge</td><td>M</td><td>H</td><td>M-H</td></tr>
<tr><td>18. Magic Reef to Wedge Island</td><td rowspan="7">M</td><td rowspan="2">H</td><td>H</td><td rowspan="7">M</td><td rowspan="2">M</td><td>M</td><td rowspan="7">M</td><td rowspan="2">M-H</td><td>M-H</td></tr>
<tr><td>17. Narrow Neck to Magic Reef</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>16. Dide Point to Narrow Neck</td><td rowspan="3">M</td><td>L</td><td rowspan="3">M</td><td>M</td><td rowspan="3">M</td><td>L-M</td></tr>
<tr><td>15. Lancelin Island to Dide Point</td><td>H</td><td>M</td><td>M-H</td></tr>
<tr><td>14. Edward Island to Lancelin Island</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>13. South Pacific Reef to Edward</td><td rowspan="2">M</td><td>M</td><td rowspan="2">M</td><td>M</td><td rowspan="2">M</td><td>M</td></tr>
<tr><td>12. Ledge Point to South Pacific Reef</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>11. Green Reef to Ledge Point</td><td rowspan="7">M</td><td rowspan="6">M</td><td>M</td><td rowspan="7">M</td><td rowspan="6">M</td><td>M</td><td rowspan="7">M</td><td rowspan="6">M</td><td>M</td></tr>
<tr><td>10. Manakoora Sand Patch to Green</td><td>M</td><td>H</td><td>M-H</td></tr>
<tr><td>9. South First Bluff to Manakoora</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>8. Second Bluff to South First Bluff</td><td>L</td><td>M</td><td>L-M</td></tr>
<tr><td>7. Eagles Nest Bluff to Second Bluff</td><td>L</td><td>L</td><td>L</td></tr>
<tr><td>6. Seabird to Eagles Nest Bluff</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>5. Moore River to Seabird</td><td>M</td><td>M</td><td>M</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>4. South Moore River to Moore River</td><td rowspan="4">N/A</td><td rowspan="4">L</td><td rowspan="4">L</td><td>L</td><td rowspan="4">N/A</td><td rowspan="4">M</td><td rowspan="4">M</td><td>M</td><td rowspan="4">N/A</td><td rowspan="4">L-M</td><td rowspan="4">L-M</td><td>L-M</td></tr>
<tr><td>3. North Two Rocks to South Moore</td><td>L</td><td>M</td><td>L-M</td></tr>
<tr><td>2. Two Rocks to North Two Rocks</td><td>L</td><td>M</td><td>L-M</td></tr>
<tr><td>1. Wreck Point to Two Rocks</td><td>L</td><td>L</td><td>L</td></tr>
</table>

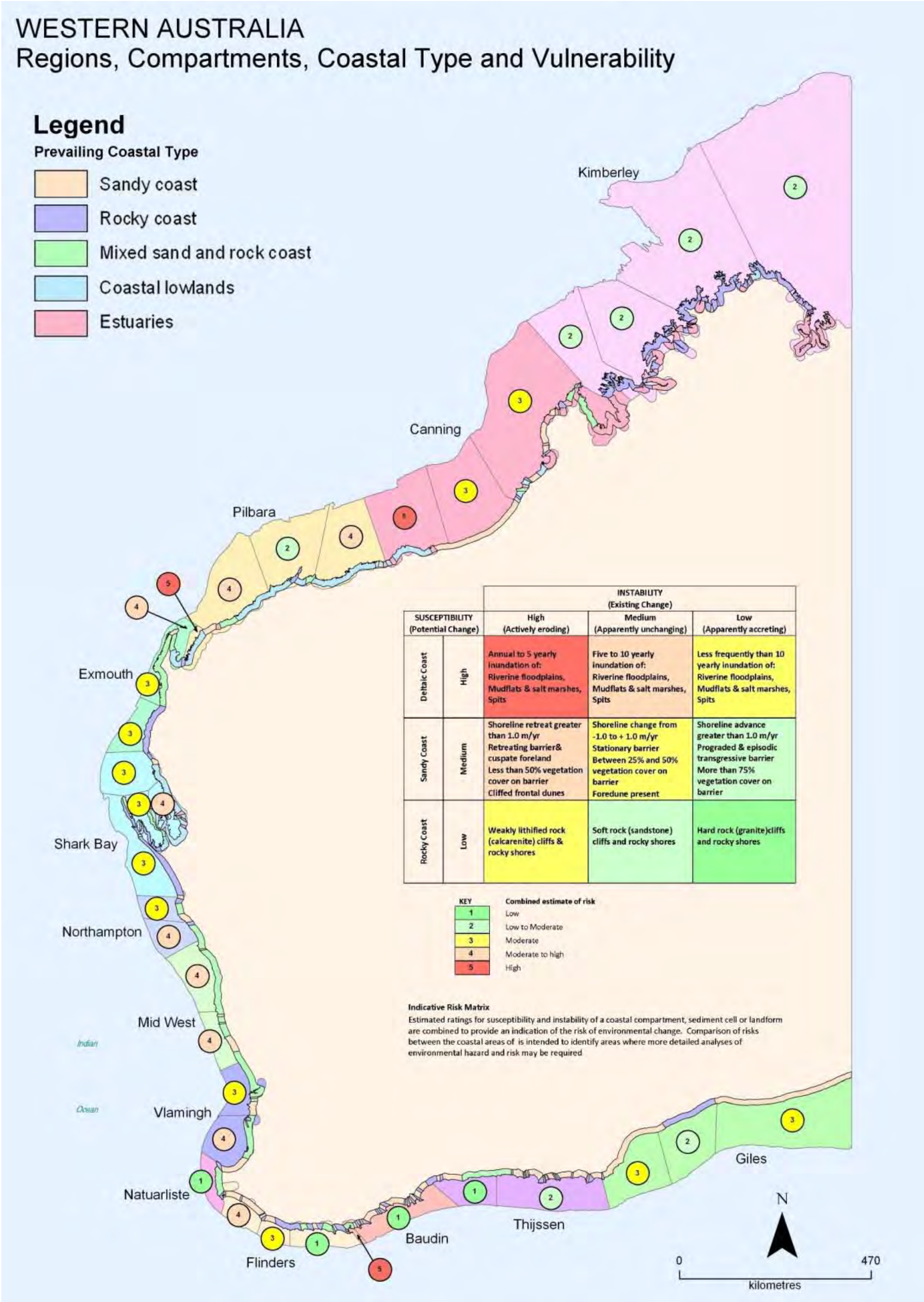


Figure 5-2: Coastal Landform Types and Vulnerability for Western Australia

There are three sets of information on this map: (1) The broad coloured strip map covering the nearshore waters indicates the coastal regions; (2) The narrow ribbon along the shore indicates the coastal type as per the legend and has been derived from the OSRA/WACoast databases; (3) The small coloured circles indicate coastal vulnerability (indicative risk) for each of the primary compartments. The colours in the circles are consistent with the colours in the indicative risk matrix.

The risk matrix considered very large scale land systems, particularly sandy, rocky and deltaic coastal systems relevant for a State-wide assessment of coastal vulnerability. This is the same approach as that used for consideration of the more detailed land systems of the Gingin-Dandaragan Coast shown in Figure 2-10.

(Source: Eliot *et al.* 2011a).

6. Areas of Planning Interest

Areas of Planning Interest are those that are under development pressure or have been identified for future land use change. In some cases, these areas have been identified in Local Planning Strategies, sub-regional plans or local strategic plans (WAPC 1996; Ecoscape & SJB 2005; WAPC 2006; Shire of Dandaragan 2007; Taylor Burrell Barnett 2009a, b; Department of Planning: DoP 2010a; O'Brien & Landvision 2010). Further information on relevant planning documents at regional and local scales is contained in a summary document prepared by the Department of Planning (2010b).

The Areas of Planning Interest identified for the Gingin-Dandaragan Shires include from south to north (Figure 1-1):

- South Moore River
- Seabird
- Ledge Point
- Lancelin
- Cervantes
- Ardross Estate (from Hill River northwards to Jurien Bay)
- Jurien Bay
- North Head

Each Area of Planning Interest includes: identification of the relevant sediment cells; identification of the levels of susceptibility, instability and vulnerability across those cells; a comparison of historic aerial imagery; and initial planning advice.

All location names within the text are based on the following sources:

1. Australian Land Information Group: AUSLIG. (1993) *Topographic Series*, *1:100 000 Map Sheets for Western Australia.* Commonwealth Government, Canberra.
2. Geological Survey of Western Australia: GSWA. (2007) *Atlas of 1:250 000 Geological Series Map Images, Western Australia, April 2007 update*. GSWA, Perth.
3. Department of Transport and Australian Navy Navigation Charts. Index of Department of Transport (previously Department for Planning and Infrastructure and Department of Marine and Harbours) charts available at http://www.transport.wa.gov.au/mediaFiles/mar_chart_index.pdf.

6.1. SOUTH MOORE RIVER

The proposed development area up to 3km south of Moore River is located within Cell 4 (South Moore River to Moore River) (Figure 6-1; Figure C - 27; Cell description in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10).

Coastal susceptibility, instability and vulnerability: The cell has low susceptibility with the perched transgressive barrier having a low-to-moderate susceptibility to long-term change. The cell has moderate instability with the frontal dune ridge comprised of nested blowouts, including active dunes associated with access tracks. Some instability is associated with the discontinuous foredune. There is low-moderate vulnerability with coastal risk of Moore River activity, sandsheet movement, dune mobility and foredune activity on the wider salient presenting a low constraint to development.

Advice: Detailed setback investigations are advised to determine the setback allowances for river migration and sandsheet/blowout activity adjacent to the Moore River. Construction on the foredune and frontal dune (particularly on the broad salient) is likely to be affected by the vulnerability to metocean processes. Development should be located landward of the foredune and frontal dune (particularly on the broad salient). It is advisable to align access away from the prevailing wind direction to minimise the risk of blowouts.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

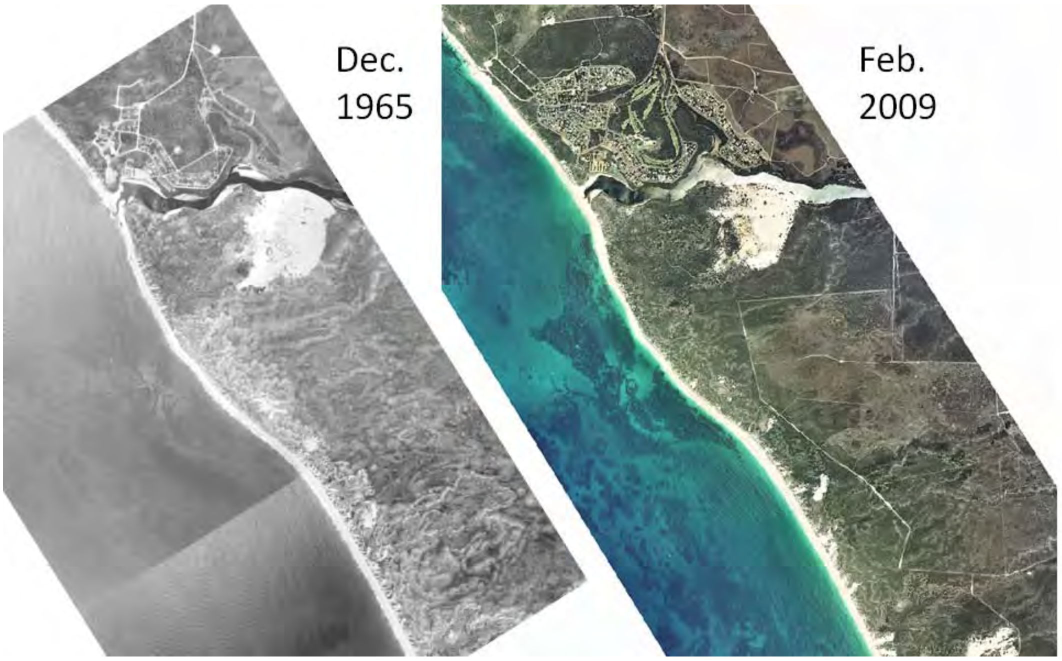


Figure 6-1 : Aerial Photography South Moore River (1965 and 2009)

6.2. SEABIRD

The Seabird townsite is located on the boundary between Cell 5 (Moore River to Seabird) and Cell 6 (Seabird to Eagles Nest Bluff) (Figure 6-2; Figure C - 23; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10).

Coastal susceptibility, instability and vulnerability: The cells both have moderate susceptibility with the transgressive barrier having a moderate-to-high susceptibility to long-term change. The cells both have moderate instability ranking due to erosion of the frontal dunes. Instability is indicated by the discontinuous to absent character of the foredunes. The coastal risk of salient migration, beach width fluctuations and dune mobility may be a moderate constraint to coastal development for both cells (moderate vulnerability).

Advice: The townsite is on a localised area of greater vulnerability on a broad salient that is susceptible to migration, with present retreat on the southern side. Ongoing maintenance and management will be required on the south of the salient. Any future development should allow for migration of the salient, with a greater setback than presently exists. Dune stabilisation and modification of beach access (realignment away from the prevailing wind direction and reduction in the number of access points) is presently required to the south, with any future plans to consider adaptation and potential retreat.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

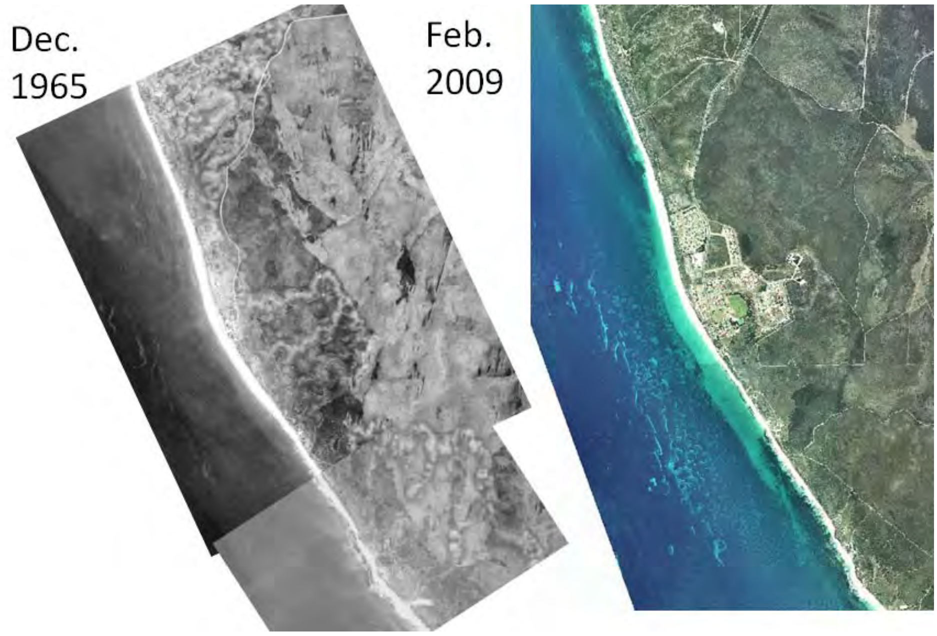


Figure 6-2 : Aerial Photography Seabird (1965 and 2009)

6.3. LEDGE POINT

The Ledge Point townsite is located on the boundary between Cell 11 (Green Reef to Ledge Point) and Cell 12 (Ledge Point to South Pacific Reef) (Figure 6-3; Figure C - 21; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10). It is intended for Ledge to be expanded to the north (to approximately 0.75km south of the sandsheet).

Coastal susceptibility, instability and vulnerability: The susceptibility and instability are moderate for both cells. In Cell 11 the perched transgressive barrier has a low-to-moderate susceptibility to long-term change, with a high exposure to major storms. In Cell 12 it is the salient and perched barrier that has a low-to-moderate susceptibility. Both cells have exposed beaches and scarped foredunes that contribute to the moderate instability. Further landforms contributing to the moderate instability are active blowouts in the frontal dune complex of Cell 11 and mobile sandsheets and parabolic dunes common in the frontal dune complex of Cell 12. The coastal risk of beach width fluctuations, migration of the Ledge Point landform, dune mobility and blowouts may be a moderate constraint to coastal development for both cells (moderate vulnerability). This section of coast is modified by two groynes.

Advice: Development is not advised on the foredune, foredune plain and frontal dune owing to vulnerability to metocean processes. It is advisable to align access away from the prevailing wind direction and restrict the number of locations to a minimum, to minimise the risk of blowouts. Potential changes in sediment supply and wave climate should be included in a setback assessment. Retreat may occur if there was a reduction in onshore sediment supply and/or an increase in the formation of blowouts.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

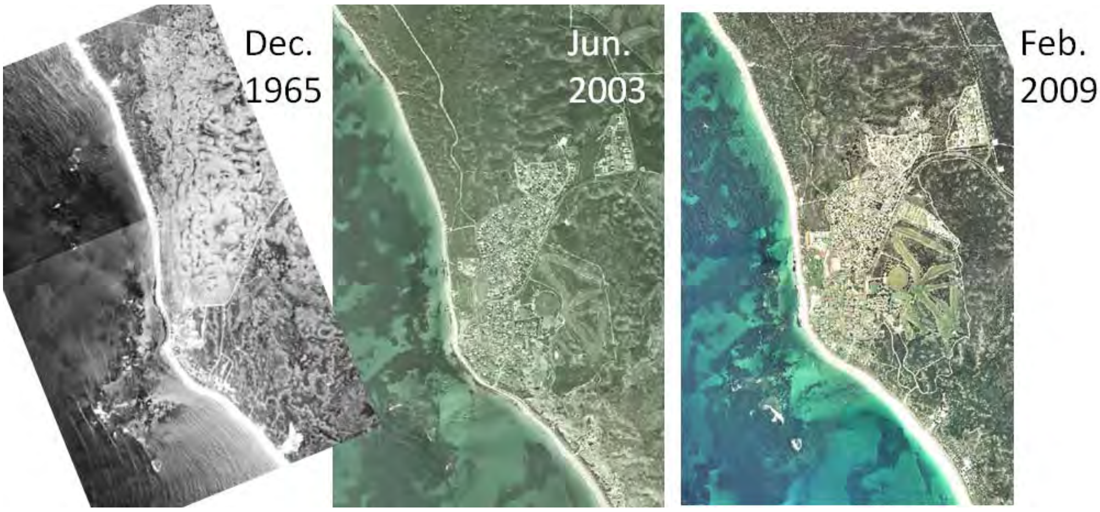


Figure 6-3 : Aerial Photography Ledge Point (1965, 2003 and 2009)

6.4. LANCELIN

The wider Lancelin townsite is located within the four sediment cells of 12 (Ledge Point to South Pacific Reef), 13 (South Pacific Reef to Edward Island), 14 (Edward Island to Lancelin Island) and 15 (Lancelin Island to Dide Point) (Figure 6-4; Figure C - 19; Figure C - 21; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained Table 2-6, Table 2-10 and Figure 2-10). Development is proposed in three areas: (i) south of the Lancelin sandsheet; (ii) on the south side of the cuspate foreland behind Edward Island; and (iii) at the small salient in the lee of Fence Reef, south of the golf course at the South Pacific Reef cell boundary (DoP 2010a; Taylor Burrell Barnett 2009; WAPC 2006; Ecoscape & SJB 2005).

Coastal susceptibility, instability and vulnerability: The susceptibility ranges from moderate (Cells 12-14) to high (Cell 15), with all four cells demonstrating moderate instability. The susceptible landforms are the salient and perched barrier for Cell 12; the transgressive barrier for Cell 13; and the transgressive barrier and forelands for Cells 14 and 15. The unstable landforms are exposed beaches, scarped foredunes and mobile sandsheets and parabolic dunes in the frontal dune complex for Cell 12; exposed beaches and active blowouts in the frontal dune complex for Cell 13; eroded foredunes and a mobile sandsheet on the cuspate forelands for Cell 14; and a lack of vegetation cover and disturbance by ORV tracks on the frontal dune complex of Cell 15.

The northern cell (Cell 15), containing the cuspate foreland behind Lancelin Island and the Lancelin sandsheet, has a moderate-to-high vulnerability and therefore the coastal risk of sandsheet activation (or reactivation), cuspate foreland/salient migration and fluctuations, dune mobility and blowouts is likely to be a constraint to development. The same coastal risks may be a moderate constraint to development in the three southern cells (12-14; moderate risk).

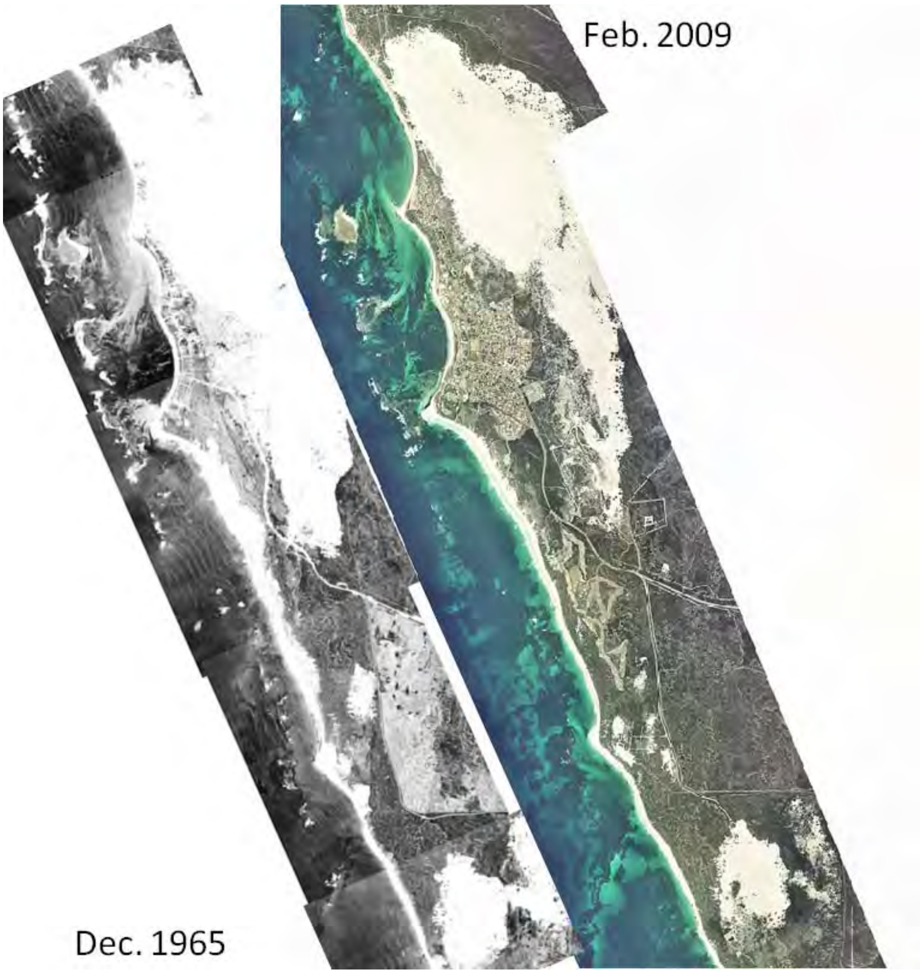


Figure 6-4 : Aerial Photography Lancelin (1965 and 2009)

Advice: Construction on the foredune, frontal dunes and historic blowouts on any section of this coast (>100m in locations) is highly likely to be affected by the vulnerability of this part of the coast to metocean processes. This is demonstrated by historic fluctuations in dune and blowout activity, which has reduced since the 1960s. It is advisable to align access away from the prevailing wind direction and restrict the number of locations to a minimum, to minimise the risk of blowouts.

Development on the south side of the Edward Island cuspate foreland is not advised because of dune instability and potential modification to the landform. Similarly, Fence Reef (off South Pacific Reef in Figure C - 18) is a salient feature that could migrate with a likelihood of extensive dune blowouts and sandsheet formations.

The risk of reactivation of the southern flank of the Lancelin sandsheet requires further investigation prior to any development approval. The increase in vegetation cover and reduction in sandsheet mobility that has occurred since the 1960s may not continue. There is a risk of increased activity as a result of changes in the wind regime, changes in rainfall altering the saturation of the sediment, removal of vegetation, channelling of winds by buildings and destabilisation of vegetation due to a potential drying climate.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

6.5. CERVANTES

The Cervantes townsite is located in Cell 25 (Hansen Head to Thirsty Point) and Cell 26 (Thirsty Point to Black Head) (Figure 6-5; Figure C - 9; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Tables Table 2-6, Table 2-10 and Figure 2-10).

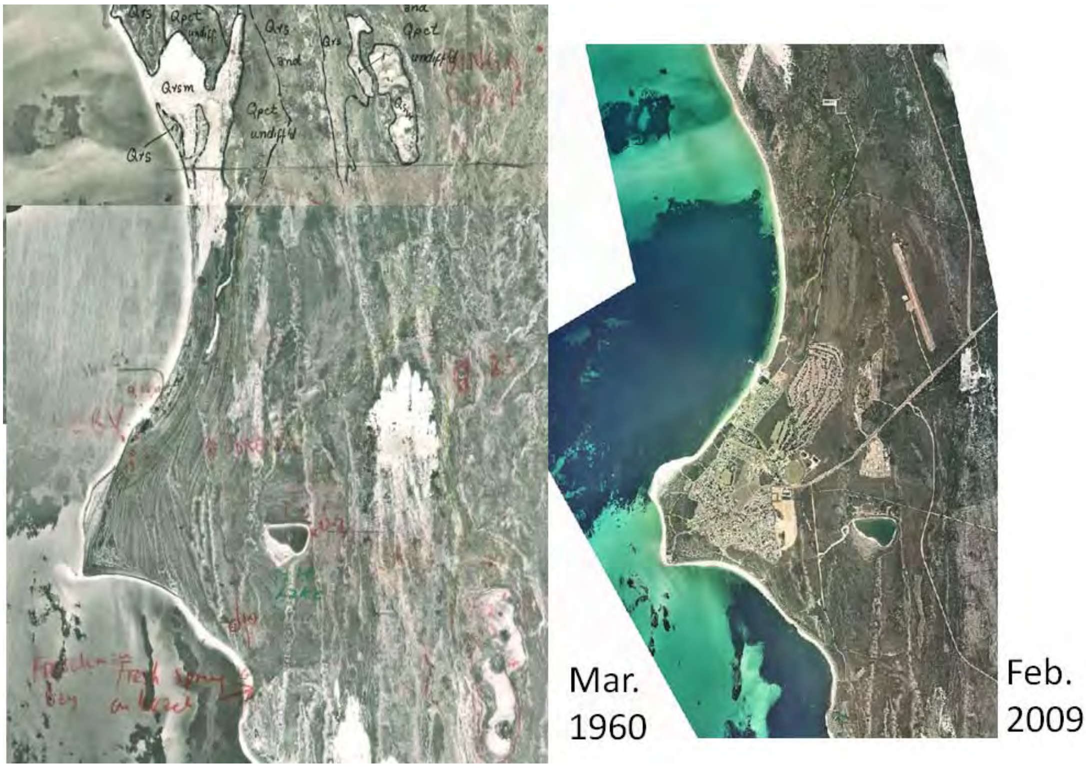


Figure 6-5 : Aerial Photography Cervantes (1960 and 2009)

Coastal susceptibility, instability and vulnerability: The cells have moderate susceptibility and moderate instability. The southern flank of the cuspate foreland of Thirsty Point in Cell 25 has a high susceptibility; and the northern flank of the cuspate foreland in Cell 26 has a moderate susceptibility to long-term change and a moderate-to-high exposure to major storms. The moderate instability relates to inshore instability for Cell 25 and the discontinuity of vegetation cover and disturbance by ORV tracks on the frontal dune complex for Cell 26. There is a moderate vulnerability with coastal risk of cuspate foreland migration and/or retreat, reduction in onshore sediment supply, fluctuations in beach width and dune mobility possibly presenting a moderate constraint to development.

Advice: Development should be avoided closer to the coast than the present infrastructure (including recently accreted areas on the north of the Thirsty Point cuspate foreland) owing to potential landform migration or retreat. Retreat may occur if there was a reduction in onshore sediment supply, with the sediment stripped from the foredune plain. If the townsite is expanded to the north, construction on the foredune and frontal dune is highly likely to be affected by the vulnerability to metocean processes. It is advisable to align access away from the prevailing wind direction to minimise the risk of blowouts.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

6.6. ARDROSS ESTATE

Ardross estate is located south of the present Jurien Bay Townsite, between north of Black Point and Island Point, including the Special Development zone between the present Jurien Bay townsite and Hill River and an area identified for future residential development south of Hill River (O'Brien & Landvision 2010). This Area of Planning Interest encompasses Cell 28 (South Hill River to South Booka Valley) and Cell 29 (South Booka Valley to Island Point) (Figure 6-6; Figure C - 5; Figure C - 7; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10).

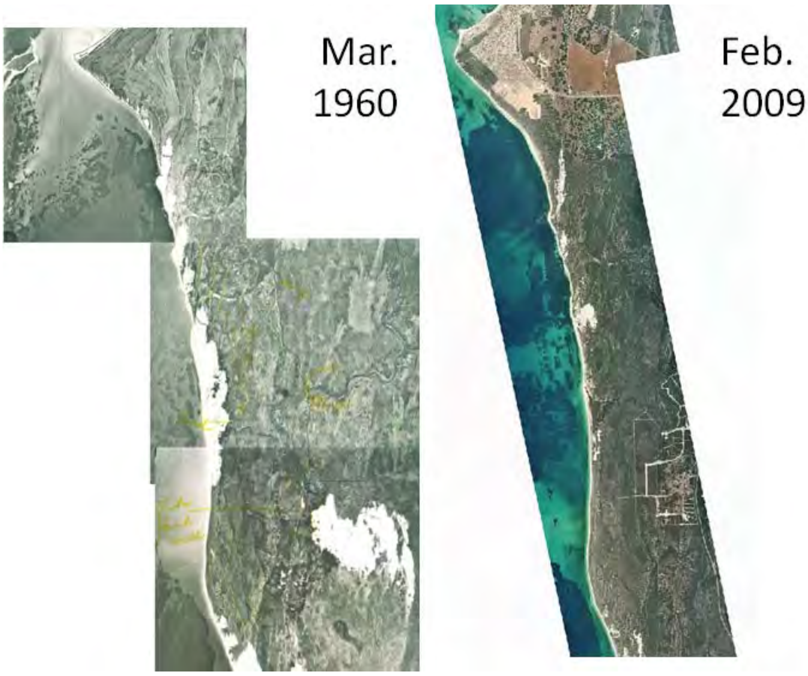


Figure 6-6 : Aerial Photography Ardross Estate (1960 and 2009)

Coastal susceptibility, instability and vulnerability: The susceptibility ranges from moderate to the south to high in the north, with instability as high to the south and moderate to the north. Cell 28 contains the susceptible Hill River delta with high exposure to major storms and Cell 29 contains the highly susceptible southern flank of the Island Point cuspate foreland. The bare sand surfaces and eroded landforms of the inshore substrate, beach and frontal dune systems of Cell 28 are moderate-to-highly unstable. The unconsolidated inshore sediments, active beach, scarping and blowouts of the frontal dunes of Cell 29 are moderately unstable.

The coastal risks of Hill River activity, dune mobility and blowouts are likely to be a constraint to coastal development for the southern cell (moderate-to-high vulnerability). The coastal risk of retreat of the Island Point cuspate foreland (and ongoing northwards migration and fluctuations), dune mobility and blowouts are likely to be a constraint for the northern cell (moderate-to-high vulnerability).

Advice: It is advisable to avoid construction: in the vicinity of the present Hill River alluvial delta and estuarine flats owing to potential migration; on the south side of the Island Point cuspate foreland because of potential wholescale retreat of the landform; on the foredune, frontal dunes and historic blowouts on any section of this coast (with frontal dunes of up to 60m wide) because of historic fluctuations in dune and blowout activity. It is advisable to align access away from the prevailing wind direction and restrict the number of locations to a minimum, to minimise the risk of blowouts. Dune stabilisation and modification of beach access (realignment away from prevailing wind and reduction in the number of access points) is presently required on the south side of the Island Point cuspate foreland.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

6.7. JURIEN BAY

The Jurien Bay townsite is largely located within Cell 30 (Island Point to Middle Head), with the southern extension considered in the Ardross Estate Area of Planning Interest below (Figure 6-7; Figure C - 5; Cell description in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10).

Coastal susceptibility, instability and vulnerability: The cell has moderate susceptibility due to the moderate-to-highly susceptible cuspate foreland and moderate instability due to inshore and foredune instability, including foredune scarping. There is a moderate vulnerability with coastal risk of landform retreat, beach width fluctuations, dune mobility and blowouts possibly presenting a moderate constraint to development.

Advice: Development should not occur closer to the coast than the present development (including recently accreted areas on the north of the northwards migrating Island Point cuspate foreland [Figure 6-8]). Construction in the northern section of the cell is vulnerable to potential for blowout activity. If the townsite is expanded to the north of the harbour, construction on the foredune and frontal dune is highly likely to be affected by the vulnerability to metocean processes. It is advisable to align access away from the prevailing wind direction to minimise the risk of blowouts. Retreat may occur if there was a reduction in onshore sediment supply.

Further studies require site-specific investigations that will contribute to a detailed understanding of the coastal sediment budget. Studies of particular importance to each sediment cell are suggested in Table 2-11 and Appendix E, linked to the vulnerability ranking.

Figure 6-7 : Aerial Photography Jurien Bay (1960 and 2009)

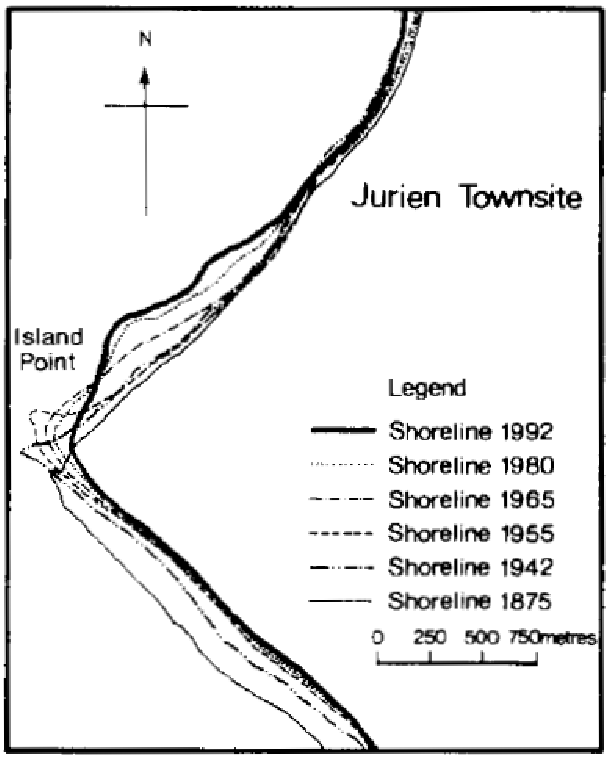


Figure 6-8: Shoreline Change at Jurien Bay 1875-1992 (Sanderson 2000)

6.8. NORTH HEAD

The North Head development is proposed to extend from north of Middle Head to onshore of Bartle Reef (3-6km north of Jurien Bay Boating Facility). This Area of Planning Interest encompasses the three sediment cells of 31 (Middle Head to Pumpkin Hollow), 32 (Pumpkin Hollow to North Head) and 33 (North Head to Sandland Island) (Figure 6-9; Figure C - 3; Figure C - 5; Cell descriptions in Appendix D; Susceptibility, instability and vulnerability rankings are in Table 5-1, Table 5-4, Table 5-6 and Appendix E with classifications contained in Table 2-6, Table 2-10 and Figure 2-10).

Coastal susceptibility, instability and vulnerability: The susceptibility is low-to-moderate for all cells, with instability ranging from low to moderate. The susceptible landforms are the perched barrier in Cell 31, the perched tombolo in Cell 32 and the perched barriers and pocket beaches in Cell 33. Moderate-to-high levels of landform instability are related to scarping of the foredunes and frontal dunes in Cell 31. Low-to-moderate levels of landform instability are apparent on the dune and barrier overall in Cell 32, including an active parabolic dune in the centre of the embayment. Moderate levels of landform instability are apparent overall in Cell 33, with 25-50% vegetation cover in the 500m landward of the shore markedly affected by ORV tracks in the southern part of the cell.

There is a moderate vulnerability for Cell 33, with coastal risk of dune mobility and blowouts potentially presenting a moderate constraint to development. Cell 31 has low-moderate vulnerability, with coastal risk of dune mobility and blowouts presenting a low constraint to development. Cell 32 has a low vulnerability, with coastal risk unlikely to be a constraint to development.

Advice: Construction on the foredune and frontal dunes is likely to be affected by the vulnerability of the coast to metocean processes. It is advisable to align access away from the prevailing wind direction to minimise the risk of blowouts.

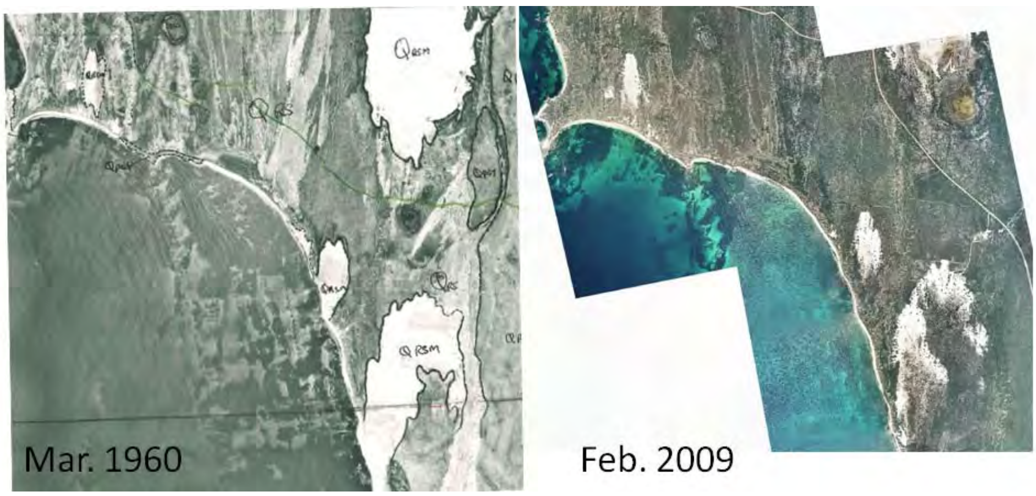


Figure 6-9 : Aerial Photography North Head (1960 and 2009)

7. Discussion & Overview

A major aim of the project was to provide strategic advice concerning the geomorphology of the Gingin-Dandaragan coast between Wreck Point and Fisherman Islands, with particular reference to Areas of Planning Interest at eight sites: South Moore River, Seabird, Ledge Point, Lancelin, Cervantes, Ardross Estate (from Hill River towards Jurien Bay), Jurien Bay and North Head. Accordingly, coastal landforms for the Study Area have been examined at several scales: description of the coastal barrier systems and their relationship with the geologic framework provided by the underlying coastal limestone; landform patterns such as nested parabolic dunes and blowouts, occurring in discrete sediment cells within each compartment; and the individual landforms comprising the landform patterns at each of the Areas of Planning Interest.

Two facets of coastal change were considered to provide a strategic description of the vulnerability of coastal land to current and projected changes in metocean forcing. First, the relative susceptibility or potential for erosion of a geologic structure in response to variation in metocean processes, particularly changes in sea level was estimated for different landforms comprising the sediment cells. Second, levels of relative instability were ascribed to landforms according to their current responses to metocean processes such as storms and sediment supply as well as anthropogenic factors. The estimates of susceptibility and instability were then combined to indicate the likely vulnerability of the landforms within the compartments or cells. Vulnerability in this context provides an overall estimate of landform susceptibility and instability for each sediment cell.

Combination of the susceptibility of coastal landform associations to changes in the metocean regime with the current stability of landforms they support identifies components of the coast potentially subject to risk in response to projected environmental change. Both facets are applicable at each level in the planning hierarchy and have relevance to coastal land use. Coastal plans traditionally focus on the instability of coastal landforms, with allowances for erosion (coastal setbacks) related to the historical variability of the beach-foredune system under consideration as well as projected sea level change being taken into account (WAPC 2003, 2006). However, feedback mechanisms linking structure and stability indicate landform susceptibility to metocean forcing is at least as significant, with changes in either susceptibility or stability highly likely to trigger changes to the other, particularly on unconsolidated coasts.

The potential contribution of vulnerability assessment based on the susceptibility and instability of land systems and landforms to a more complete risk assessment process, such as that proposed by ISO 31000 (Standards Australia 2009), is illustrated in Figure 7-1. This is discussed further in Section 7.4.1 below.

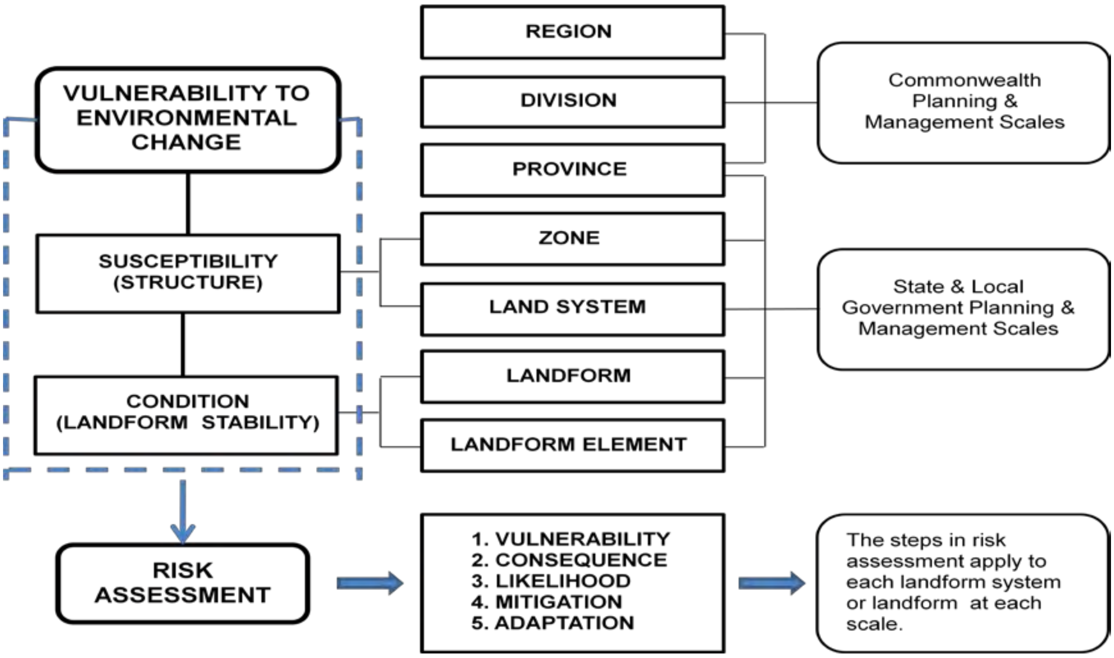


Figure 7-1: Vulnerability Assessment, Risk Assessment and Scales of Application

7.1. ASSESSMENT SCALES

At a geological timescale, the hard-rock geologic framework has provided topographic control for formation of Holocene barrier structures as unconsolidated sediment accumulated and the dune ridge evolved during the past 10,000 years, along the coast between Wreck Point and Fisherman Islands. Albeit slowly, barrier evolution is continuing at present as sediment is moved along and across the shore. The structure of the barrier, with unconsolidated Holocene sands overlaying the older limestone topography, implies marked geographic variation in the susceptibility of the shore to erosion and the need to apply different models for the prediction of shoreline movement to different parts of the coast. Hence the assessment of the susceptibility of the coast to observed and projected changes in metocean conditions has been undertaken for sediment cells that support different landform associations.

The degree of susceptibility has been estimated on a comparative basis as being low, moderate or high depending on the presence, extent and elevation of outcropping bedrock. At the broadest scale a barrier may not be susceptible to long-term change whereas elsewhere a different type of barrier system may be highly susceptible. This is apparent when the perched barrier south of Grey (Cell 21) is compared to the cuspate forelands at Edward Island (Cell 14) and Wedge Island (Cells 18 and 19) which may have formed over a deeper rocky basement. The disparity provides rationale for more detailed consideration of the geotechnical qualities of different systems.

Phases of dune activity through the Holocene are apparent as the nested blowouts and parabolic dunes which form the barrier ridge or the sequence of foredune ridges comprising the foredune plains of cuspate forelands at Wedge Island, Lancelin and Island Point, Jurien Bay. Small variations in dune activity identified from the photographic record used to examine the Areas of Planning Interest (Section 6) indicate the phases are associated with variation in the intensity and duration of metocean processes. In the long-term these will continue to contribute to development of the barrier ridge and migration of the point on cuspate forelands through the formation and destruction of foredunes, blowout activity and the migration of nested parabolic sand dunes, especially along parts of the shore susceptible to erosion.

Rise in sea level, whether a recurrence of historically extreme conditions due to storminess or a result of projected Global warming, potentially would trigger increased destabilisation of the foredunes and frontal dune belt along the shore, facilitating landward migration of the barrier where it is not perched on the coastal limestone. Barriers and cuspate forelands are viewed as being inherently unstable and require careful consideration in land use planning and management for this reason that. As O'Brien Planning Consultants (1987) noted a section of the Mid-West coast between Dongara and Cape Burney, the most stable sections of the dune ridge comprising the barrier are the undulating swales of long-walled parabolic dunes on its landward side. However, these are not always in locations where access to the shore can be established without incurring ongoing maintenance costs for dune stabilisation and beach access management.

Roy *et al*. (1994) attributed the type of barrier found on wave dominated coasts to variation in continental shelf gradient and sand supply as well as the wave regime. The types identified ranged from (a) sediment poor areas of eroding coast where there was a continuing loss of sand onto a steep continental shelf to (b) transgressive dune barriers and a large sand supply from a low-gradient continental shelf. With notable variations their models are applicable to parts of the Gingin-Dandaragan coast. The coast between Ledge Point and Cervantes is a major sediment sink on the Swan Coastal Plain. Sediment transported along and across the inner continental shelf has supplied the nested blowouts and parabolic dunes which formed the transgressive barrier during the mid to late Holocene. However, extensive tracts of limestone reef, low bluffs and rock platforms outcrop intermittently along the coast, particularly between South Grey and Grey (Cell 21) and in the vicinity of North Head. Together with the relative stability of the coast at present, these indicate substantial geographic variation in volumes of sediment moving alongshore and shoreward and bring into question the time scales at which phases of sediment loss and accretion are occurring.

Medium time scales are relevant to barrier changes occurring over decades and centuries. In this context, dune formation and migration along the coast is ultimately dependent on sediment supply from offshore and alongshore. Currently, shoreline change is highly variable along the coast between and within compartments and cells. From a management perspective the patterns of change will require resolution and description at local and site scales as part of any development proposal.

In addition to the land systems of the compartments the large cuspate forelands and tombolos of the Gingin-Dandaragan coast warrant comment. The principal cuspate forelands are those at Ledge Point, Edward Island, Lancelin, Wedge Point, Thirsty Point, Island Point, Sandland and Sandy Point. Although these accumulation forms commonly have been identified as the boundaries of compartments and sediment cells, they are complete land systems and display similar landform features. Foredune plains constituting cuspate forelands are generally low lying with narrow ridges of blowouts and parabolic dunes along their southwestern flanks. Historically their flat lands have been popular areas for urban development. However, all cuspate forelands along the Swan Coastal Plain have been subject to erosion on their southern flank where the coast is exposed to swell and wind waves driven by S-SW sea breezes. Coastal erosion is most severe around the point of the cuspate forms and changes to deposition in foredune ridges along the northern flank of the landforms. This sequence of erosion and deposition from the southern to northern flank is reversible with phases in north-westerly storm activity (Sanderson & Eliot 1996; Sanderson 2000). The structure and highly dynamic nature of these land systems indicates they are potentially susceptible to the impacts of the projected rise in sea level.

At sub-decadal time scales, interaction of modern metocean processes with the inherited geologic framework has two ramifications.

1. First, alongshore variation in beach erosion, foredune formation and dune development occurs as a result of the interaction, with the reaches of coast most susceptible to environmental change commonly being in close proximity to shoreline salients and extensive rock outcrops.
2. Second, it invalidates application of the Bruun Rule (Bruun 1988) that has been widely applied in the calculation of setback to development on mixed sandy and rocky coast in Western Australia (WAPC 2003; Jones 2005). This implies that localised estimation of shoreline change is necessary and should be linked to geophysical determination of the distribution and elevation of the underlying limestone topography supporting the barrier at places where development is under consideration.

7.2. ADVICE

A precautionary approach was adopted for the purposes of this report in the absence of an existing policy for susceptibility and instability on mixed sand and rocky coast, such as that of the Gingin-Dandaragan coast. The approach involved an analysis of coastal vulnerability based on available information, including published descriptions of the relative susceptibility of coastal land systems to change with variation in metocean processes as well as the current stability of individual landforms comprising them. The vulnerability analysis is the first part of a more extensive risk assessment which would identify the processes of change in more detail; examine social and economic implications; determine the consequences of projected and existing patterns of coastal change; and plan and implement adaptation strategies. To some extent, some of the adaptation strategies are embedded in the guidelines of the State Coastal planning Policy (SPP 2.6) and these provide the principles and rationale for the advice arising from examination of vulnerability on the Gingin-Dandaragan coast.

7.2.1. General Principles

The general principles applied in framing the advice were:

1. The State Coastal Planning Policy SPP 2.6 identifies a range of considerations for the determination of coastal setbacks. The first two factors identified are coastal erosion and landform instability. Both are related to the interactions amongst the metocean

processes, geological framework, unconsolidated sediments and landforms comprising the morphodynamic system of the coast. Briefly, following Wright & Thom (1977) a basic tenet of the vulnerability assessment applied here is that if one component of the morphodynamic system changes the rest respond to some extent on the soft-rock coast of the Swan Coastal Plain.

2. The distribution and elevation of the coastal limestone are significant in that the presence of rock invalidates the so called 'Bruun Rule' of erosion which is commonly applied in setback calculations under the State Coastal Planning Policy SPP 2.6, a point made by Bruun (1988) in his critical assessment of the 'rule'. However, the limestone topography provides the geological framework for the development of unconsolidated, sedimentary landforms and therefore is a major determinant of the susceptibility of the coast to changes in the metocean regime.

3. A secondary determinant of the susceptibility of a coastal land system is related to the volume of unconsolidated sediment comprising the landforms of the shoreface (Houser & Mathew 2011). Herein the principle followed is that the different types and dimensions of barrier systems present along the coast are related to sediment availability. Although outside the scope of this report, this proposition warrants closer consideration, particularly with respect to the perched barrier systems common along the Swan Coastal Plain.

4. Conceptual models of beach type, barrier structure and dune typology developed elsewhere (Section 2.4) are broadly applicable to the south-west coast of Western Australia and identification of the relative stability or instability of coastal landforms.

7.2.2. Coastal Management Advice

Advice specifically pertaining to the coastal management of each sediment cell is listed in Appendix E.

The advice for each cell follow the format outlined in Table 2-11 to ensure a consistent interpretation has been applied for planning and development purposes and they comply with established guidelines developed by the WAPC (2003), DPI (2006) and DoT (2010). More specific information on the integrity of natural structures (susceptibility to change) and stability (instability) of landforms is obtainable through combined interpretation of the landform descriptions for each cell (Appendices C & D) and the criteria used to rate landform susceptibility and stability (Table 2-6, Table 5-1 and Table 5-4).

Detailed interpretation and advice has also been made for the eight Areas of Planning Interest in Section 6 above. These follow the same format as the analysis of the cells containing them.

More general advice is as follows:

1. Locally the elevation of limestone underlying the beach and dunes directly affects the susceptibility of the coast to changes in the metocean regime and influences coastal stability. It is a factor that could be determined as a planning requisite prior to

implementation of any development proposal involving the establishment of rural-urban infrastructure in areas where there are perched beaches.

2. There is a need to develop policy and guidelines related to the siting of infrastructure on cuspate forelands and barriers, especially the former.
    a. Cuspate forelands are particularly vulnerable and may require reconsideration of the methods used to determine setback to development.
    b. Different types of barrier support different assemblages of dunes. It is advised that the determination of setback to development be tailored to the different types with a larger setback allowance for barriers that are notably susceptible to change due to metocean forcing.
    c. Further, it is suggested development on dune ridges and crests in green field sites initially be restricted in preference to development of more stable areas in dune swales not prone to marine inundation or flooding, as was recommended by O'Brien and Associates (1987) for the Dongara-Cape Burney Coast.
3. Overall, the seaward part of a barrier is highly susceptible to destabilisation by metocean processes, which also means it is highly likely to be destabilised through land use pressures. This is a major problem on the southern flanks of cuspate forelands, such as Ledge Point, Wedge Point and Island Point in areas where dune blowouts commonly occur at present; as well as on the northern flanks where accretionary lobes in the lee of each point give way to erosion further updrift, as occurs at Cervantes.
    a. Following the guidelines of the State Coastal Planning Policy (SPP2.6), it is advised that shore parallel development of infrastructure such as coastal roads, car parks and buildings should not occur in the frontal dunes.
    b. Additionally, cells with an unstable (moderate or high instability ranking) require controlled beach access from the coastal hinterland.
4. A wide setback for growth and change in dune landforms should be allowed in places where foredunes are missing or eroded, and where more than approximately 50% of the length of coast along the vegetation line on the backshore of the beach is influenced by active blowouts. It is advised that the setback to development currently applied under the State Coastal Planning Policy (SPP 2.6) be calculated from the landward extent of the mobile dunes on these reaches of coast.
5. Preliminary schedules in the State Coastal Planning Policy (SPP 2.6) are outlined for the calculation of coastal erosion allowance, but there is no corresponding information for the susceptibility of a land system to change due to metocean forcing or the overall instability of landforms comprising the system. It is advised that these two aspects of coastal vulnerability be addressed in any review of the policy guidelines.

7.3. INCORPORATION IN POLICY

The susceptibility of coastal land systems to projected changes in metocean forcing over a planning horizon of 100 years, and the stability of the landforms each system supports could be incorporated in existing State planning policies and guidelines (WAPC 2002, 2003; DPI 2006). Examples of susceptibility, instability and vulnerability rankings as well as their implications for planning and recommended planning guidelines are listed in Table 2-12. The rankings, their implications for land use and suggested guidelines for management are listed in Appendix E for each cell.

The analysis of compartments and cells is intended to provide a natural framework with potential for a variety of applications in coastal planning and management. In this context Geographic Information Systems (GIS) models of the cells may be populated with information at the user's discretion and at appropriate spatial scales. Under the policy and guidelines provided by the State Government, possible applications depend on the information linked with cells as overlays or tables for comparative purposes as has been done in this report. Potentially, applications range from structured audits of coastal population associated with individual land systems or landforms, infrastructure, beach use and tourism activities to comparative assessment of different parts of the coast to geographically different hazards and risks.

Direction for coastal planning and management by the State and Local Government is provided in the Coastal Planning Policy for Western Australia (WAPC 2003). The policy supports strategic objectives for environmental, community, economic, infrastructure and regional development interests; particularly through the recognition of natural hazards and minimisation of risk to people and property. Application of coastal zone management is mainly directed through the State Coastal Planning Policy SPP 2.6 (WAPC 2003), the Coastal Protection Policy (DPI 2006) and Department of Transport (DoT 2010) recommendations for inclusion of sea level change projection in coastal planning. These policies contain specific reference to incorporation of coastal landforms and metocean processes in coastal planning and management. The reference provides a direct link to the hierarchy of coastal compartments and sediment cells and, through them to coastal planning at all levels.

The SPP 2.6 (WAPC 2003) promotes the establishment of coastal setbacks and foreshore reserves to achieve strategic objectives, with focus on the following:

- *Recognition of the dynamic nature of coastal environments and the consequences for coastal development and use.*
- *Avoidance or mitigation of the impacts of natural hazards through intelligent siting and design of infrastructure, based on ongoing scientific research.*

Through the SPP 2.6 (WAPC 2003) and the Coastal Protection Policy (DPI 2006) it is recognised that land developments may be adversely affected by a range of physical processes occurring at the coast, with three of the most common being:

- Coastal erosion or accretion;
- Coastal flooding; and
- Coastal landform instability.

A general method for calculating a horizontal setback allowance for coastal erosion is outlined in the SPP 2.6. Calculation of coastal setback to development is most appropriate at more-detailed local area planning and site scales than the sediment cell scale adopted for this report. However, the principles of recognising coastal dynamics and avoiding adverse impacts incorporated in the policy are relevant to vulnerability assessment. They are applicable in assessment of flooding and landform instability. Although site specific, they loosely entrain consideration of the susceptibility of each site to potential change and its current state of stability. Typically applications of SPP 2.6 include identification of minimum development levels, or minimum reserve widths to cater for shoreline movement and changes in sand dune formations.

Where use of wide setbacks is not practical or subsequent shoreline change has significantly reduced a setback allowance the Coastal Protection Policy (DPI 2006) allows for development of protective structures. However, clear justification for protective works is required, and unacceptable adverse environmental, social or financial impacts to neighbouring areas must be avoided. Within this context, the effects of sand impoundment by a protective structure must be considered:

> "*The natural supply of littoral sand is a resource shared by all West Australians. Accordingly, those benefiting from future works or developments that change the natural supply of sand along the coast shall compensate for the change to that supply...*"

The points made in State coastal policy guidelines of the WAPC (2003), DPI (2006) and DoT (2010) provide direction for the advice arising from the vulnerability analysis in two respects. First, coastal development should not be proposed in areas where there is a high probability of adverse environmental and other impacts occurring that would require installation of protective works in the projected 'life' of the proposed development, especially on 'green field' sites. Second, the requirement to consider the impact of proposed development on sand impoundment necessitates determination of the coastal sediment budget at a scale commensurate with the scale of the proposed development.

Through its context in coastal policy guidelines the vulnerability assessment also provides insight into approaches that may be used in land use adaptation to projected climate change and rise in sea level. Different facets of adaptation may be considered. For example, in undeveloped areas where there is a higher than moderate level of risk the vulnerability analysis can be used to plan avoidance of sites with potential risks or incorporated in plans that include contingency measures should development be necessary. Second, in areas with established infrastructure the vulnerability analysis may be used to determine the suite of environmental problems requiring more detailed risk assessment and the incorporation of social and economic considerations.

7.4. FURTHER STUDIES

In addition to further studies required for hazard and risk assessment under the State Planning Policy 2.6 (WAPC 2003) requirement for them is founded the need to redress information gaps and for management purposes.

7.4.1. Risk Assessment

This report is intended to be indicative rather than prescriptive and have application for strategic planning purposes. It focuses specifically on the current and potential changes to the geomorphologic features of the coast. In a more complete assessment of coastal hazard and risk the assessment should be extended to include descriptions of landform change associated with meteorologic and oceanographic variables as well as consideration of the social and economic factors at risk. Results reported herein thus provide a first step to the application of more detailed risk and coastal vulnerability assessment procedures, such as those described by Kay *et al.* (1996), Brooks (2003), Harvey and Nicholls (2008), Harvey and Woodroffe (2008) and Finlayson *et al.* (2009). It broadly establishes the first steps to a full risk assessment. Full risk assessments are recommended for developed areas, including the townsites, and areas subject to increasing use for tourism and recreational purposes.

Frameworks and guidelines for risk assessment previously have been applied in an assessment of risk to the sustainability of a coastal, natural-resource based industry by Ogburn & White (2009) and to coastal management in New South Wales by Rollason *et al*. (2010). Both applications use the AS/NZS ISO 31000 risk assessment framework (Standards Australia 2009) to determine management outcomes in circumstances where there is considerable uncertainty and a lack of detailed data to describe coastal changes. Both describe circumstances relevant to vulnerability assessment for land systems and landforms along the Gingin-Dandaragan coast. A similar approach has been adopted in this report by using a combination of structure and condition to determine vulnerability of landforms to existing and projected changes in metocean forcing. The vulnerability estimates are subsequently linked to broad estimates of the likelihood of environmental changes occurring. Vulnerability rankings then may be used to establish consequence and risk tables for the coastal landforms for a more detailed risk analysis that is not undertaken in the context of this report. However, it does provide an indication of further information requirements.

Risk assessment is commonly is undertaken in an established framework, such as the principles and guidelines within AS/NZS ISO 31000 (Standards Australia 2009). Assessment provides an estimation of the likely consequences arising from occurrence of a hazardous event, ranging from insignificant to catastrophic outcomes. Estimations of the likelihood of the event occurring (Table 7-1) are based on limited experience with hazard identification, description and mitigation within the region of interest. The hazard estimates are used in consequence tables such as that presented by Australia Pacific LNG (2010) to examine the likelihood of health, safety and environmental consequences of different types of hazards (Table 7-2). They are prepared as part of Environmental Impact Statements (EIS) for major development proposals in Australia. The method subsequently enables the consequences of hazards impacting on the environment to be prioritised and considered in a full risk assessment. In this respect the framework provided by AS/NZS ISO 31000 guidelines (Standards Australia 2009) has relevance to the State Planning Policy 2.6 (WAPC 2003). Regardless of risk a full hazard and risk assessment is required for all development under existing State Government coastal planning and management policies.

Steps in the framework provided by AS/NZS ISO 31000 guidelines presuppose the availability of a wide variety of metocean, geomorphologic, social, cultural and economic information. Advisedly, collation of the physical information required for a full risk analysis would be based on a comprehensive review of available data to identify gaps and directed to enable:

- Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones and river discharge), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate This is most likely to be where it affects elements or landforms with lower integrity of natural structures or limited natural resilience.

- Determination of the potential impacts of extreme metocean events (such as storms) on these elements or landforms based on geological and historical (measured and surrogate) information as well as modelling of projected future extreme events.
- Identification of sediment sources, sinks and key transport pathways as a first step to determine the rate of coastal change and the potential impact of any proposed land through modification of the coastal sediment budget and its affect on the most unstable landforms.

Table 7-1: Probability Table Based on Metocean Forcing and Geologic Records (Source: Rollason *et al.* 2010)

Probability	Likelihood
Almost Certain	There is a high possibility the event will occur as there is a history of periodic occurrence
Likely	It is likely the event will occur as there is a history of casual occurrence
Possible	There is an approximate 50% chance that the event will occur
Unlikely	There is a low possibility that the event will occur. However, there is a history of infrequent and isolated occurrence
Rare	It is highly unlikely that the event will occur, except in extreme circumstances which have not been recorded historically.

Table 7-2: Health, Safety and Environment Consequence Categories for Critical and Catastrophic Levels of Risk (Source: Australia Pacific LNG 2010: p6)

	Impact to company personnel	Natural environment	Community damage/ impact/ social/ cultural heritage
Catastrophic 6	Multiple fatalities ≥4 or severe irreversible disability to large group of people (>10)	Long term destruction of highly significant ecosystem or very significant effects on endangered species or habitats	Multiple community fatalities, complete breakdown of social order, irreparable damage of high value items of great cultural significance. Adverse international or prolonged (>2 weeks) national media coverage
Critical 5	1-3 fatalities or serious irreversible disability (>30%) to multiple persons (<10)	Major off-site release or spill, significant impact on highly valued species or habitats to the point of eradication or impairment of the ecosystem. Widespread long-term impact	Community fatality. Significant breakdown of social order. Ongoing serious social issue. Major irreparable damage to highly valuable structures/items of cultural significance. Adverse national media coverage (>2 days)

7.4.1. Data Requirements

Data requirements include:

- Baseline coastal monitoring information such as shoreface and beach profiles should be collected for reaches of coast supporting infrastructure and where there is increasing use of the coast for tourism and recreational purposes where limited historic information is available.

- It is recommend LiDAR mapping of the inshore waters between Cape Naturaliste and Yanchep be extended for the Gingin and Dandaragan coasts. This would provide a wider context for available bathymetric information and facilitate a more complete assessment of natural resources, including sediment availability and distribution.
- Coastal sediment budget information, including identification of sediment sources and sinks as well as determination of approximate volumetric rates of sediment transport is to be completed for the areas of Planning Interest as well as cells in adjoining Wedge Island and Grey.
- Determination of the elevation and coverage of underlying rock are required for sites supporting urban-rural development and infrastructure that may be located on unconsolidated sediments overlying bedrock surfaces. Full geotechnical survey using drilling or other appropriate technique is recommended for these sites. This is considered to be particularly significant for Seabird, Ledge Point, Wedge Island, Grey and Lancelin.

7.4.2. Other Requirements for Management Purposes

Other requirements for management purposes include:

- Identification and costing of ongoing management requirements at developed sites as well as those proposed for development or increased land use.
- Determination of potential migration or retreat of unstable landforms and the potential impacts of landform change on existing and proposed development.
- Identification of costs and allocation responsibility for management of coastal protection and stabilisation works, such as engineered structures and sediment bypassing, for the adjacent coast, as well as for ongoing coastal monitoring, maintenance and management of the site.
- Strategies to respond to metocean events and other site disturbances of various frequencies and magnitudes.

8. References

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Appendix A The Project Brief

THE BRIEF

Development of Sediment Cell Concepts for the

1) Shires of Gingin to Dandaragan,

2) Shires of Coorow to the Shire of Northampton, and

3) Shires of Shark Bay, Carnarvon and Exmouth

1. BACKGROUND

Previous investigations undertaken to identify coastal stability and susceptibility to change along parts of the Western Australian coast have been conducted in consultation with officers from the Departments of Planning, Transport, Environment and Conservation and the Geological Survey of Western Australia, as well as private industry groups, to assist the State Government provide informed planning guidance for regional and sub-regional strategic planning. The investigations parallel procedures developed in the United Kingdom and have resulted in development of an approach that provides consistency and coherence in its application across planning scales as well as from place to place. This Brief is for a project to link the areas examined and provide comprehensive information for the coast between the Shire of Gingin and the Exmouth Gulf. The intention of the project is to expedite decision making for planning and management of coastal and inshore marine resources.

Detailed investigations have been completed for the coast between Cape Naturaliste and Lancelin, and for the Batavia Coast between Leander Point and Cape Burney. This Brief will result in the extension of these investigations to the coastal areas between Lancelin and Kalbarri and broadly in the Gascoyne region. The areas for investigation are under increasing pressure for development and they require strategic planning guidance for future land use. Such guidance is a not readily available for all sections of the coast proposed for examination but is required to inform regional strategies currently being prepared. For example, a final draft of the Wheatbelt Regional Strategy and review of other regional coastal strategies.

The coastal area of the Wheatbelt Region has been identified as requiring a high level of detailed investigation due to emergent development pressures. The opening of the final section of the Indian Ocean Drive, due for completion by mid 2011, will result in increased number of visitors to the region's coastal settlements and other recreation sites. It is anticipated landuse pressure will increase on recreational sites not currently accessible to two-wheel drive vehicles, such as Grey, Wedge Island and a number of smaller sites that are or were previously occupied by squatter shacks. The new road will also enable off-road vehicle users to gain easier access to inappropriate sites such as steep vegetated dunes and exposed mobile sand sheets, thus increasing the rate of destabilisation of these landforms. There is also pressure is for additional facilities, including moorings, new ramps for small boats and upgrading of existing facilities.

Recommendations of the Wheatbelt Region Strategy for future development need to be grounded in knowledge of coastal landform stability and susceptibility to change if potential maintenance and management costs are to be minimised.

Further north, the Midwest Region is under pressure for coastal development in towns such as Horrocks, Port Gregory and Kalbarri. The region is becoming more attractive to retirees for the lifestyle opportunities and to those gaining employment in industrial and mining sectors in and around Geraldton. Tourism is a key driver for growth in the Gascoyne region and areas need to be identified that support this landuse so not to negatively impact on the natural environment. Appropriate locations for coastal nodes for recreational and tourism development need to be determined, such as those designated along the Ningaloo coast.

The aim of this Consultancy is to:

> *"Provide strategic planning guidance, management strategies and direction on appropriate land uses for future subdivision and development of coastal land in the Shires of Gingin to Northampton and broadly in the Gascoyne Region by the identification of sediment cells that define coastal stability and susceptibility to change in the coastal zone".*

2. CONSULTANCY FRAMEWORK

The investigation will provide a broad understanding of the landform components in the subject areas and the metocean processes affecting them. This will involve assessment of aerial photography of the study area, site visits, preparation of a GIS information base for use by natural resource managers and a review of relevant and available metocean information. Certain landforms and coastal features are more at risk from variations in climate and fluctuation in sea level than others. Interpretation of the data gathered will assist decision-making regarding coastal development by allowing identification of areas for potential future development as well as vulnerable locations within the study area that are less suitable. It will also highlight areas that require more detailed, site specific, assessment.

3. GEOGRAPHIC AREAS

The Consultancy will involve three geographic areas:

1. The Wheatbelt Regional Strategy study area. This covers the coastal portions of the Shire of Gingin and the Shire of Dandaragan;
2. The Midwest coastal area that stretches from the Shire of Coorow in the south to the Shire of Northampton in the north (excluding Dongara to Cape Burney); and
3. The Gascoyne coastal area including the Shires of Shark Bay, Carnarvon and Exmouth.

The Consultancy components below, will need to be completed for each of the three geographic regions mentioned above.

4. CONSULTANCY COMPONENTS

The proposed Consultancy has the following components:

1. Description of coastal landforms and identification of sediment cells, with particular reference to coastal dunes, beaches, rocky shores and inshore morphology.
2. Review of available information describing coastal processes affecting landform development, including metocean processes.
3. Identification of landforms and reaches of coastal land susceptible to risks related to natural variation in climate and sea level fluctuations, and which may be affected by projected changes in climate.
4. The preparation of management strategies, recommendations and appropriate land uses for each sediment cell based on the outcomes of 1-4 above.
5. Preparation of a report and presentation to nominated stakeholder groups.

5. OUTPUTS

The Consultancy will provide the following outputs:

1. Site visits and aerial analysis of the three coastal areas identified in Section 3.
2. Detailed identification and mapping of coastal landforms (including structural susceptibility to change and landform stability) and sediment components for the three geographic areas identified in section 3.
3. Mapping of sediment cells, susceptibility to change and stability in the coastal zone over time be prepared for the three geographic areas identified in section 3.
4. A report prepared that includes:
    a. background literature and methodology;
    b. analysis of coastal processes (identifying areas potentially at risk from sea level fluctuations and other metocean processes);
    c. identification, description and mapping of landforms and sediment cells;
    d. identification, discussion and mapping of landform stability and susceptibility to change for each sediment cell (including a detailed glossary); and
    e. a discussion, including management strategies and recommendations (including appropriate land uses) for each sediment cell.
5. Presentations made to LGAs and state government on the findings of the investigations for the three geographic areas identified in section 3.

These outputs will need to be completed for each of the three geographic areas e.g. three comprehensive reports (4) will need to be completed.

The Consultant shall meet with the project management team at DoP on a regular basis, or at completion of each milestone, for discussion and review of progress of the Consultancy.

Draft reports should be provided to the project management team at DoP, for discussion and feedback prior to finalisation.

6. REPORTS

Project reports shall be in Microsoft Word format, with three hard copies of each to be provided. Maps will be produced in GIS compatible format.

7. TIMING

The Consultancy, and completion of the final reports, is anticipated to take no longer than 1 year to complete, commencing in June 2010 with an end date of September 2010 for the Shire of Gingin and Dandaragan and May 2011 for the Midwest and Gascoyne components.

Prior to commencing the Consultancy, the Consultant shall arrange an inception meeting with the project management team to:

- Confirm and clarify the scope of the Consultancy;
- Confirm Consultancy milestones, reporting timeframes and meeting timescales;
- Confirm arrangements (methodology) to commence of the Consultancy;
- Verify any other matters concerning the review;
- Obtain any relevant documents;
- Discuss specific issues related to each geographic area, for example:
    a. Potential and appropriate land uses in each geographic area;
    b. Coastal 'hotspots' in each geographic area;
    c. Clarification of study area boundaries in each geographic area; and
    d. Any other issue deemed relevant by the Consultant or DoP.

8 .KEY PERFORMANCE INDICATORS

Indicators of performance will include -

- Compliance with the Brief;
- Expertise and applicability of information provided to coastal management and coastal land use planning; and
- Timing and ability to meet agreed deadlines for reporting.

8.1 Location of Service Provision

The Consultant may be required to attend meetings at any of the Department's metropolitan premises. The Consultant may also be required to attend meetings at the premises of other key stakeholders located in the Midwest or Gascoyne Regions.

It is expected that travel will be required outside of the metropolitan area. Generally however, it is expected that the Services will primarily be undertaken using phone, facsimile and email.

9. TRAVEL AND OTHER DISBURSEMENTS

All travel and disbursements are to be factored into the lump sum for each geographic stage of the project in the RFQ. The details below are to be used as the baseline for the Consultant to cost its travel and disbursements. The Consultant may, if it believes it is warranted for its methodology, propose additional travel within its quotation for consideration by the Department. The acceptance of any additional travel proposed is at the discretion of the Department.

1. The Wheatbelt Regional Strategy study area. This covers the coastal portions of the Shire of Gingin and the Shire of Dandaragan;
    a. Site visit
    b. 2 x stakeholder presentations
2. The Midwest coastal area that stretches from the Shire of Coorow in the south to the Shire of Northampton in the north (excluding Dongara to Cape Burney);
    a. Site visit
    b. 3 x stakeholder presentations
3. The Gascoyne coastal area including the Shires of Shark Bay, Carnarvon and Exmouth.
    a. Site visit
    b. 3 x stakeholder presentations

Appendix B Glossary

	Term	Explanation
A	Alongshore	Marine and beachface processes operating along the coast are *alongshore* processes. The term alongshore also indicates direction.
	Arcuate shoreline	An *arcuate shoreline* is an embayed shoreline. In plan form the arc is concave to shoreward and may be a half-heart shape, occasionally referred to as a zeta-form, or semi-circular in form. The shape provides an indication of ocean processes affecting the shore of the embayment.
	Aspect	*Aspect* is the direction to seaward the coast faces. It is estimated in the centre of the coastal feature being examined and at right angles to the trend of the coastline in plan. The direction faced by the coast determines the prevailing and dominant metocean processes to which it is susceptible. For example, unsheltered NW facing coasts in the region are fully exposed to storms from that direction.
	Avulsion	*Avulsion* is the switching, or rapid migration, of a river channel location and abandonment of the prior channel. This behaviour may be common on large active delta systems.
B	Backshore	The most landward extent of bare, unvegetated beach is the *backshore*. It is a zone infrequently inundated by storm waves active during phases of extreme, higher-than-average sea-level conditions.
	Backbarrier	The most landward barrier landforms, particularly the coastal dunes furthest inland, sandflats and washover lobes extending into coastal lagoons are referred to as *backbarrier* features.
	Barrier	*Barriers* are relatively narrow strips of sand parallel to the mainland coast. The sands occur in distinct lenses deposited at a particular geological time, with the most recent barriers being formed during the Holocene, over the past 10,000 years. Landforms associated with barriers extend from the inner continental shelf include those of the active shoreface, beach and dunes along the coast. The suite of dunes comprising the landform may be referred to as *barrier dunes*.
	Beach profile	The beach profile is the cross-sectional shape of the beach from the seaward toe of the foredune or upper reach of wave action to the seaward limit of currents generated by breaking waves. In a seaward sequence the profile may include the following morphology: berm, beachface, step, trough, ripples and bar. It is comprised of several zones defined by the dominant processes, including the subaerial beach, swash zone, and nearshore zone.
	Beach rock	A friable to well-cemented sedimentary rock, formed in the intertidal zone.
	Beach type	Beaches are categorised according to their environmental setting and profile configuration. In the context of this report the first distinction is between beaches located in *sheltered* or *exposed* locations where the most common wave conditions are less or higher than 50cms. *Sheltered beaches* have profiles that are flat or rounded. Both exposed and sheltered beaches may overlie a rocky substrate. These are *perched beaches*.
	Blowout	In plan form a *blowout* has a parabolic form with a width greater than its length. Blowouts occur in partially vegetated foredunes. A *blowout* forms when a patch of protective vegetation is lost,

		allowing strong winds to "blow out" sand and form a depression.
C	Calcarenite	A limestone consisting predominantly of sand-sized carbonate grains.
	Cliffed dune	The seaward margin of a foredune or frontal dune may be cut by coastal erosion that results in the formation of a low sandy cliff.
	Coastal compartment	A coastal *compartment* is a component of the geological framework of the coast. It is an area of coast bounded alongshore by large geologic structures, changes in geology or geomorphic features exerting structural control on the planform of the coast. Compartments contain a particular Land System or landform association depending on the scale at which they are being described.
	Continuous reef	*Continuous reef* occurs where an unbroken line of reef extends parallel to the shore for at least the length of the coastal feature under consideration.
	Curvilinear (rounded) beach	Beaches in sheltered environments subject to a relatively high wave regime compared with other sheltered beaches may have an upwardly convex or concave beachface profile. These are curvilinear in form and may grade to a step at the seaward limit of the swash zone.
	Cuspate foreland	On the Central Coast of Western Australia *cuspate forelands* are triangular-shaped accretions of sand extending seawards in the lee of an offshore reef. *Cuspate forelands* principally develop in response to longshore movement of sediment and hence are highly susceptible to changes in metocean processes.
D	Discontinuous reef	*Discontinuous reef* occurs where the line of reef extending parallel to the shore has gaps or breaks over the length of the coastal feature under consideration. The length of gaps along the coast under consideration is significantly less than that occupied by reef.
	Dissipative beach	A *dissipative beach* is one in which wave energy is substantially expended as the wave moves from its break point to the shore. Multiple lines of breakers are present. On an exposed wave-dominated coast wave heights exceed 2.0m and the profile includes a flat beachface with multiple bars and troughs in the inshore zone. In a sheltered environment where wave heights are less than 0.25m the profile is planar, with a very broad sub-tidal terrace.
	Division	A *division* is a subdivision of a broad climatic zone. The unit provides an overview of the whole state suitable for maps at scales of about 1:5,000,000. For example, wet-dry tropics and sub-tropical areas are subdivisions of the tropical zone in north Western Australia.
E	Eolianite	*Eolianite* is weakly cemented rock that is commonly comprises calcareous dune sand derived from a marine environment. The stratigraphy of the dunes in which the eolianite has formed is usually present in outcrops.
	Episodic, transgressive dune barrier	An *episodic, transgressive dune barrier* comprises nested blowouts and/or parabolic dunes. The dunes commonly form a ridge of irregular height along the coast. The ridge and its dunes are the surface features of the barrier which also extends offshore as a marine deposit of sands with a similar mineral composition to those found in the dunes.
	Exposed beach	*Exposed beaches* are open to the full effects of metocean processes. The beaches experience average wave heights of over 1 metre and are considered to be wave dominated. They have reflective, transitional or dissipative profile features.
F	Flat beach	*Flat beaches* occur in very sheltered environments, those with a

		modal wave height of less than 25cms. The beach profile is likely to have a negative exponential shape with a small, narrow, upwardly concave beachface grading to a flat low tidal and wide intertidal terrace that terminates in a steep drop to deep water.
	Foredune	A *foredune* is a small coastal dune or low ridge. Foredunes are commonly less than 10m in elevation, located parallel to the shoreline and along the landward margin of a beach and stabilised mainly by pioneer vegetation. Foredunes are built through pioneer vegetation trapping of windblown sand directly from the beach. They build in height until the vegetation is destroyed; blowouts are formed and migrate landwards.
	Foreshore	The *foreshore* of a beach includes the berm, swash zone and lower intertidal zone.
	Frontal dune	Blowouts and parabolic dunes closest to the shore and immediately landward of the backshore where foredunes have formed or potentially could form are the *frontal dunes* or *primary dunes*. Absence of a foredune supporting pioneer species and scarping (cliffing) of the frontal dunes is indicative of a depleted sediment supply and coastal erosion.
G	Geologic framework	The *geologic framework* of a coastal area is the surface topography or geometry of bedrock in a designated area that interacts with metocean processes and the sediment transport regime to affect the distribution of unconsolidated sediments and the development of coastal landforms.
H	Hind Dunes	*Hind dunes* are those landward of the frontal or primary dunes.
	Holocene	The *Holocene* is a geological epoch that began approximately 12,000 years ago. It is an interglacial period of atmospheric warming and sea level rise. During the last 10,000 years before present sea level rose from below 50m to a peak of 1 to 2 metres above its present level approximately 6,000 years ago. The modern coast developed in response to this rise and subsequent fall.
I	Inshore	In the context of this report the term *inshore* refers to waters and seabed less than 25m deep adjoining the shore. The area commonly includes offshore reefs and the lagoons they impound.
	Instability	*Instability* refers to the current condition of similar landforms from different places. For example, it may be apparent as the percentage of vegetation cover on different dune fields, the completeness of foredune development on sandy beaches or differences in the historical records of shoreline movement on beaches.
	Isobath	An *isobath* is a submarine contour line indicating points of equal depth on a bathymetric map.
	Intermittent reef	*Intermittent reef* occurs where outcrops are uncommonly distributed in waters along the coastal feature under consideration.
J		
K		
L	Lagoon	A coastal *lagoon* is a water body sheltered from the full impact of oceanographic processes by an offshore reef or dune barrier.
	Land system	A *land system* is an area of characteristic landform patterns suitable for mapping at regional scales of 1:50,000 to 1:100,000. Several landforms form a landform pattern which in turn comprises a land system.
	Landform	A *landform i*s a natural feature of the Earth's surface. Landforms range in size from small features apparent at a local scale to large structures apparent at a land system or regional scales. In the context of this report the term is used to describe features apparent

		at a local scale of 1: 500 to 1:25,000.
	Landform association	A *landform association* is a group of contiguous landforms that are associated in some way, commonly by shared location or age structure. For example, a Holocene sandy beach perched abutting an older dune and perched on a Pleistocene limestone platform..
	Landform element	Each landform is made up of geometrically recognised components or *landform elements*. For example a blowout dune includes a slack, side walls, dune crest, slipface and toe slope.
	Landform pattern	A *landform pattern* is a group of landforms of a common geologic age that is the landform part of a land system. For example, a Holocene progradational barrier (landform system) is a low-lying plain (landform association) comprised of a sequence of foredune ridges, a beach and shoreface morphology.
	Littoral	The adjective *littoral* is used to designate the beachface and adjoining inshore areas of a sandy beach as well as the processes affecting them. The *littoral zone* extends from the spring high tide line to submarine areas affected by swash processes.
M	Mainland beach	Mainland beaches are apparent where a thin deposit of marine sands abut Pleistocene or older landforms. In some instances the sand may be subtidal and abut a platform or cliff.
	Metocean	*Metocean* is an abbreviation of meteorological and oceanographic. Hence *metocean processes* include all atmospheric and oceanographic processes such as storms, winds, waves, currents and tides.
	Mobile dunes	*Mobile dunes* are apparent as partially vegetated and open sand masses associated with blowouts, parabolic dunes and sand sheets.
	Morphodynamic	The coastal system is one in which morphology, sediments and processes are dynamically linked such that change in one will be associated with change in the others. This is referred to as a *morphodynamic* system.
	Morphostratigraphic	The term *morphostratigraphic* is used to indicate linkages between coastal morphology and stratigraphy.
	Morphology	*Morphology* describes landform assemblages or systems comprised of unconsolidated sediment.
N	Natural Structure	*Natural structures* are geologic or geomorphological features, such as a rocky promontory or a sandy barrier.
O	Offshore	The term *offshore* is used in the report to designate either ocean seaward of the 30m isobath or shallower water seaward of the zone in which waves break.
P	Parabolic dune	In plan, a *parabolic dune* is a long U-shaped dune with long trailing arms (the vertical part of the U) pointing to windward. Parabolic dunes are common in the Central West Coast Region, where dune migration commonly occurs over a low plain or flat marl surface.
	Pavement	*Pavement* is a rock surface outcropping at an elevation close to the surrounding seabed. It may be part of a mixed sand and rock seabed, or patched reef, where it is irregular in form and elevation.
	Perched beach	Sandy beaches on which the sand overlies a rock pavement, beachrock ramp or rock platform is referred to as *perched beaches*. Under an engineering definition beaches immediately landward of a rock outcrop but separated from it by a narrow lagoon may also be classed as perched beaches.
	Pioneer vegetation	Herbaceous and grassy vegetation that first colonises the storm wrack line along the backshore as well as disturbed sites in dunes to landward is *pioneer vegetation*.
	Platform	A gently sloping surface produced by wave erosion, extending into

		the sea from the base of a wave-cut cliff.
	Pleistocene	The *Pleistocene* is the first geological epoch of the Quaternary Period and spans geologic time from approximately 2.6 million to 12,000 years before present. It is a time of repeated glaciations and sea level fluctuation on Earth.
	Pocket beach	A *pocket beach* is a small beach fixed between two headlands. Pocket beaches are commonly crescentic in plan, with the concave edge toward the sea. There is very little or no exchange of sediment between the beach and the adjacent shorelines.
	Prograded barrier	A succession of multiple foredune and/or beach ridges on the open coast and in sheltered waters form low-lying plain referred to as a *prograded barrier*. The plain may be features of a composite barrier where they merge with transgressive dune fields to landward or are overlain by blowouts along their seaward margin.
	Province	A *province* is an area defined on geological (lithology, topography and stratigraphy) or geomorphologic (major land systems) criteria suitable for a regional perspective at a scale of about 1:1,000,000. Originally described by CSIRO (1983).
Q	Quaternary	The *Quaternary* Period is the most recent of the three periods of the Cenozoic Era in the geologic time scale and has extended from approximately 2.6 million years ago to the present. The Quaternary includes two geologic epochs: the Pleistocene and the Holocene Epochs
R	Receded barrier	On coasts where sediment supply is limited *receded barriers* are thin marine sand deposits in narrow dunes that overlie estuarine, backbarrier or mainland features which outcrop at the shore.
	Reef	In the context of this report the term *reef* refers to any rock outcrop with an elevation above the surrounding sea bed. Herein, reef is described as being *continuous, discontinuous* and i*ntermittent* or as *pavement.*
	Reflective beach	A *reflective beach* is one on which incident waves are reflected seaward from a steep beachface following backwash run out. Reflective beach profiles are characterised by a berm or berms, a steep beachface, a step at the bottom of the swash zone and a deep, planar inshore zone. They are common features of coasts with a modal wave height of approximately 0.5 to 1.5 metres but also are observed on beaches comprised of coarse sediment and subject to larger waves.
	Region	A *region i*s an area with a characteristic pattern of land systems that differentiates it from adjacent areas. The unit is suitable for mapping at scales of approximately 1:250,000. This differs from the definition provided by CSIRO (1983) and Schoknecht *et al.* (2004).
	Rhythmic shoreline	An uninterrupted sandy shoreline is considered to be *rhythmic* when it has a sinuous plan form with shallow embayments separated by shoreline salients.
S	Salient	Part of a sandy coast protruding seaward of the average trend of the shoreline.
	Sand sheet	A *sand sheet* is either a mass of mobile sand that has become detached from a blowout or parabolic dune and is moving freely across the landscape; or it is an area of bare sand where active blowouts and/or parabolic dunes have coalesced.
	Sediment cell	A coastal *sediment cell* is a section of coast and its associated nearshore area within which the movement of sediment is apparent through identification of areas which function as sediment sources, transport pathways and sediment sinks. Classically, interruptions to movement of sediment within one cell

		should not affect beaches in an adjacent cell. However this is not always applicable to beaches in Western Australia where the major source of sediment is derived from offshore sources.
	Sheltered beach	*Sheltered beaches* are protected from the full effects of metocean processes by offshore reefs or by their aspect. The beaches frequently experience average wave heights of less than 1 metre and are considered to be dominated by fluctuations in sea level, particularly those associated with surge. They have flat profiles which may be segmented where longshore currents prevail, or rounded profile features under wave regimes relatively higher than those experienced on flat beaches.
	Shoreface	The *shoreface* is a zone extending seaward from the foreshore, beyond the breaker zone to the limit of wave movement of sediment. It is the zone in which the majority of sediment transport occurs.
	Shoreline	The shoreline is a discrete line along the coast. In the context of this report it is the High Water Line used in the Australian Oil Spills Response Atlas (OSRA) and described by Landgate (2006).
	Shoreline plan	The *shoreline plan* is a view of the shoreline shape from directly above so that its plan shape is readily apparent.
	Straight shoreline	A *straight shoreline* closely approximates a straight line over the length of coast under consideration.
	Stationary barrier	*Stationary barriers* are narrow, capped by blowout dunes overlying well developed backbarrier sandflats and washover lobes. Stationary barriers are commonly associated with coastal lagoons or adjoin alluvial flats to landwards.
	Stratigraphy	*Stratigraphy* is the study of geologic strata or layers of sediment.
	Substrate	The *substrate* is the surface on which a barrier sits. For example, the Holocene barriers forming the modern coast are commonly located on a coastal limestone surface of Pleistocene age.
	Susceptibility	*Susceptibility* is an estimate of the likelihood of a land system altering in structure over a planning horizon of 100 years. The estimate is based on a comparison of the existing structure with reported descriptions of the evolution of similar structures. Following Roy *et al.* (1994) for example, prolonged erosion of an episodic transgressive barrier complex may result in a change to a receded barrier.
	Swash	Swash describes the uprush and backwash of waves on the beachface of a sandy beach. The swash zone extends seaward from the limit of uprush down slope to include the step at the bottom of the beachface and the inshore area affected by backwash run out.
T	Time scales	The *long-term* times scale refers to coastal evolution and the *susceptibility* of land systems to change over geologic time, particularly over the geological epochs of the Quaternary Period; the Pleistocene and Holocene Epochs. The short-term time scale refers to factors affecting the *stability* of coastal landforms. These are linked to the 100 year planning horizon of the State Coastal Planning Policy (SPP 2.6) as follows: *Short-term*: 1 to 10 years *Intermediate-term*: 11 to 25 years *Long-term*: longer than 25 years
	Tombolo	A *tombolo* is a deposition landform in which an island is attached to the mainland by a narrow piece of land. Tombolos are developed by refraction, diffraction and longshore drift to form a spit or bar that connects the mainland coast to connecting a coast to an offshore

		island. Once attached, the island is then known as a tied island.
	Topography	In the context of this report t*opography* describes landform assemblages or systems comprised of rock
	Transgressive dunes	Blowouts and/or parabolic dunes migrating landward from the sediment source at the beach are *transgressive dunes* in that they bury older landforms (and infrastructure) as they migrate. Dune mobilisation takes place episodically hence the dunes may be overlain to form and episodic, transgressive barrier.
	Transitional beach	On exposed, wave-dominated coast sandy beaches may fluctuate in form between reflective and dissipative states as the wave regime alters between low and high wave extremes. Between these extremes the *transitional* state is one with profiles that have elements of both. Transitional sandy beaches are morphologically characterised by bars, troughs and rip current channels.
U	Unconsolidated sediments	*Unconsolidated sediments* are loose sediment particles such as gravel, sand, silt and clay that have not been lithified or consolidated into rock.
V	Vegetation cover	For a designated area *vegetation cover* is the proportion of the land surface covered by plants.
	Vulnerability	*Vulnerability r*efers to the likelihood of a land system or landform changing in response to changing metocean conditions. It is estimated as a combination of the long-term susceptibility and short-term instability of a coastal compartment or sediment cell.
W	Washover lobe	Under extreme storm conditions and high sea levels low barriers may be breached by waves that wash sediment from the beach onto lowland or into lagoons landwards of the barrier. The sediment is deposited in fans or *washover lobes.*
X		
Y		
Z	Zone	*Zone* has two meanings. Firstly, in a land system context it is a broad section of the Australian Coast based on climate, and separating the tropical from temperate zones. These are referred to as regions by CSIRO (1983) and Schoknecht *et al.* (2004). Secondly, at a more detailed scale zone describes a small area where a particular suite of coastal processes and landforms are present. For example, the nearshore zone is where waves, wave driven currents and tides determine the pattern of bars and beach shape.

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Appendix C Coastal Landforms: Wreck Point to Fishermans Island

Figure C - 1: Compartment, Cell and Landform Map Legend
Landforms defined in Table 5-3

Figure C - 2: Vulnerability for Cells 33-36

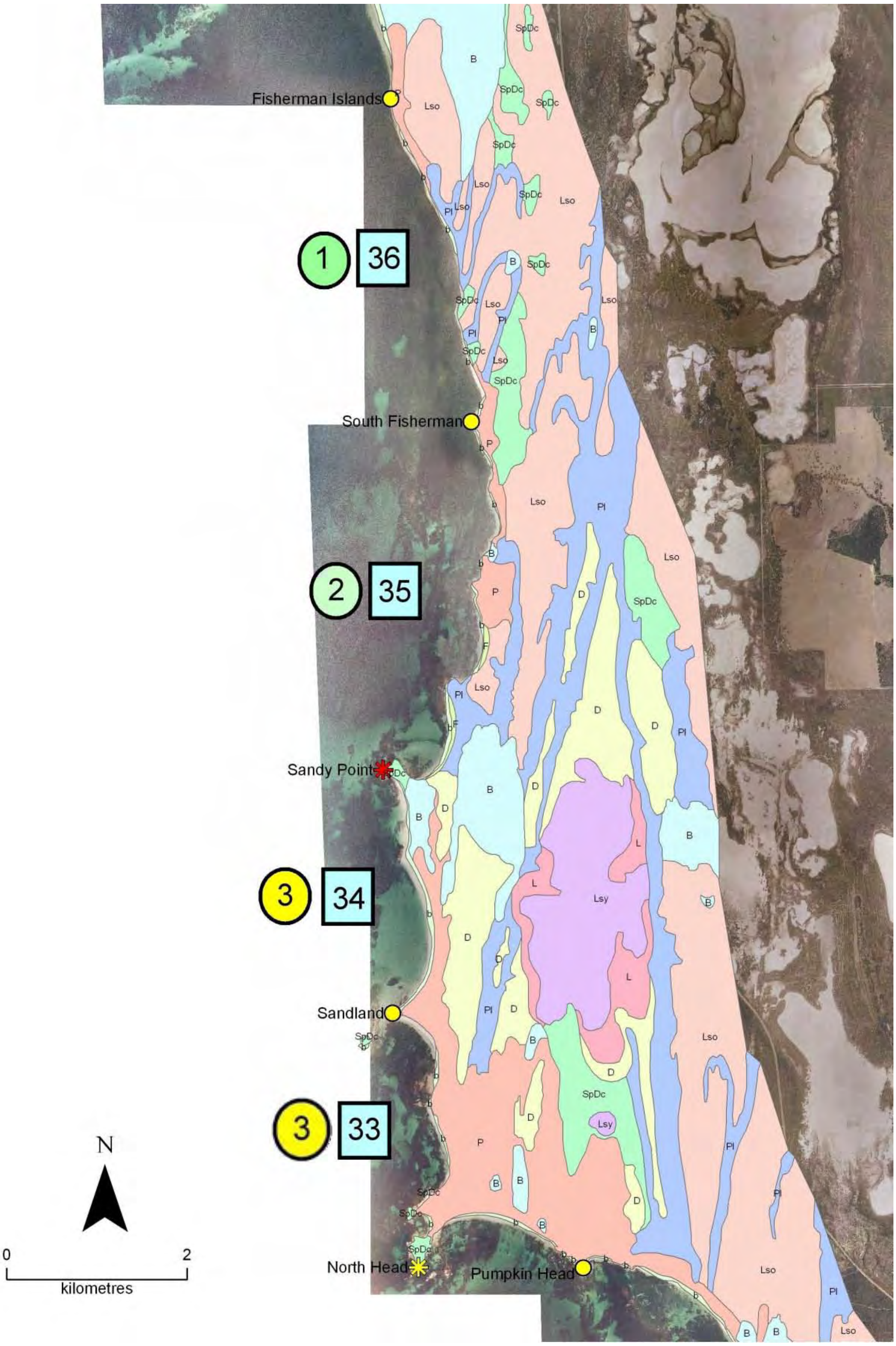

Figure C - 3: Landforms for Cells 33-36

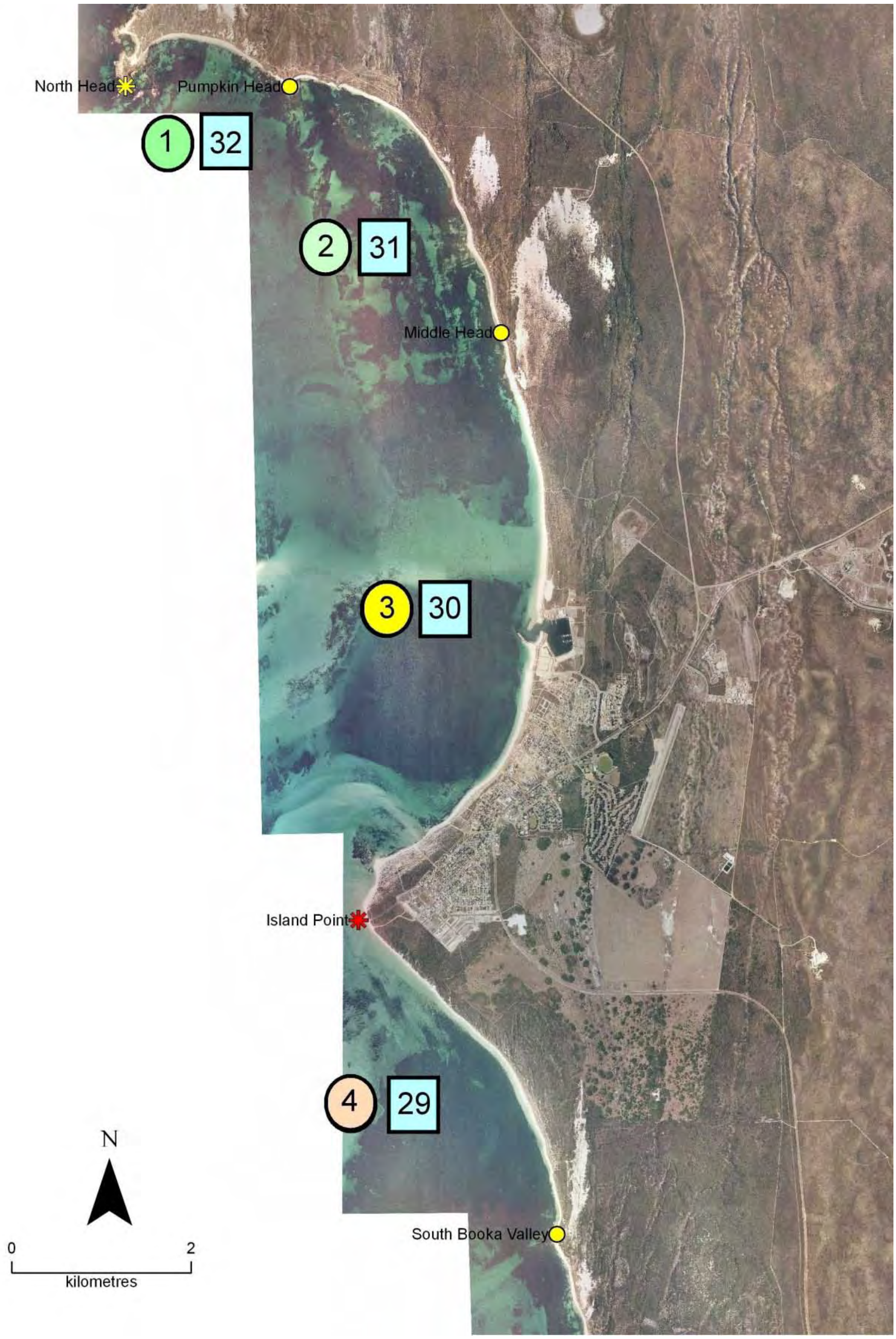

Figure C - 4: Vulnerability for Cells 29-32

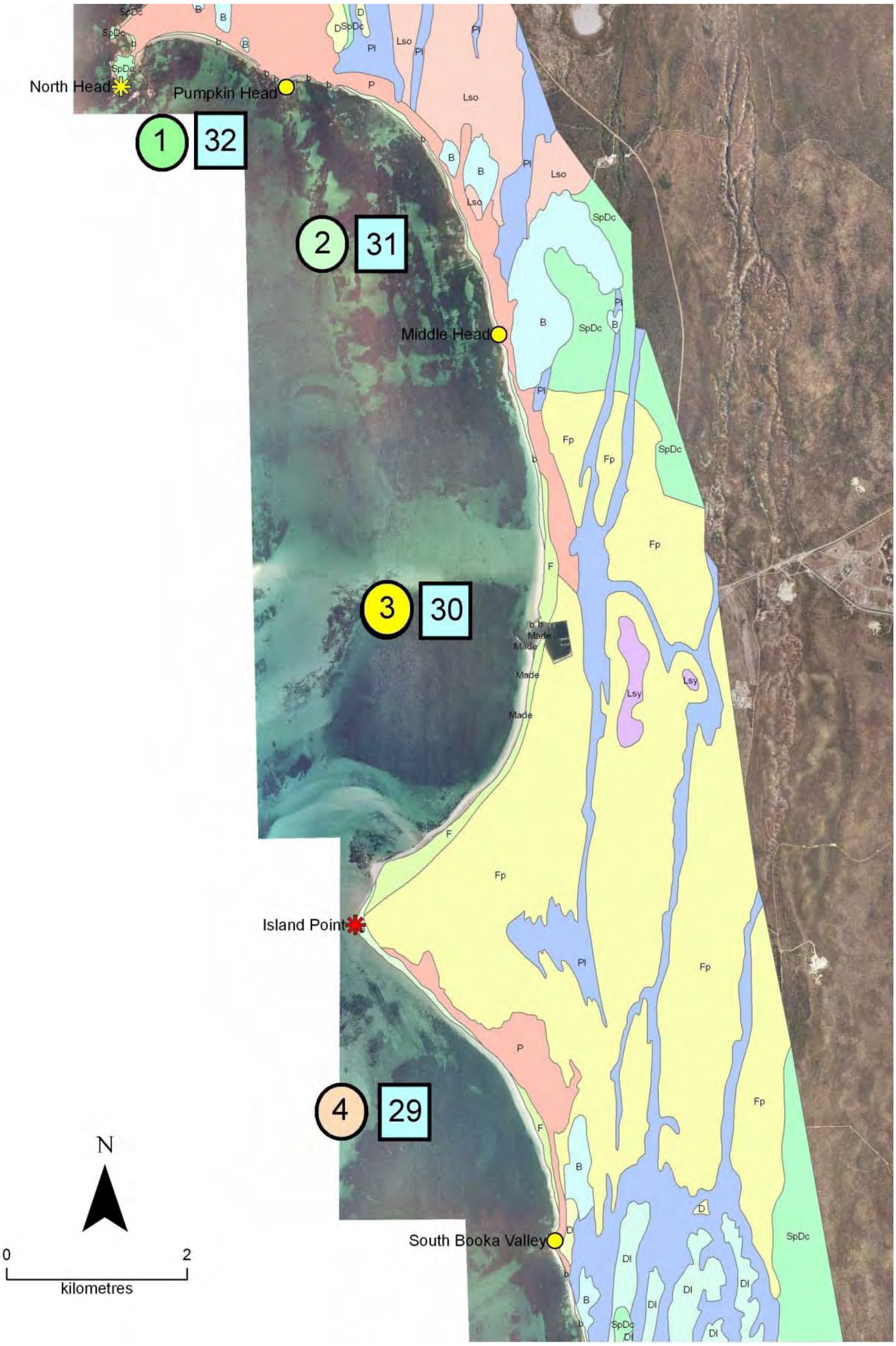

Figure C - 5: Landforms for Cells 29-32

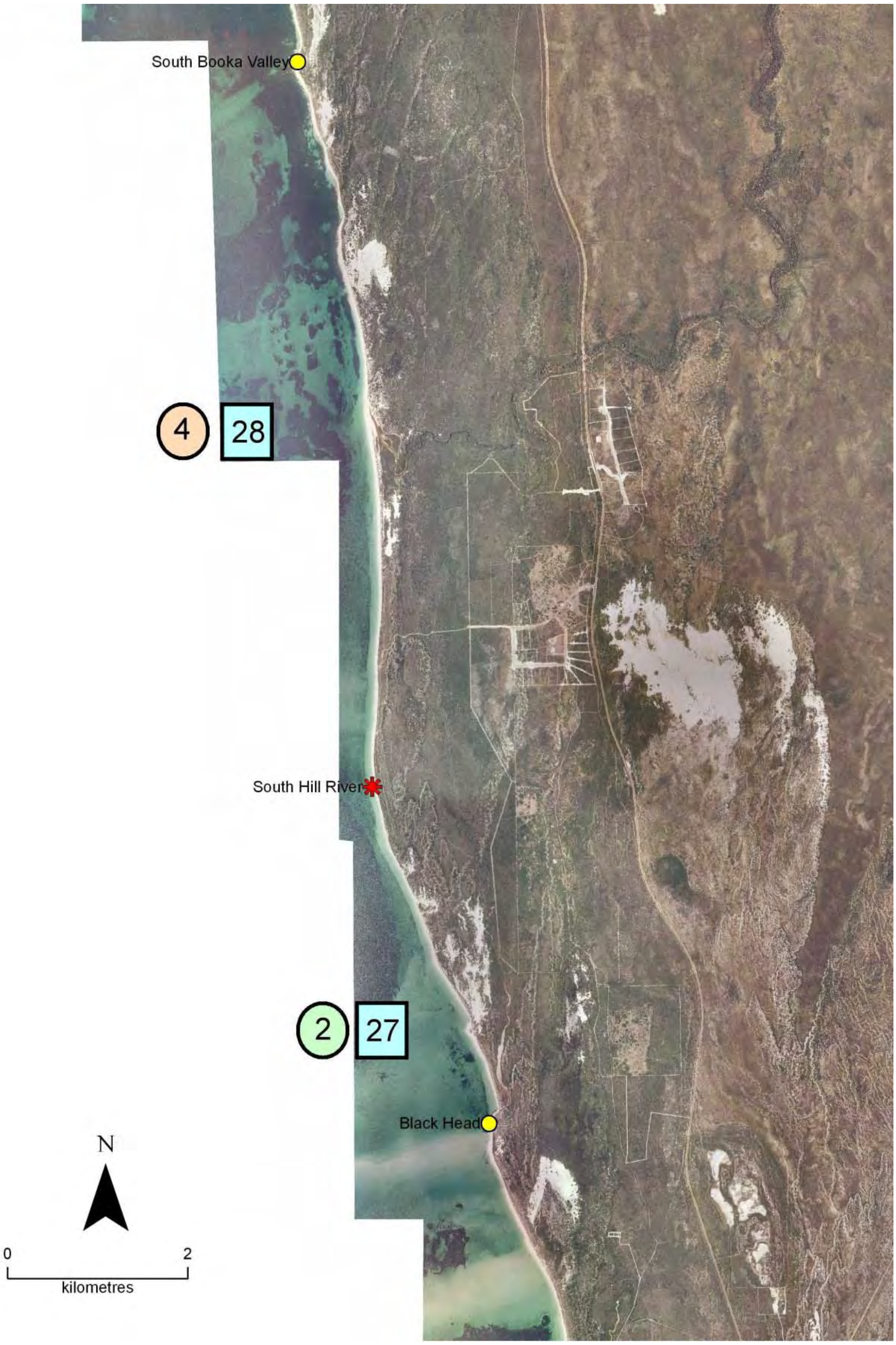

Figure C - 6: Vulnerability for Cells 27-28

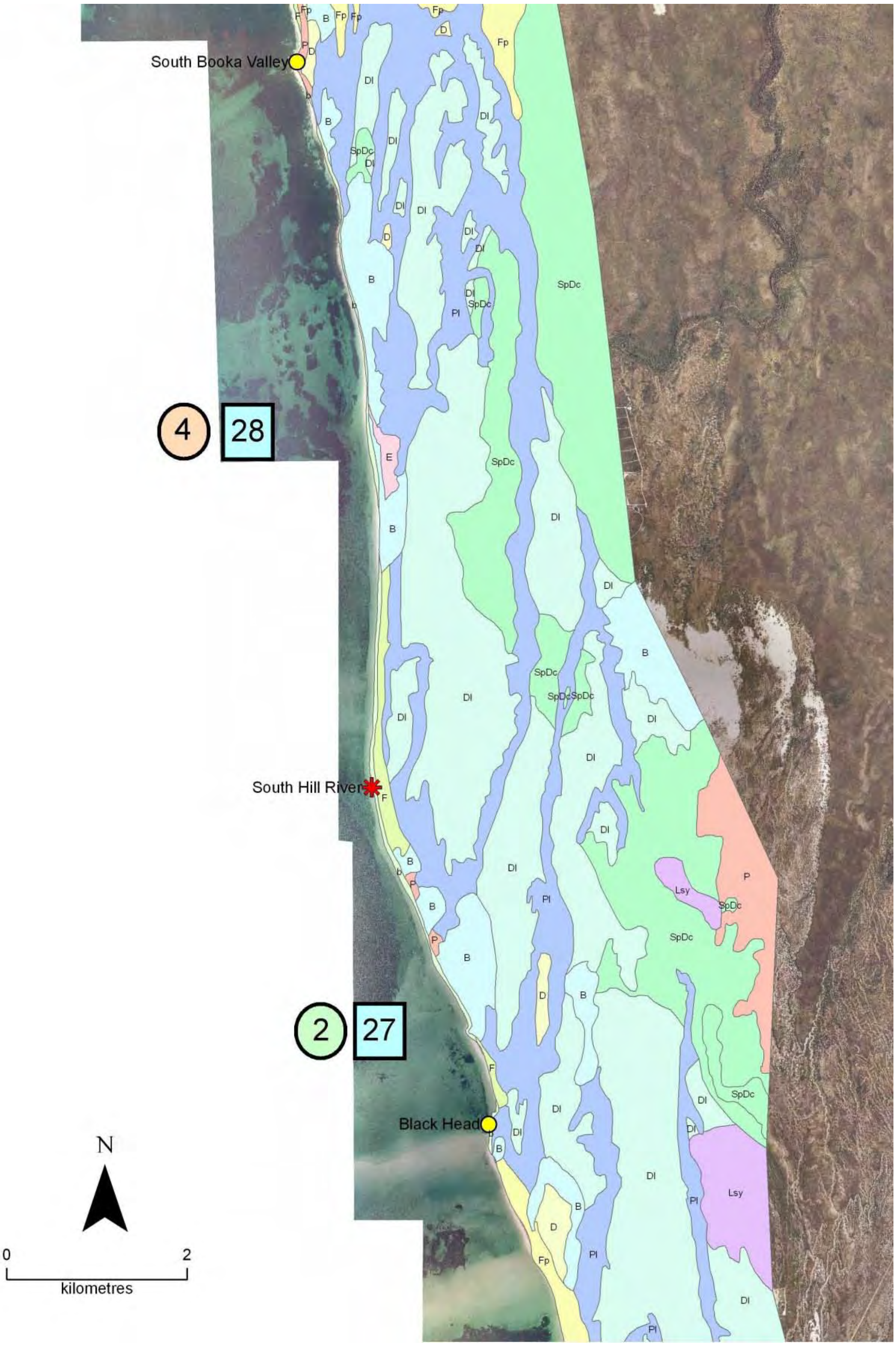

Figure C - 7: Landforms for Cells 27-28

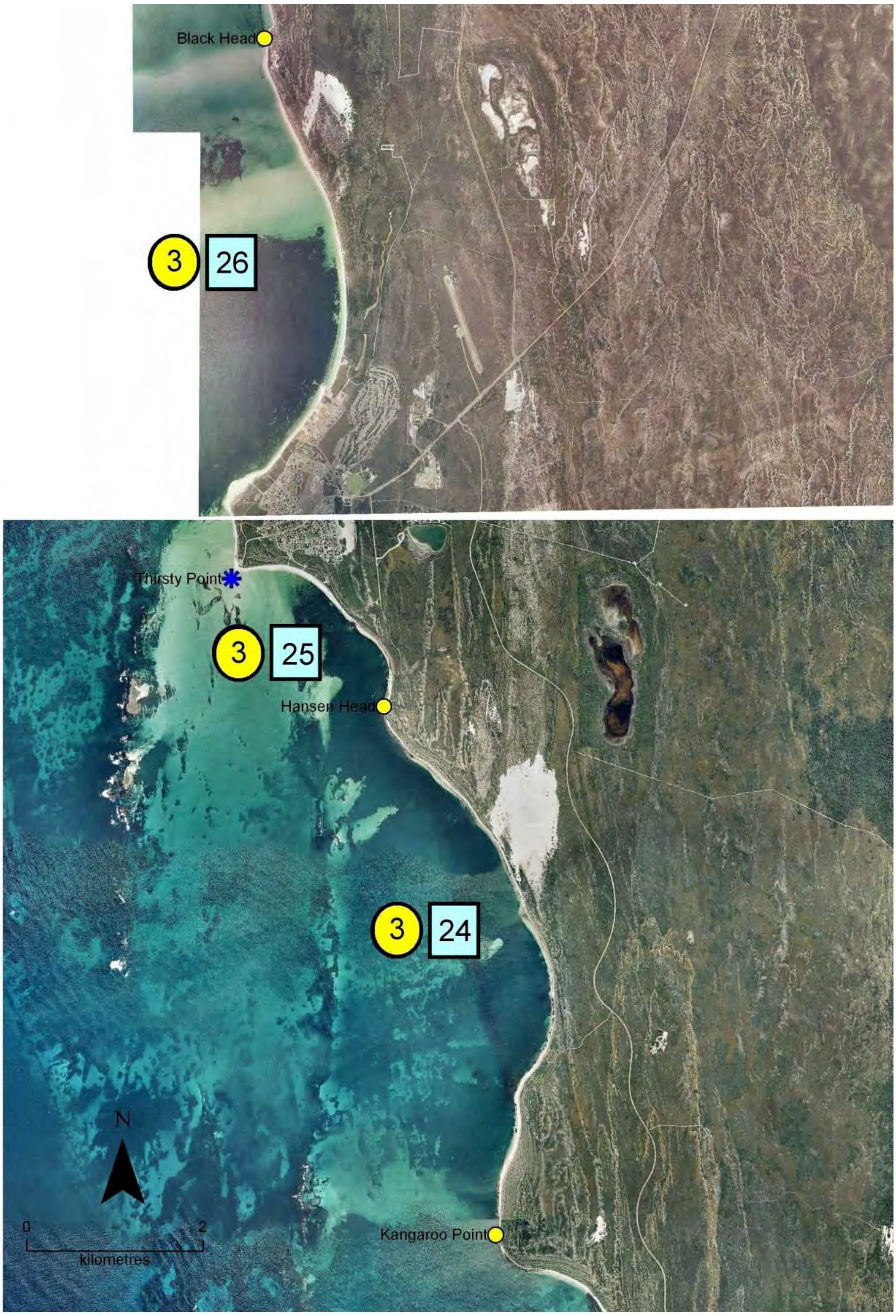

Figure C - 8: Vulnerability for Cells 24-26

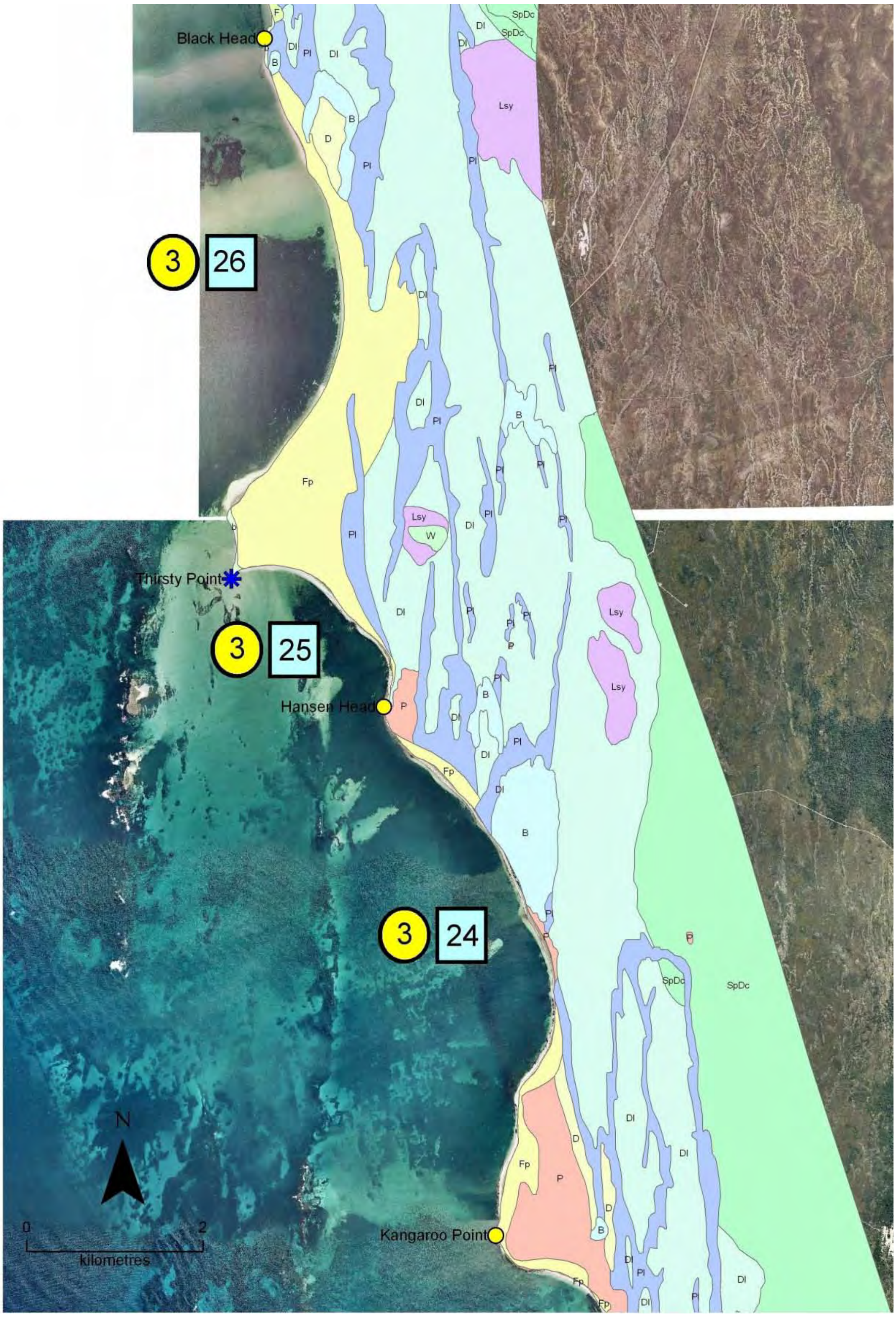

Figure C - 9: Landforms for Cells 24-26

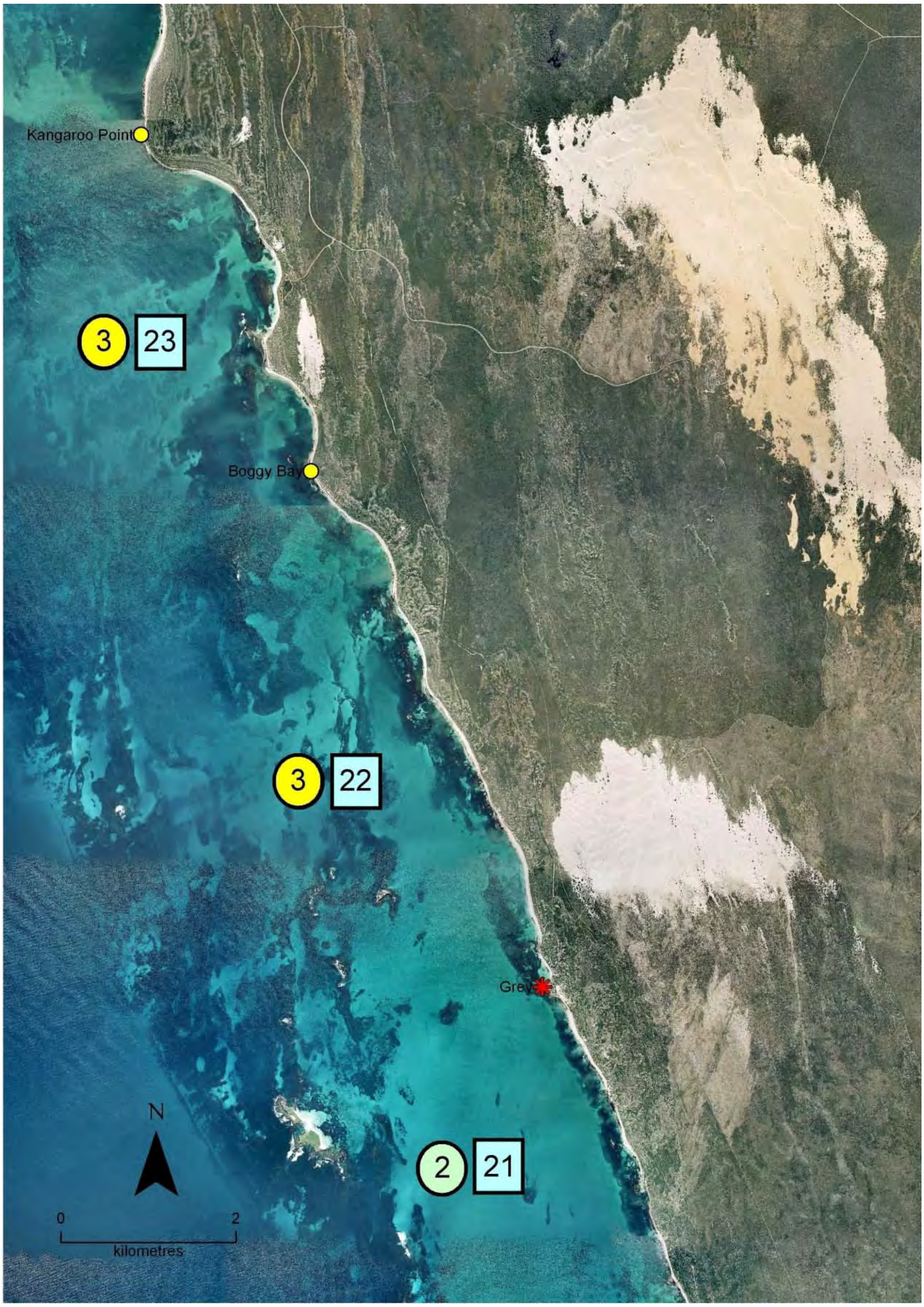

Figure C - 10: Vulnerability for Cells 21-23

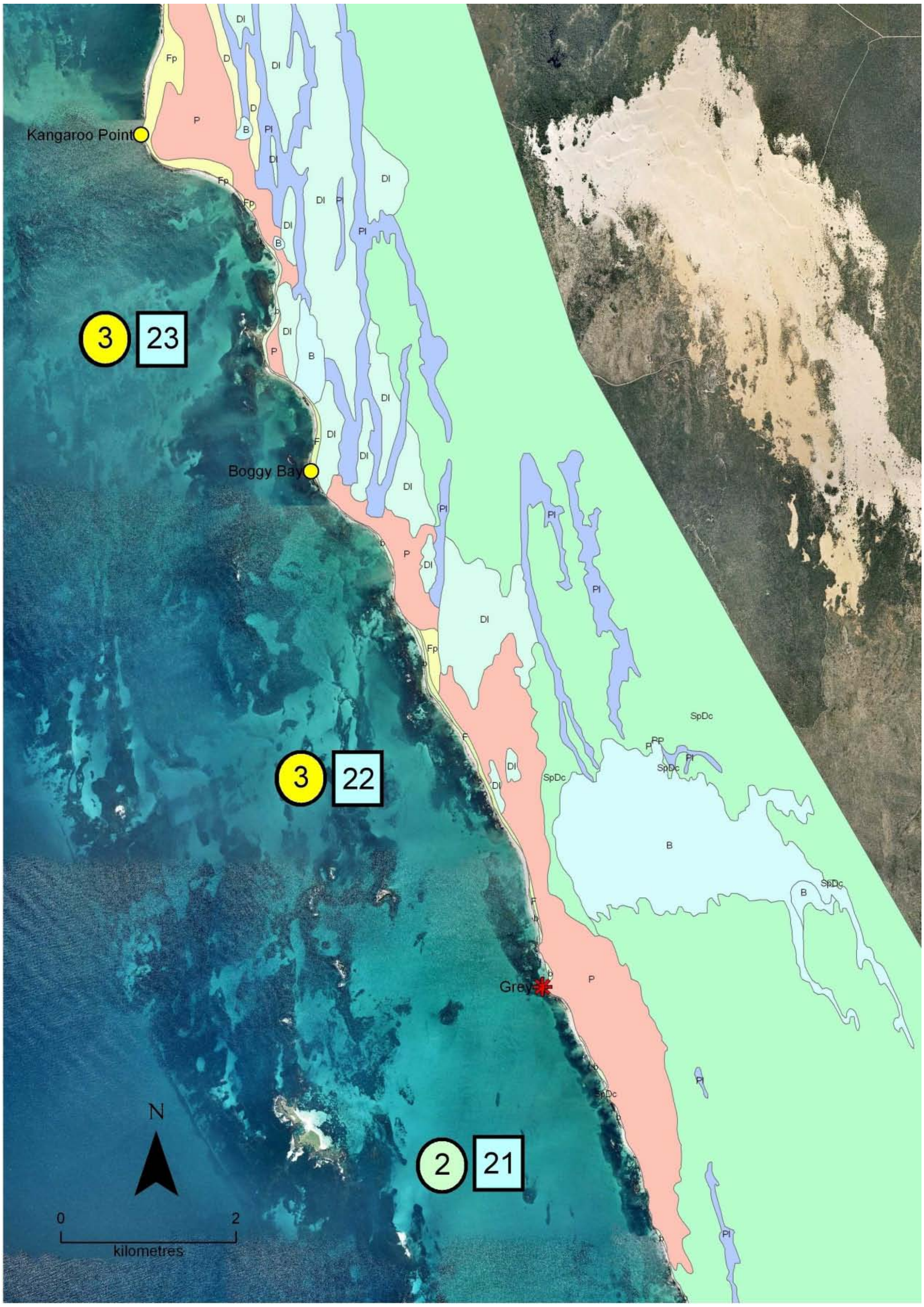

Figure C - 11: Landforms for Cells 21-23

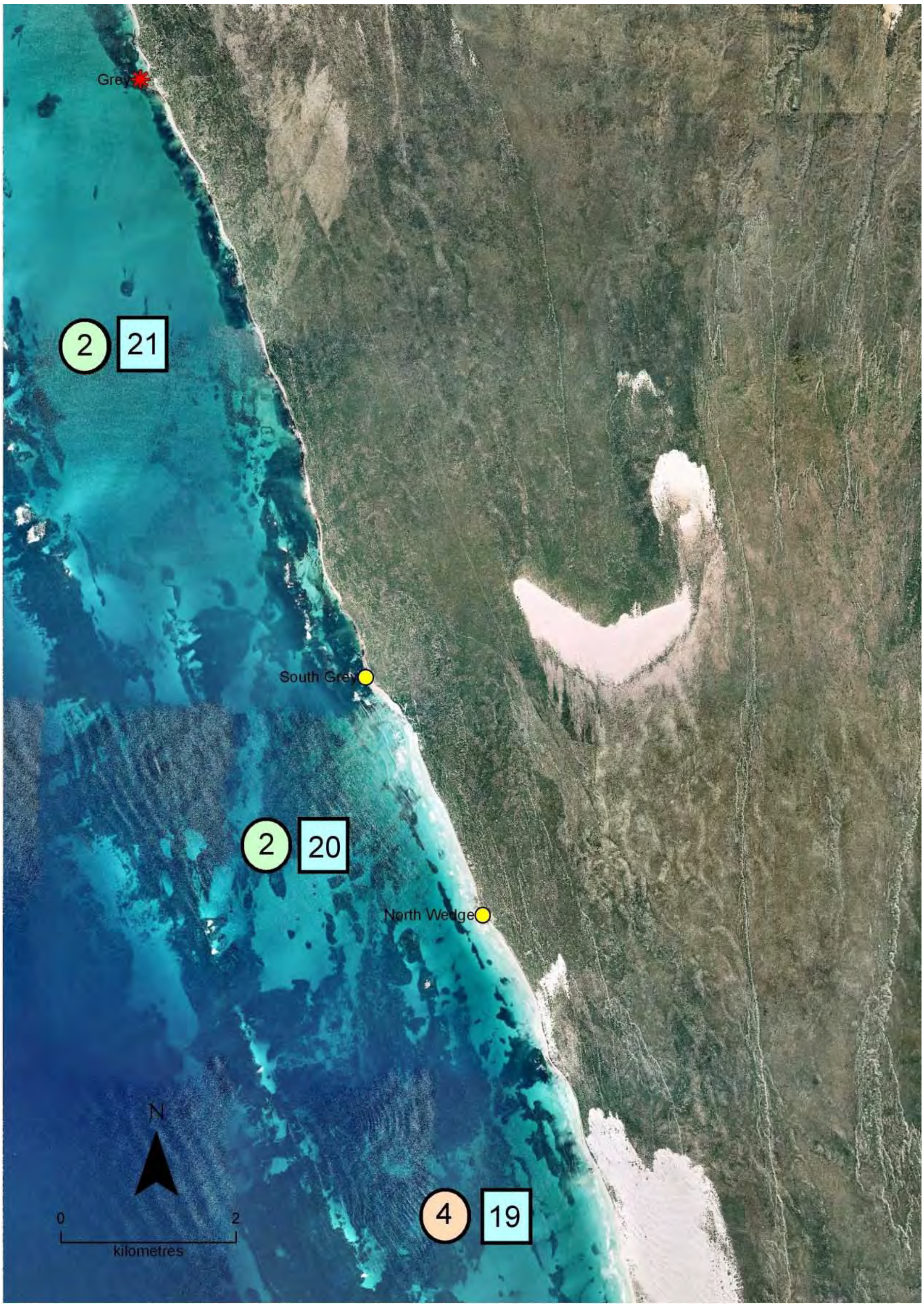

Figure C - 12: Vulnerability for Cells 19-21

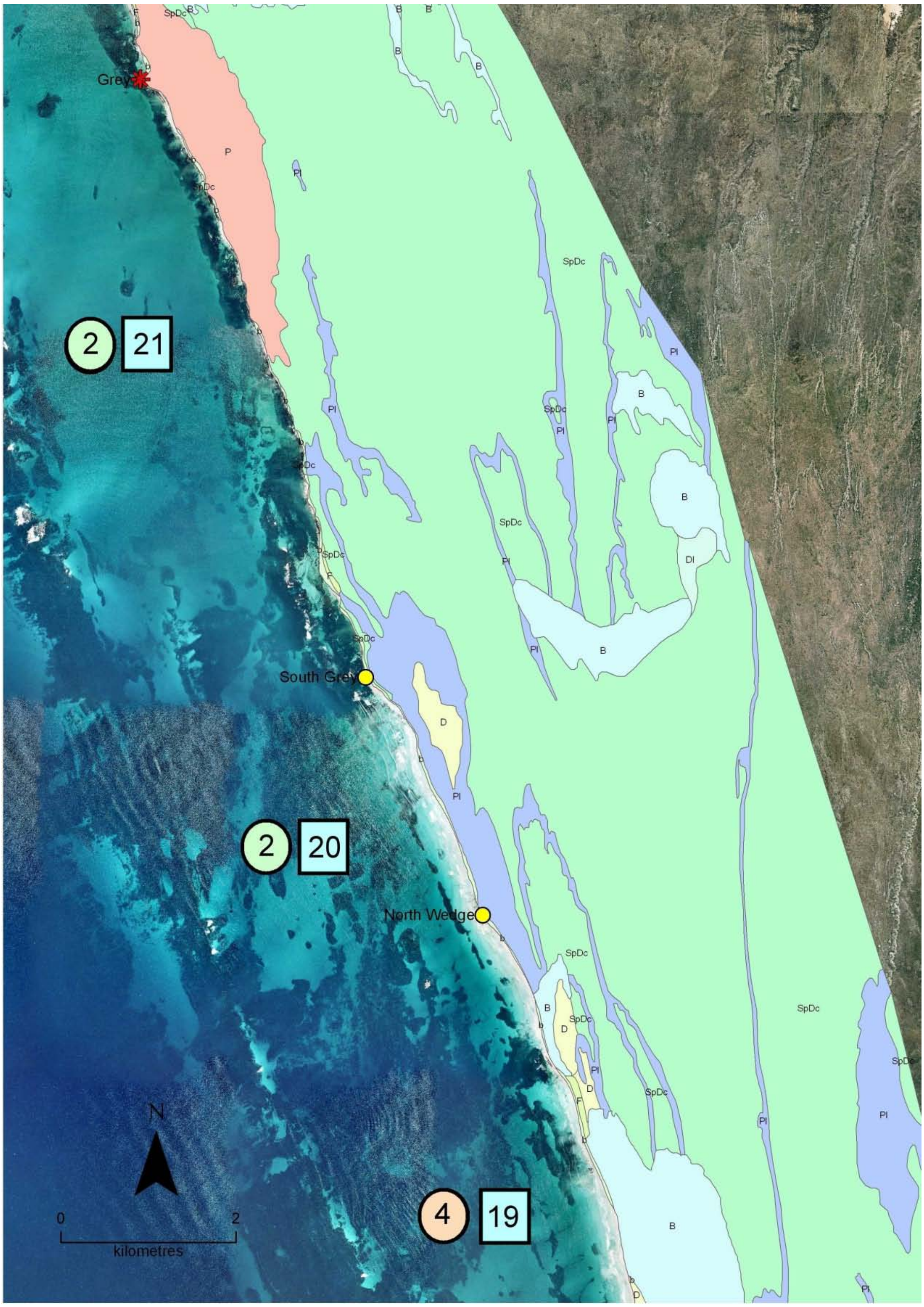

Figure C - 13: Landforms for Cells 19-21

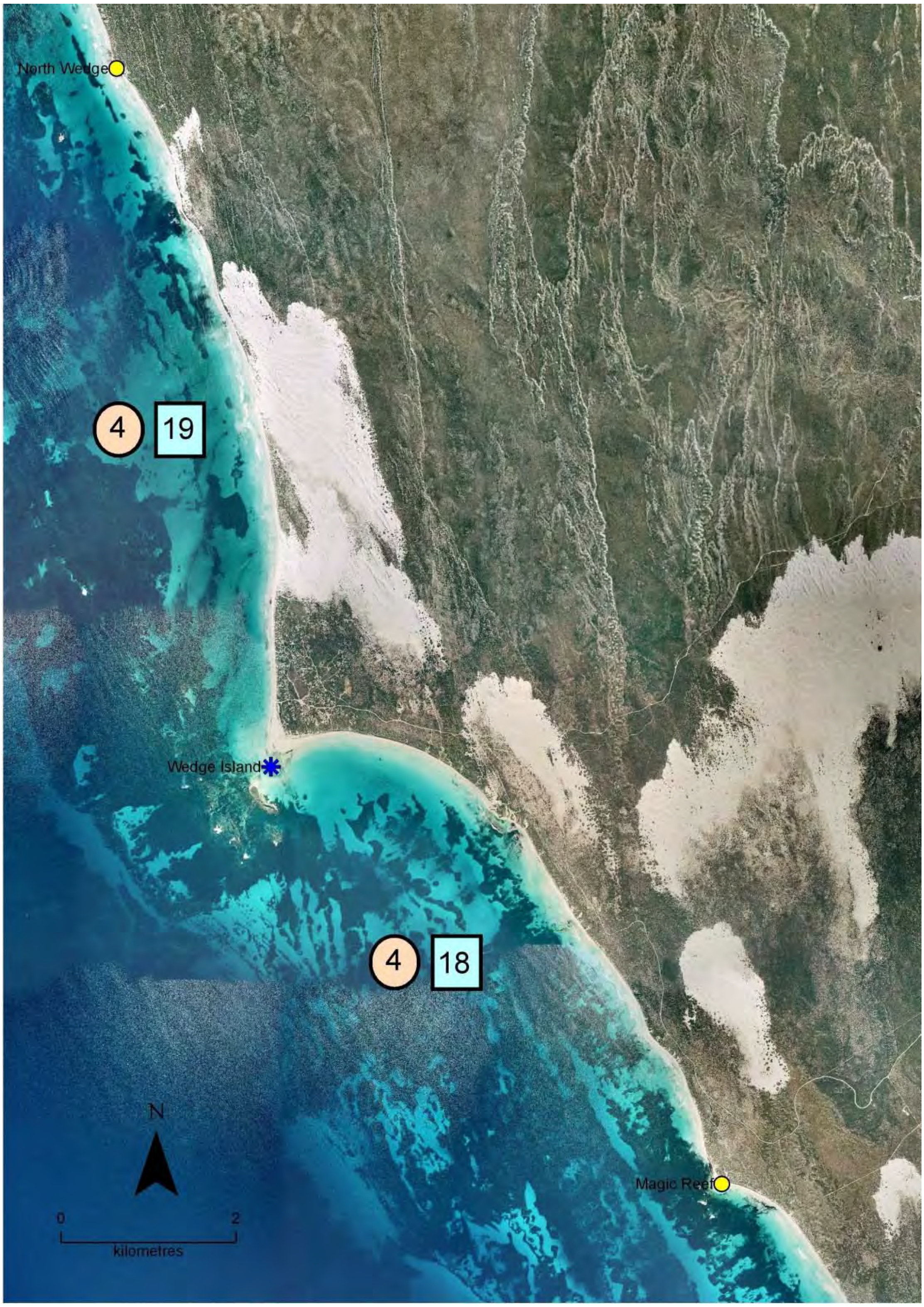

Figure C - 14: Vulnerability for Cells 18-19

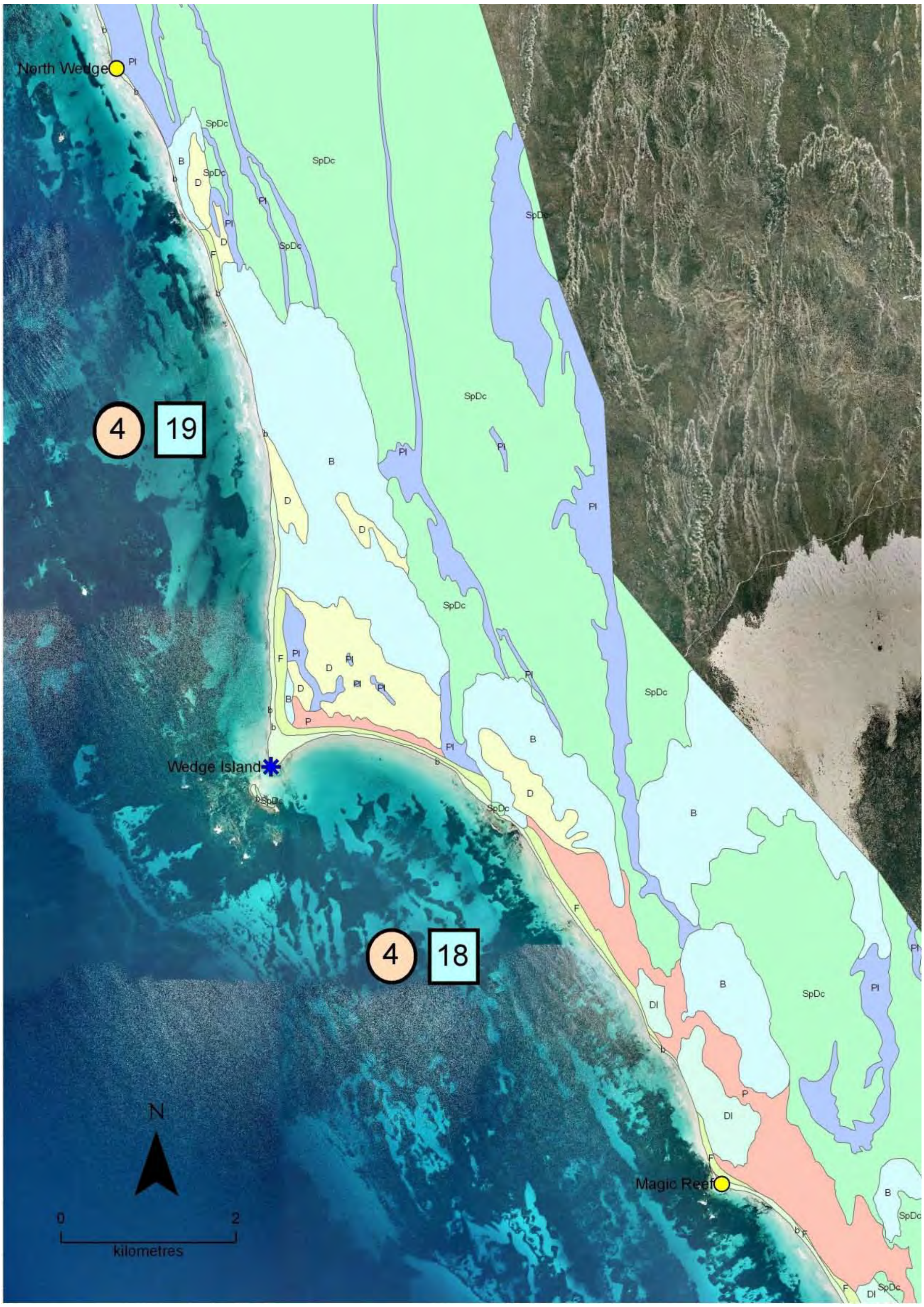

Figure C - 15: Landforms for Cells 18-19

Figure C - 16: Vulnerability for Cells 15-17

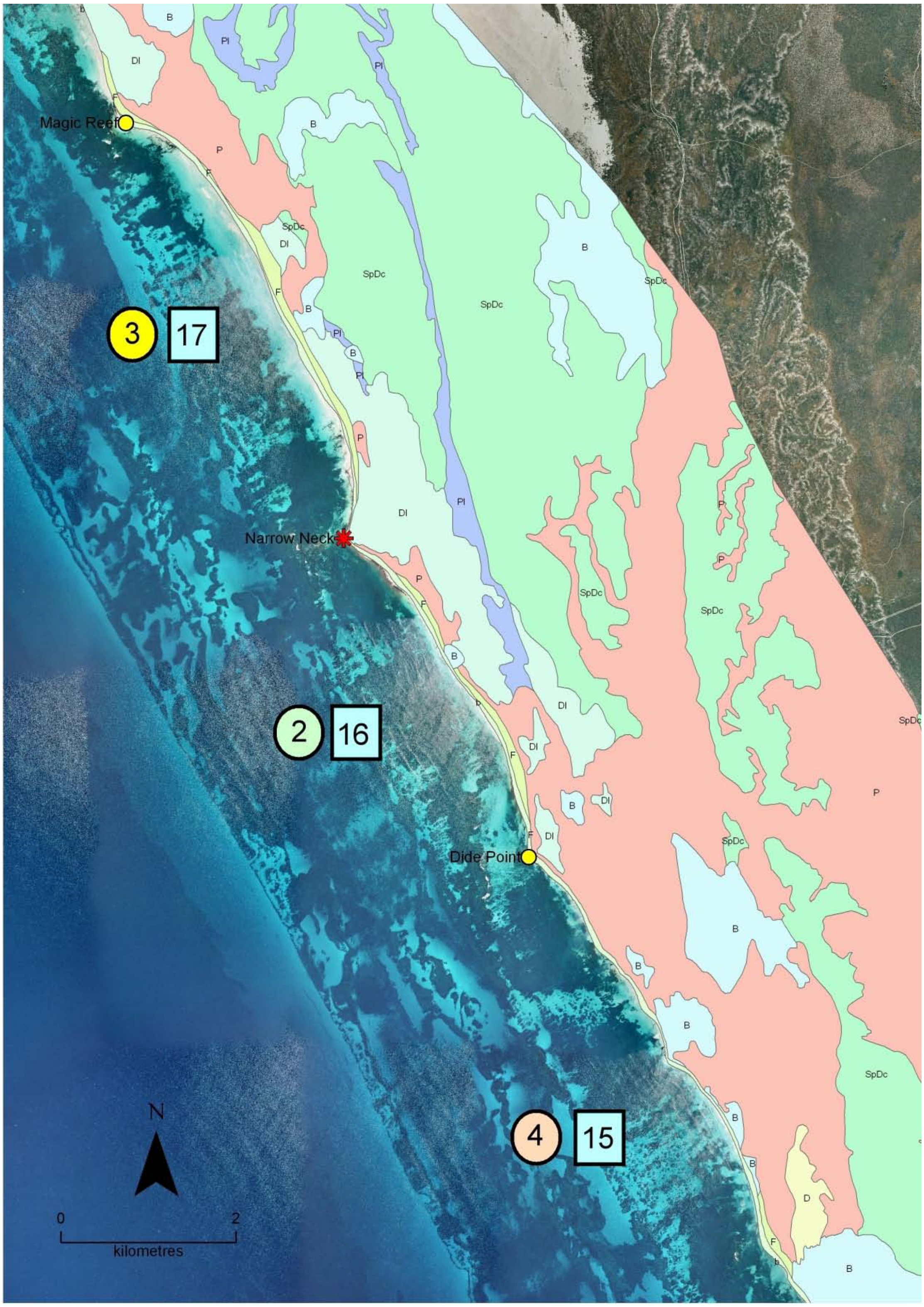

Figure C - 17: Landforms for Cells 15-17

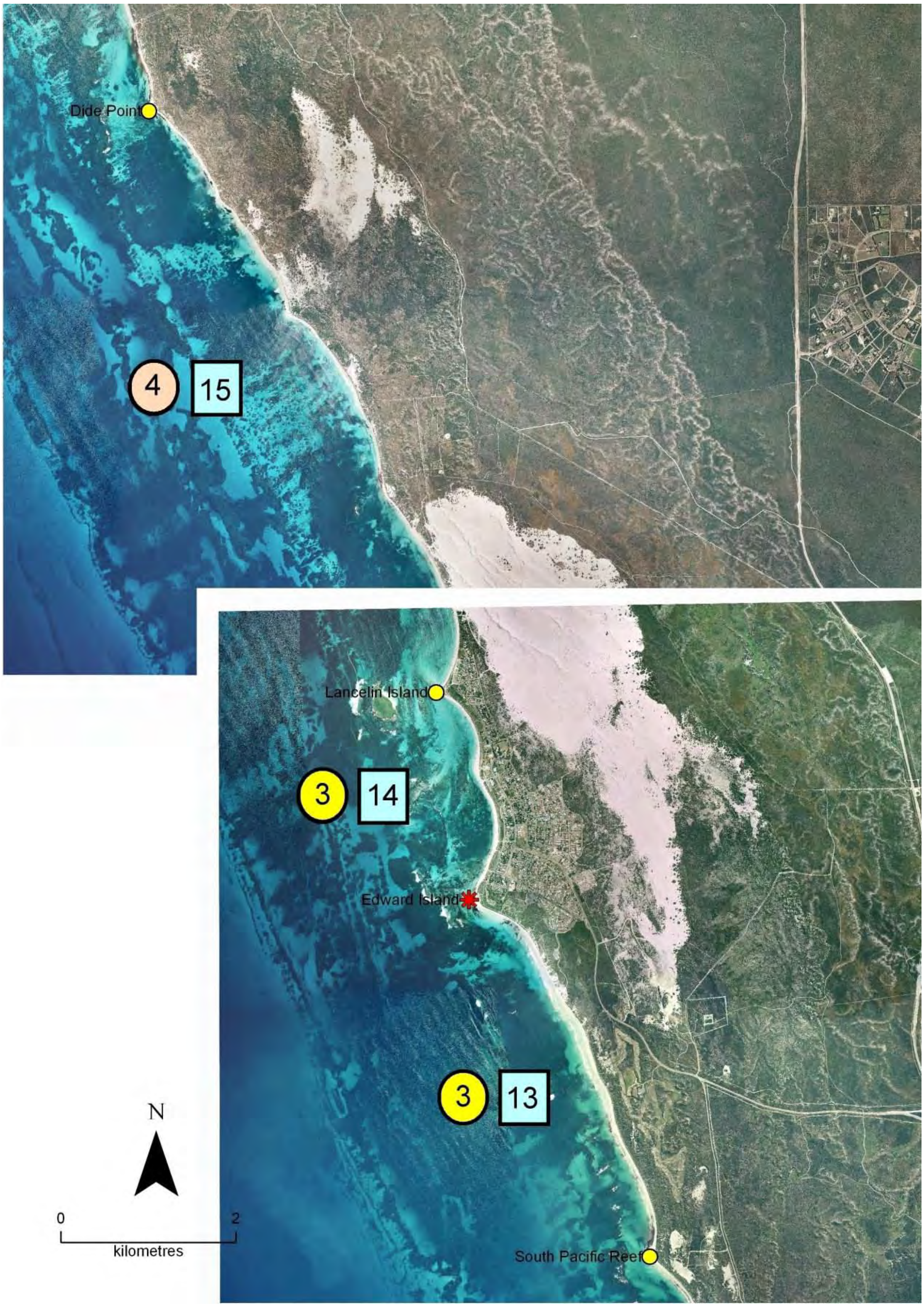

Figure C - 18: Vulnerability for Cells 13-15

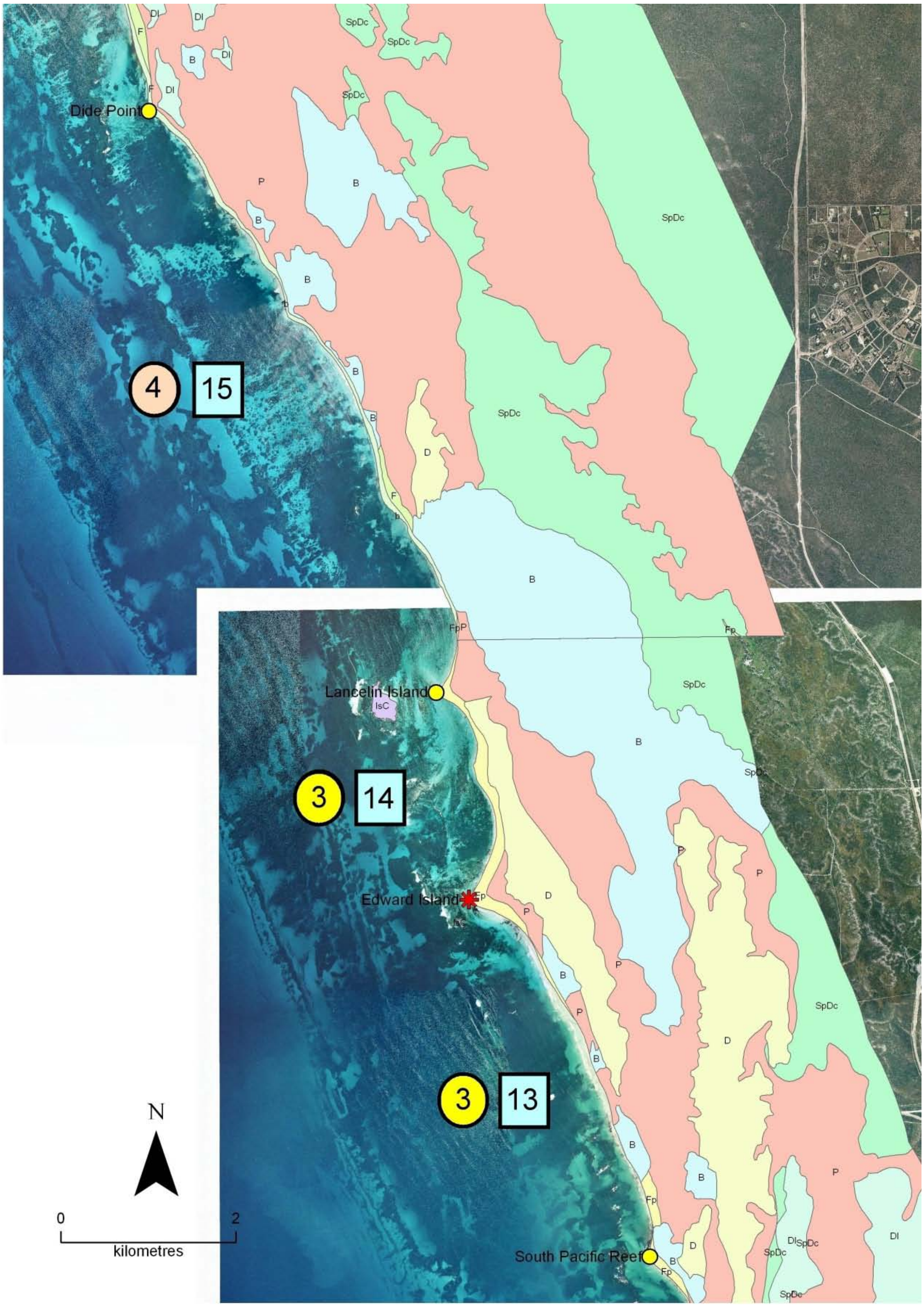

Figure C - 19: Landforms for Cells 13-15

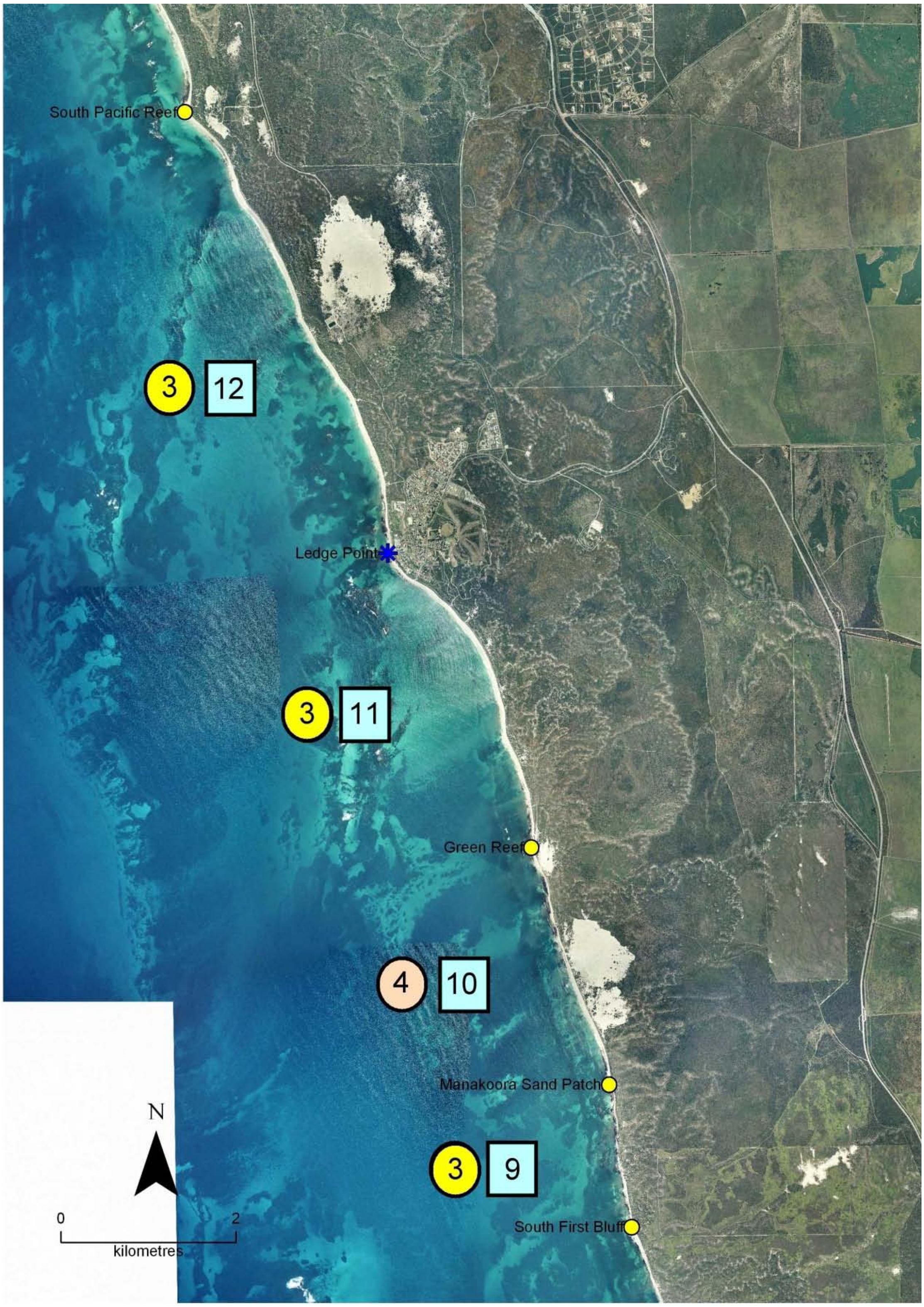

Figure C - 20: Vulnerability for Cells 9-12

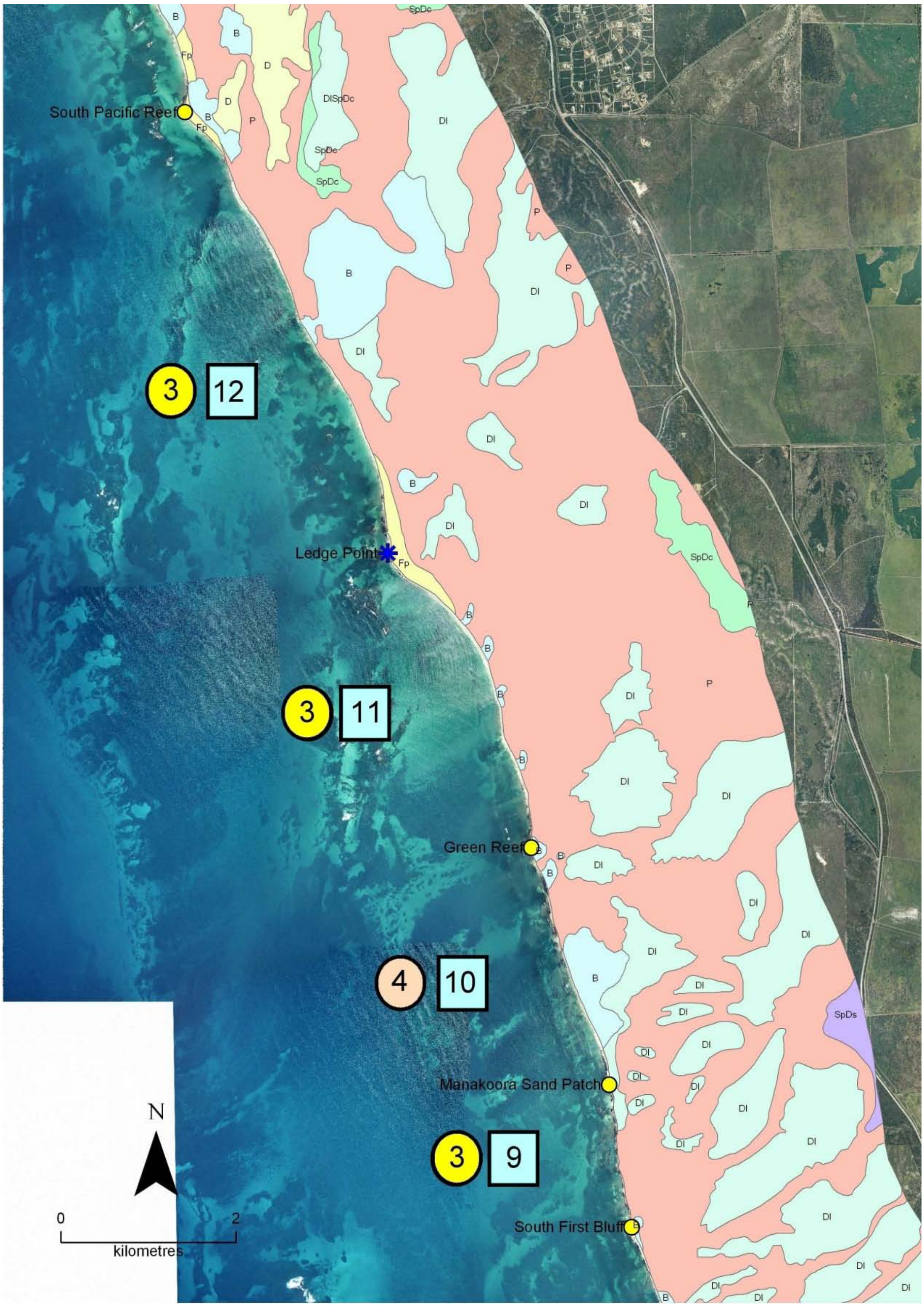

Figure C - 21: Landforms for Cells 9-12

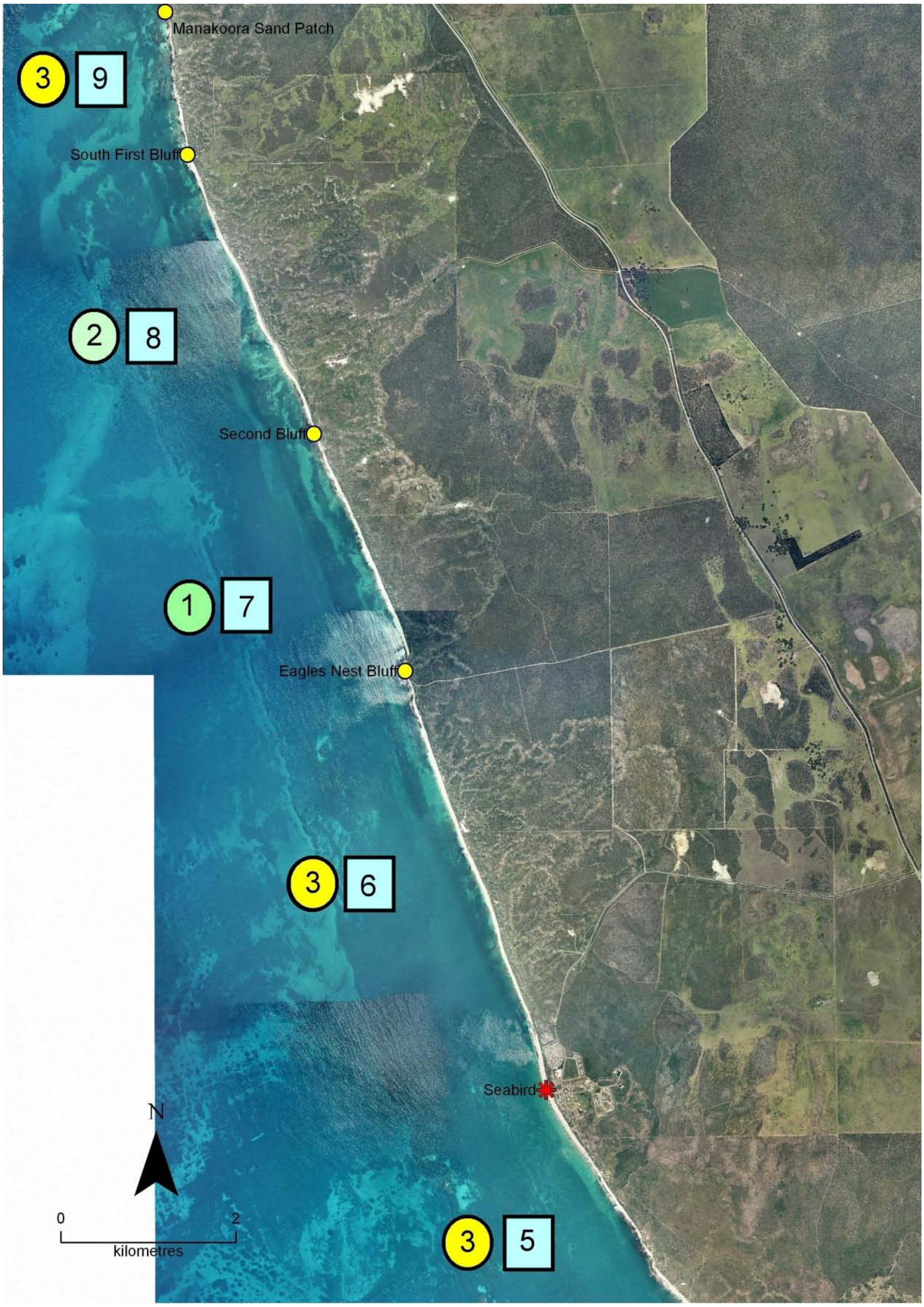

Figure C - 22: Vulnerability for Cells 5-9

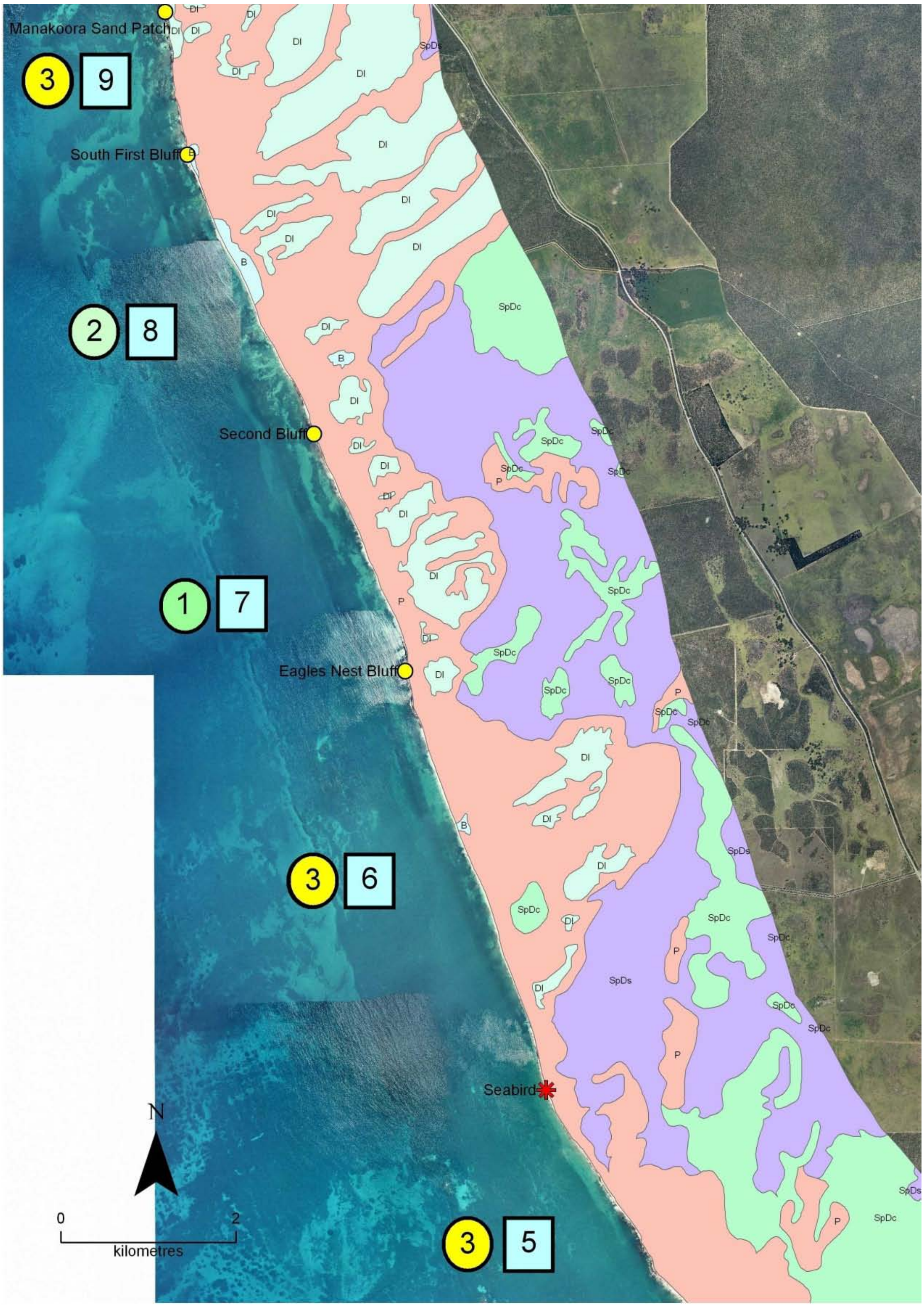

Figure C - 23: Landforms for Cells 5-9

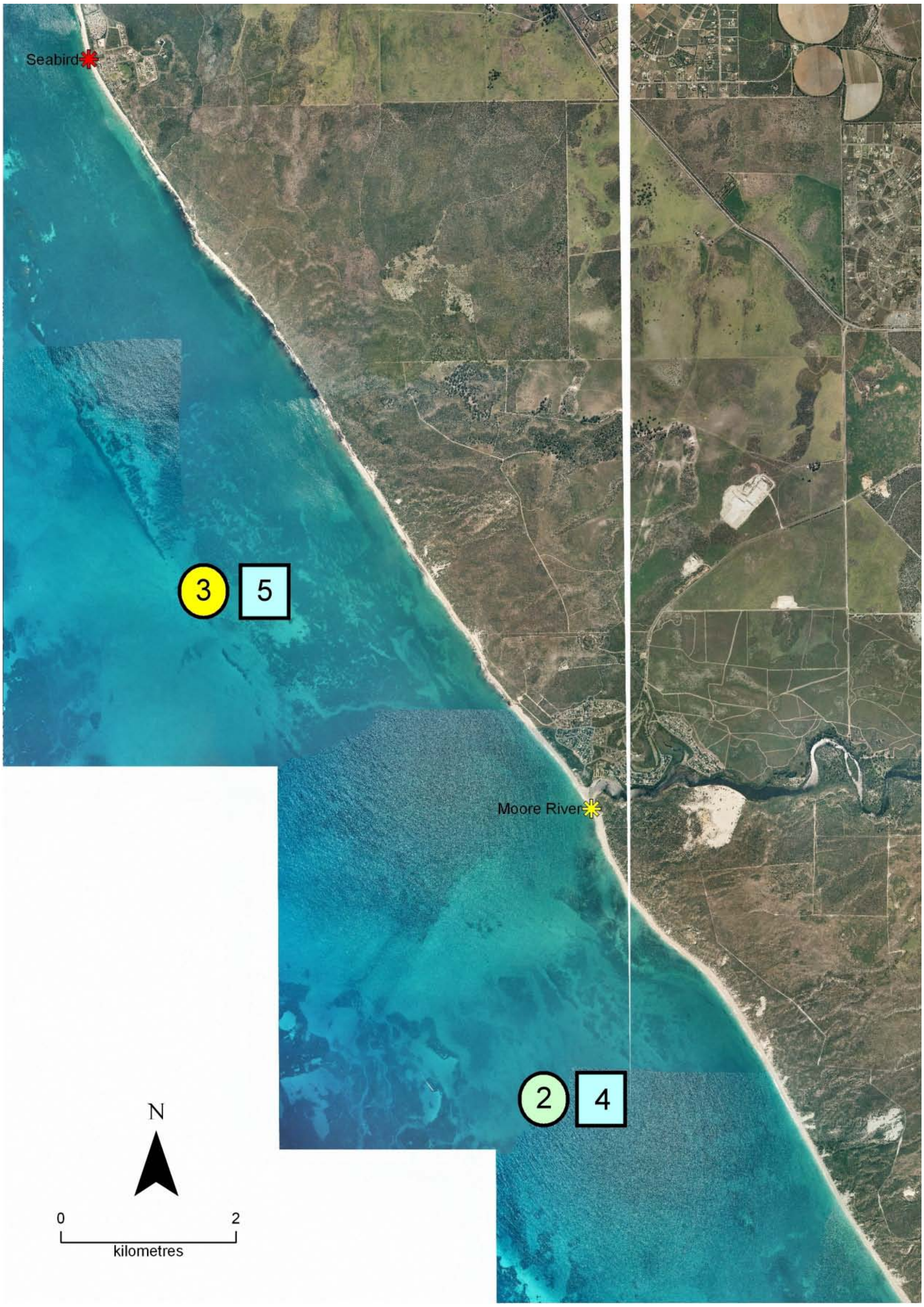

Figure C - 24: Vulnerability for Cells 4-5

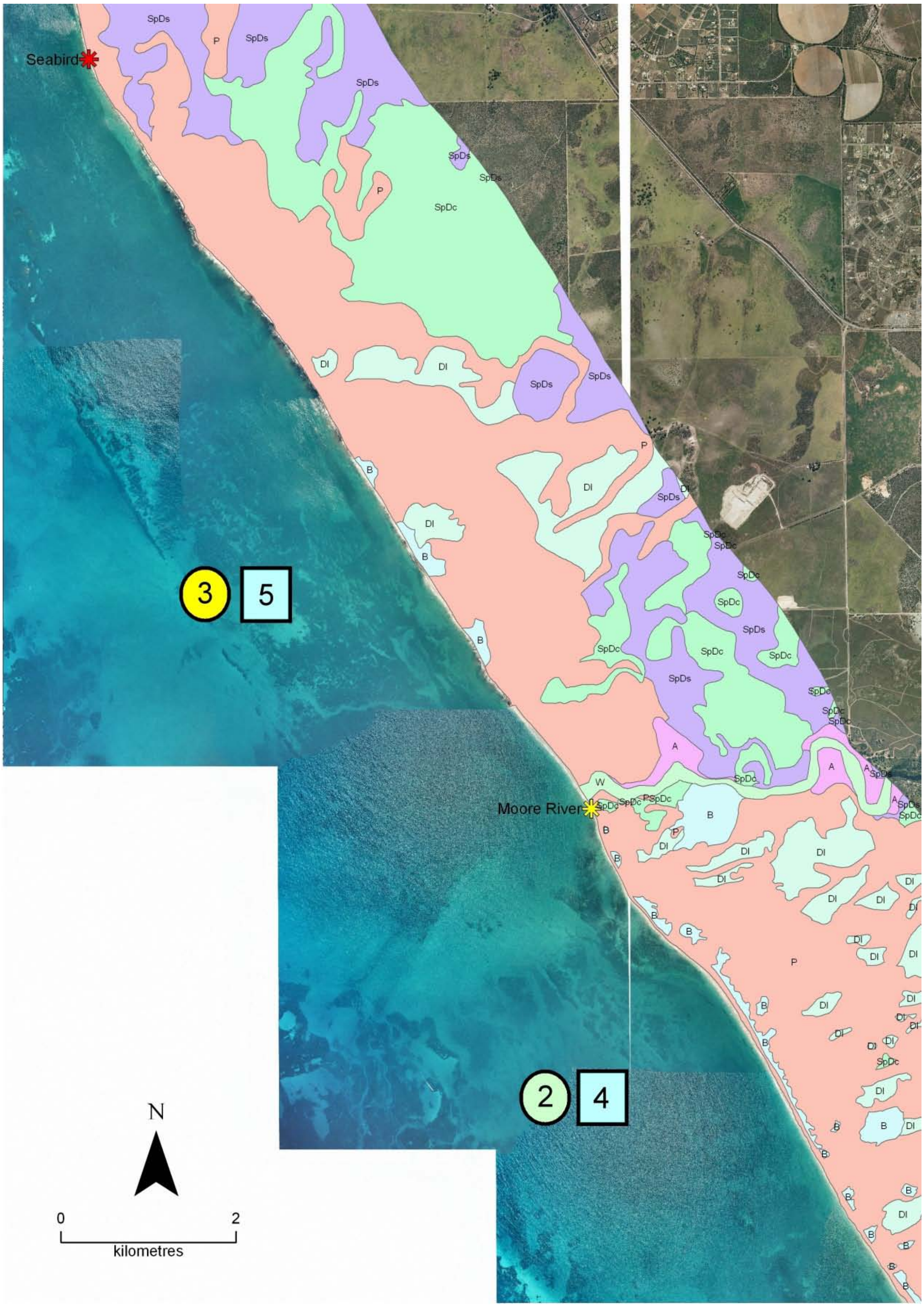

Figure C - 25: Landforms for Cells 4-5

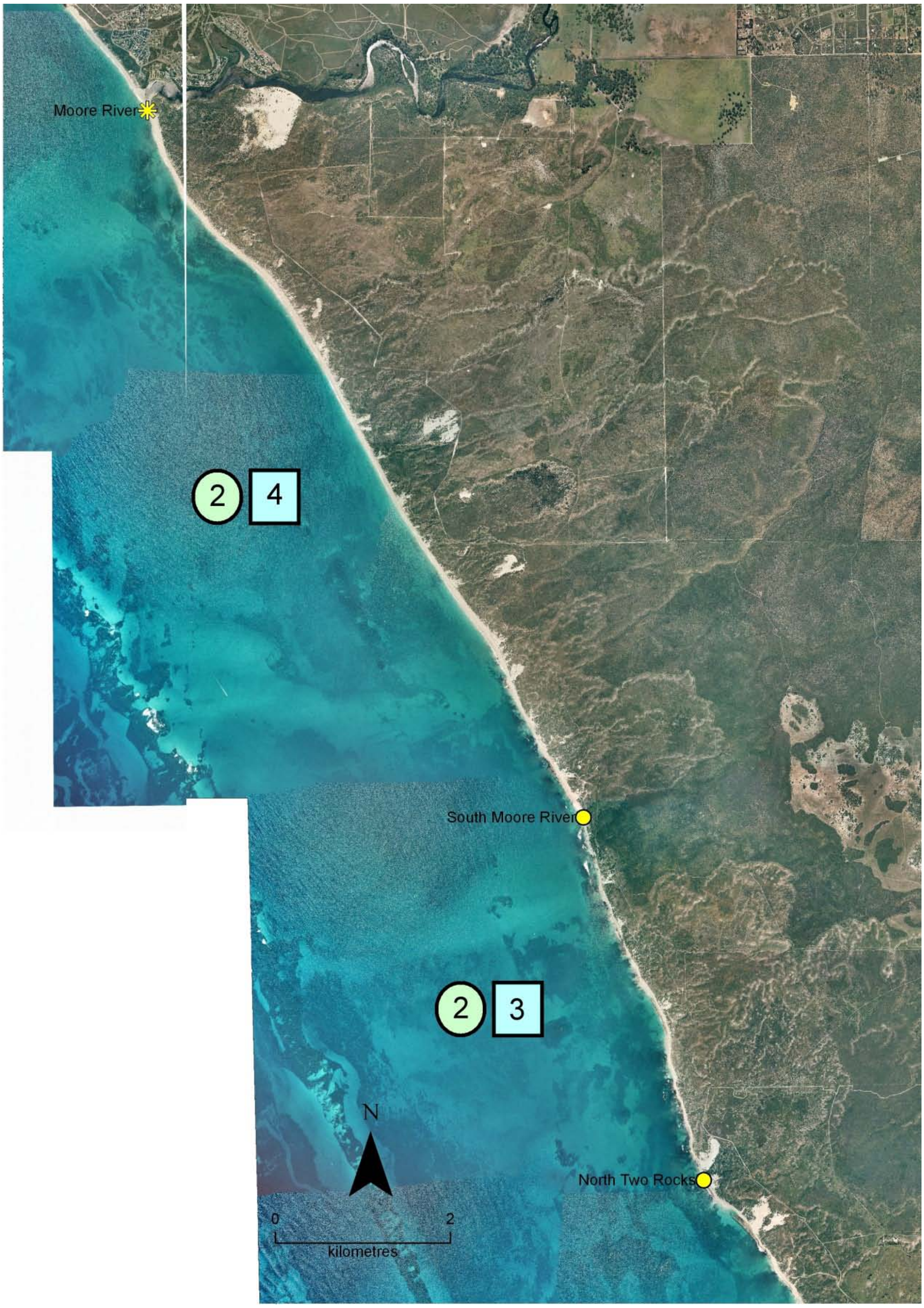

Figure C - 26: Vulnerability for Cells 3-4

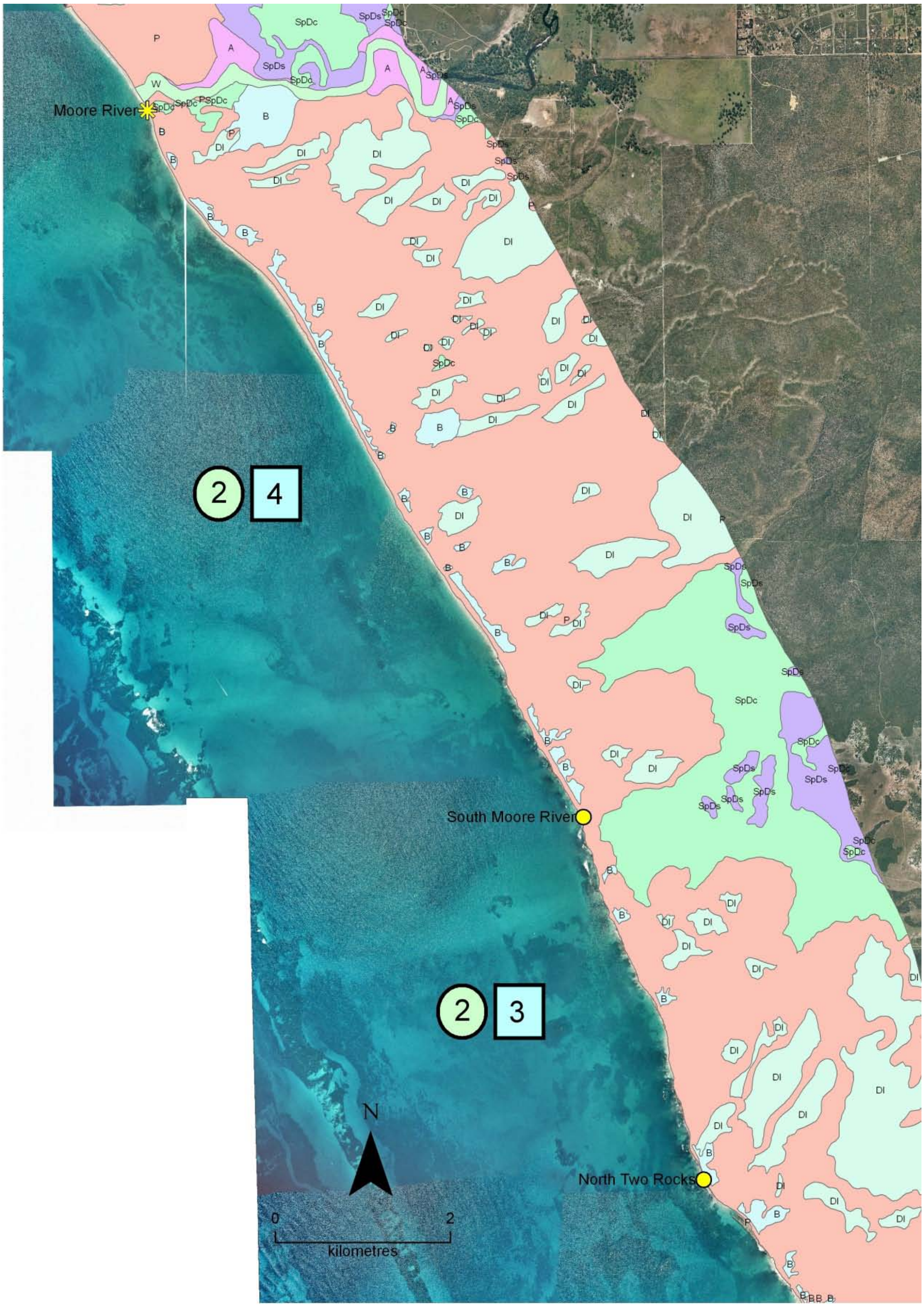

Figure C - 27: Landforms for Cells 3-4

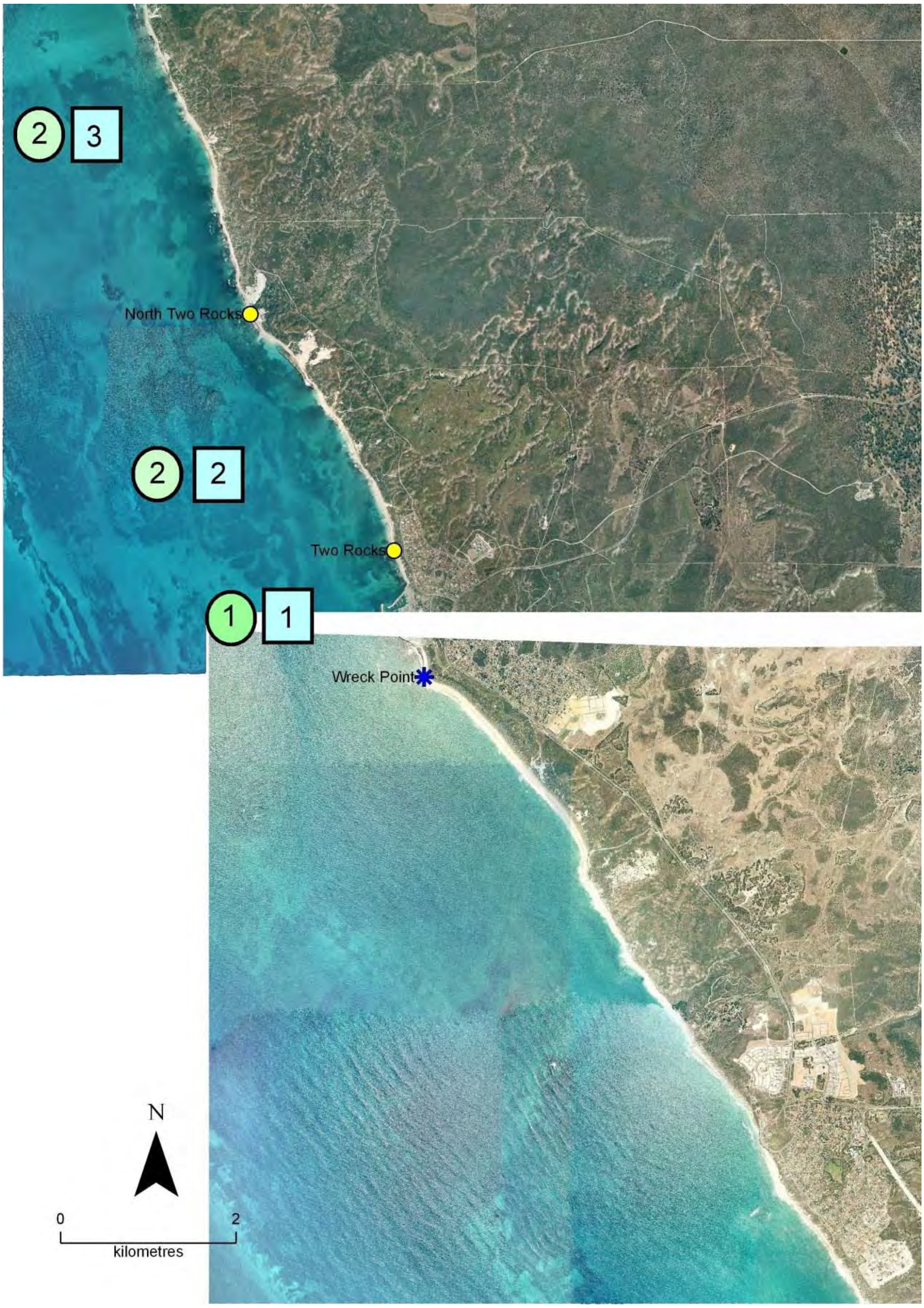

Figure C - 28: Vulnerability for Cells 1-3

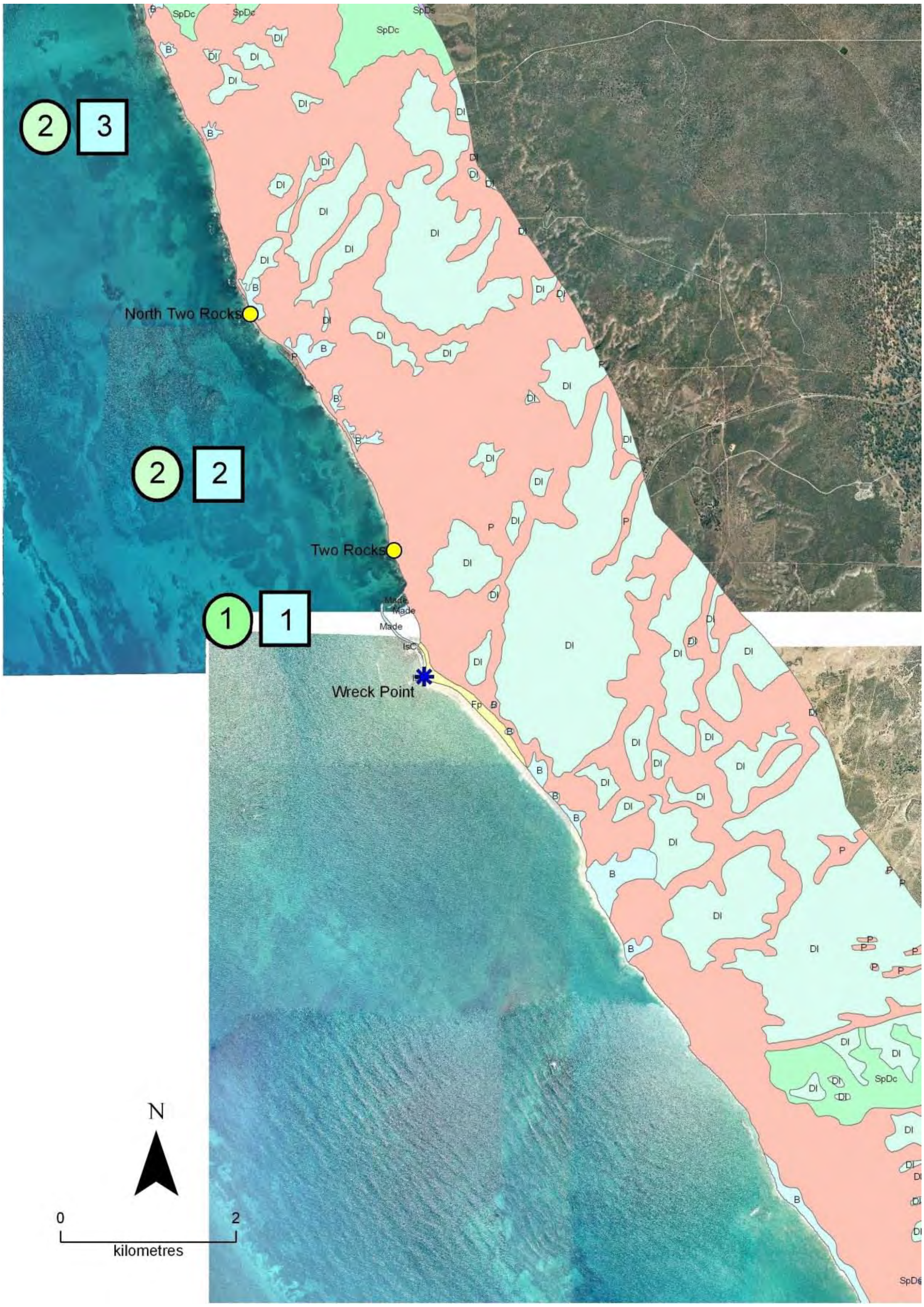

Figure C - 29: Landforms for Cells 1-3

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Appendix D Sediment Cell Descriptions

All location names within this table are based on the three sources listed in Section 6.

Cell	S	N	INSHORE	SHORE	BACKSHORE
36	South Fisherman	Fisherman Islands	A broad shallow ridge of limestone extends ENE from Fisherman Islands to the mainland. It is commonly <5m deep, and forms a discontinuous pattern with intermittent outcrops, especially close to shore.	A narrow sandy beach facing WSW extends along a nearly straight shore. In parts it is perched on rock platform and at one point interrupted by a rocky headland. A substantial volume of wrack has accumulated on the beach. Where not covered in wrack, the beach morphology is flat or rounded.	Long, nested parabolic dunes form an episodic, transgressive barrier overlying an irregular limestone surface. There is over 75% vegetation cover with mobile sands occurring in the northern part of the cell. Frontal dune complex is fully vegetated.
35	Sandy Point	South Fisherman	Intermittent limestone reef, pavement and unconsolidated sediment occur on the seabed of inshore waters from the latitude of Sandy Point northwards to that approximating the southern extent of the Fisherman Islands reefs. Pavement and platforms are close to shore along the southern section of the coast in this cell, with pavement and intermittent outcrops more common in the north.	The shoreline is rocky, irregular and broken into a series of four small embayments containing sandy beaches. The embayments are zeta formed in shape with the two southern embayments facing WNW and northern embayments facing W and WSW. The reflective southern beach is the northern flank of the Sandy Point tombolo and has unconsolidated sands in its nearshore zone. The other beaches have rounded profiles characteristic of perched beaches.	Long, nested parabolic dunes form an episodic, transgressive barrier overlying an irregular limestone surface. North of the mobile sand sheet near Sandy Point there is greater than 75% vegetation cover. Eroded frontal dunes in the southernmost embayment have been disturbed by ORV tracks but have more than 25% vegetation cover. Elsewhere the frontal dunes are less disturbed and have a more complete vegetation cover.
34	Sandland	Sandy Point	The seabed of the inshore waters is comprised of a patchwork of intermittent reef, pavement and unconsolidated sediments. The limestone rock outcrops as pavement and platforms close to shore around three headlands that break the shore line into two small beaches. The most extensive pavement and platforms are located along the northern beach.	A continuous beach extends from Sandland to Sandy Point in two embayments. The southern embayment is approximately 1.7km across its mouth facing WNW. The northern embayment is approximately 0.9km long, faces W and is perched on an extensive pavement and rock platform. Both beaches display exposed, reflective and transitional morphologies away from the northern flank of the Sandland foreland.	A mobile sand sheet at the head of a long parabolic dune extending from the south of the Sandland foreland is located on the stationary barrier complex approximately 0.6km landward of Sandy Point. Vegetation cover on the barrier landward of the southern embayment ranges from 25 to 75% and is discontinuous. The range is similar but the discontinuous cover is lower landward of the northern embayment. There is 25 - 75% vegetation cover on the frontal dune complex with tracks and erosion apparent in the southern embayment and blowout prevalent in the northern. One of the blowouts extends northwards across the Sandy Point tombolo into the next cell.

Cell	S	N	INSHORE	SHORE	BACKSHORE
33	North Head	Sandland	The seabed of the inshore waters is comprised of a patchwork of intermittent reef, pavement and unconsolidated sediments. The limestone rock outcrops as pavement and platforms close to shore around five headlands that break the shore line into four small beaches. The Bartle Reef, which lies approximately 1km offshore, together with elongate reefs in the vicinity of North Head and Sandland Island, shelter the coast.	The shoreline consists of two major components separated by rock outcrop. The southern embayment is further divided into two components; a 270 m beach facing NW and a longer zeta formed embayment approximately 800m across the bay mouth. The straight section of the zeta form overlays a rock platform and faces WSW. The northern embayment is an arcuate beach abutting a cuspate foreland in the lee of Sandland Island. The arcuate beach faces SW. beach morphology varies with exposure but are commonly exposed reflective beaches.	Two barrier components are apparent. The first is the large stationary barrier system with its cover of nested parabolic dunes. The dunes are the dominant landforms of the southern beaches. They also anchor a small prograded barrier comprised of foredune ridges that form the cuspate foreland. Vegetation cover in the 500 m landward of the shore is between 25 and 50% but is markedly affected by ORV tracks. The frontal dune complex of the southern beach has 25 - 75% discontinuous vegetation cover. The frontal dune has been cliffed. A rocky cliff extends for over 600m along the central part of the cell. Vegetation cover on the northern beach varies from 25 to 75% and has been disrupted by settlement and tracks.
32	Pumpkin Head	North Head	The inshore waters of this small cell are open to the S . The seabed is comprised of s patchwork of intermittent reef, pavement and unconsolidated sediments. The limestone rock outcrops as rock pavement and platforms close to shore around the headland that bound the cell.	The shoreline shallowly indented and zeta-form in plan shape, with the flat arm of the embayment facing SW and its western part facing S to SE. The beach is part of the North Head - Sandy Cape tombolo complex and its morphology varies from sheltered, rounded to exposed, reflective forms. A substantial volume of wrack accumulates on the western part of the beach in the lee of North Head.	A stationary barrier has formed in the lee of limestone reefs between North Head and Sandland Island. Its surface is comprised of nested blowouts and parabolic dunes over an irregular limestone core. The dunes have migrated northwards from the beach following destabilisation of the frontal dune ridge. There are numerous ORV tracks in the area and mobile dunes, including an active parabolic dune in the centre of the embayment. Vegetation cover varies from approximately 50% in the disturbed central area to low values elsewhere. The foredune complex is cliffed in places and its vegetation cover is discontinuous but >75%.
31	Middle Head	Pumpkin Head	The inshore waters are open to the W to the NW quadrant. The seabed is comprised of a patchwork of intermittent reef, pavement and unconsolidated sediments. The limestone rock outcrops as more extensive pavements and platforms close to shore between Middle Head and Pumpkin Hollow. There are unusual columnar features in the Pumpkin Hollow sanctuary zone.	The SW facing shoreline is shallowly indented and arcuate in form. Its northern part curves to the NW to join the North Head - Sandy Cape tombolo complex. The morphology of the beaches varies from sheltered, rounded to exposed, reflective forms.	The episodic, transgressive barrier is comprised of nested blowouts and long parabolic dunes. Mobile sandsheets are present landward of the frontal dunes in the southern half of the cell where the shore faces WSW. There is between 25 and 75% vegetation cover in this area with higher cover on the frontal dune ridge. In the northern part of the cell where the shores face SW, the vegetation cover is greater than 75% although disturbed by ORV tracks. The frontal dune complex has been cliffed along the shore.

Cell	S	N	INSHORE	SHORE	BACKSHORE
30	Island Point (Jurien)	Middle Head	The limestone reef bifurcates near Escape Island. Its coast parallel component continues but deepens and becomes more discontinuous with distance north. It includes large outcrops at The Boomer, Seaward Ledge and North Tall. The second ridge of discontinuous reef trends NNE and incorporates Escape Island, Whitlock Island, Osprey Island, Boulanger Island and Favourite Island as well as a number of substantial outcrops. A shallow, <5m deep ridge extends eastwards from Favourite Island. It joins the shore and encloses a small depression with waters >10m deep off Jurien Boat Harbour.	The NNW facing shoreline is the northern flank of the Island Point salient. It is broken by breakwaters at Jurien Boat Harbour. Reflective beach morphology is common north and south of the harbour although the shore faces NW between Island Point and the boat Harbour and to the W north of the harbour.	The northern flank of the foreland forming the prograded barrier is currently undergoing accretion. The Jurien Bay Townsite occupies much of the foredune plain south of the Jurien Bay Boat Harbour. The foredune plain on which the settlement of Jurien Bay is located tapers with distance to the north and abuts the continuation of the parabolic dunes to landward. Away from the frontal dunes, the barrier is fully vegetated. On the frontal dunes the vegetation cover is discontinuous. It varies from 25 - 75% and is disturbed by ORV tracks.
29	South BookaValley	Island Point (Jurien)	NNE trending s of limestone reef almost close with the coast at island Point and constitute the northern reaches of a lagoon formed by the Hill River depression. Extensive unconsolidated sand sheets form the surface between the Boulanger Island reef ridges and the shore.	The SW facing shoreline is the southern flank of a broad salient associated with shallow waters at Island Point, landward of Boulanger Island. Reflective beach morphology is common along the shore.	Island Point is the tip of a large cuspate foreland. It is a prograded barrier comprised of a foredune plain extending approximately 2.5km landward from Island Point. The foreland is currently undergoing erosion along the northern half of its southern shore and this has triggered the formation of a frontal dune ridge of blowouts and parabolic dunes, the longest of which is a mobile dune moving north from Booka Valley. East of Island Point the foredune plain abuts an older series of nested parabolic dunes. The vegetation cover of the barrier is patchy on the frontal dunes, varying between 25 to 75% and is >75% on the barrier.
28	South Hill River	South Booka Valley	Intermittent limestone reefs outcrop in the inshore waters. The reef becomes deeper to the north where a depression is located between Three Breaks Reef and Essex Rocks, off Booker Rocks. The depression may identify an old channel of the Hill River. Essex Rocks is the start of a high reef line approximately 4km offshore That trends to the NNE and closes with the coast at Boulanger Island. The line appears to mark an old shoreline.	A west facing, shallowly arcuate shoreline extends from the peak of a broad salient to a rock platform at Booka Valley. The continuity of the shore is broken at the mouth of Hill River and a small change in orientation approximately 2km north of there. Reflective and transitional beach morphology is common along this part of the shore.	South of the Hill River mouth, a 120m wide foredune plain has formed seaward of a high frontal dune ridge that cuts nested parabolic dunes and undulating lowlands to landward. A wider series of nested blowouts and parabolic dunes extends approximately 2km landward to the north of Hill River. It includes a 50 to 60m wide ridge of frontal dunes with active blowouts and mobile sand sheets. Vegetation cover is disturbed in the vicinity of the river mouth and >75% to the south and from 25 to 75% in the northern sector. The discontinuous foredunes have been eroded and cliffed.

Cell	S	N	INSHORE	SHORE	BACKSHORE
27	Black Head	South Hill River	The inshore waters include intermittent limestone outcrops such as Outer Rocks, Brooker Rocks and The Coffins. The northernmost of the outcrops marks a change in the seaward facing trend of the 20m isobath from SW to W. Unconsolidated sandy sediments spread northwards from the Emu Rocks ridge. Elsewhere is intermittent reef.	The WSW facing shoreline is the southern flank of a broad salient associated with shallow waters landward of Brooker Rocks. The largely, straight shoreline is interrupted by a rock outcrop approximately 1km N of Black Head. The beach morphology includes sheltered profile forms to the south and more exposed reflective beaches to the north.	A narrow episodic, transgressive barrier with nested parabolic dunes extending up to 1km landward and from 2 to 5km along the coast. South of the rock outcrop the sequence of foredune ridges impounds an elongate coastal lagoon. 25 - 75% vegetation cover on this section of the shore has been affected by vehicle access tracks. Immediately N of the rock outcrop the frontal dune has been eroded along its seaward margin but cuts off sand supply to an area of parabolic dunes with approximately 50% vegetation cover. The northern kilometre of the cell has a 150m wide foredune plain and frontal dune ridge seaward of older nested parabolic dunes. An access track runs parallel to the beach along the foredune plain.
26	Thirsty Point	Black Head	The inshore waters include intermittent limestone outcrops such as North and South Ronsard Rocks, Priest Reef and Emu Rocks. There are two WSW - ENE trending sand ridges extending landwards from North Ronsard Rocks and Emu Rocks.	An arcuate W facing shoreline extends from Cervantes to Black Point. The beaches are sheltered by the offshore reefs and shallow inshore waters as well as seagrass banks in the southern part of Ronsard Bay. The beach morphology includes sheltered profile forms.	A prograded barrier impounds a narrow coastal lagoon in the south-central part of the bay. In the northern section, a narrow foredune plain has truncated nested parabolic dunes and an active blowout attached to the Ronsard Rocks sand ridge. With the exception of Cervantes and the mobile components of the blowouts there is >75% vegetation cover. In the northern part of the embayment, the frontal dunes have been disturbed by access tracks such that their vegetation cover is discontinuous and between 25- 75 %.
25	Hansen Head	Thirsty Point	Two discontinuous limestone ridge lines occur in the inshore waters. The seaward most ridge is approximately 5km offshore and trends SSE to NNW. The landward ridge which includes the Cervantes Islands trends from S to N. Between the landward ridge and the shore is an area of unconsolidated sediment.	The SW facing shoreline includes a broad embayment terminating in a cuspate foreland at Thirsty Point. The beaches are sheltered by the offshore reefs and shallow inshore waters. The morphology includes sheltered profile forms.	The barrier is prograded and mainly comprised of a plain of foredune ridges bounded to the east by parabolic dunes. Vegetation cover is >75% away from the urban settlement and access tracks. The frontal dune is continuous and with >75% cover.
24	Kangaroo Point	Hansen Head	The inshore area includes discontinuous limestone reef and north trending reef lines separating shallow lagoons with extensive areas of unconsolidated sediment.	The W to WSW facing shoreline between Kangaroo Point and South Cervantes is arcuate and indented in form. The sheltered beach is continuous and has rounded profile morphology, particularly on the NW facing coast of the Kangaroo Point salient.	Barrier morphology is mainly comprised of S-N trending episodic, transgressive dunes with insets of prograded foredune ridges at Kangaroo Point and along the southern shore of the South Cervantes salient. A mobile sandsheet is located in the centre of Nambung Bay. Elsewhere the vegetation cover varies between 25 and 75% but has been subject to fire damage.

Cell	S	N	INSHORE	SHORE	BACKSHORE
23	Boggy Bay	Kangaroo Point	A discontinuous limestone reef approximately 4km offshore. It shallows with distance north and outcrops as the Inner and Outer Seven Foot Rocks. The reef outcrops as several rock platforms.	In plan the shoreline is comprised of two embayments between shoreline salients. The southern and central salients are tied to the rock platforms. The northern salient, Kangaroo Point, is in the lee of offshore islands. The WSW facing beach is continuous, perched on the rock platforms and has a rounded or reflective form.	The barrier has a complex structure comprised of nested parabolic dunes and blowouts as well as prograded foredune ridges at Kangaroo Point. There is a small mobile sandsheet is migrating northwards from the southern embayment. Elsewhere the vegetation cover is between 25 and 75% but has been subject to fire damage.
22	Grey	Boggy Bay	The limestone reef bifurcates at the Green Islands. Its shore parallel component continues but deepens and becomes more discontinuous with distance north. A second higher ridge of discontinuous reef trends NNE and incorporates Whittell Island, Buller Island and Francis Reef.	The plan form of the shoreline is rhythmic and controlled by the geological framework. Low amplitude Salients are associated with rocky outcrops. Between them the mainly WSW facing shoreline is arcuate and shallowly indented. The beach morphology varies from sheltered forms to exposed reflective forms.	The narrow Holocene barrier is a mix of nested blowouts and parabolic dunes with occasional small foredune plains. The dunes have a >75% vegetation cover with some very small blowouts along the fore dunes.
21	South Grey	Grey	The offshore reef rises and widens to outcrop as the Green Islands. Further inshore the lagoon shallows with distance north and intermittent reef gives wave to a mainly sandy seabed.	The WSW facing shoreline is straight and predominately rocky. Small sandy beaches are perched on rock platforms and/or are situated between rock outcrops.	An episodic, transgressive barrier overlays the limestone surface and an older dune formation. There is >75% vegetation cover on the dunes slacks and ridges. Mobile sandsheets occur at the northern and southern boundaries of the cell. Where the coast is sandy the fontal dune complex has 25 - 75% discontinuous vegetation cover. It is traversed by numerous ORV tracks and the foredune eroded.
20	North Wedge	South Grey	The continuous limestone reef and lagoon extend in the inshore although the reef becomes deeper to the north. A second line of reef occurs intermittently approximately 400m offshore and appears to mark an old shoreline.	For much of its length the shoreline is straight and the 60m wide beach is exposed to dissipative conditions. The coastal aspect changes from SSW to SW in the northern quarter where rock outcrops control the beach form.	The barrier is approximately 1.5km wide and comprised of nested parabolic dunes. On most of the vegetation cover on the barrier is >75%. It is less on the frontal dune complex where there are small blowout dunes and access tracks that are particularly common in the northern quarter if the cell.
19	Wedge Island	North Wedge	Continuous limestone reef approximately 2km offshore and a lagoon are apparent in the inshore zone. Reef outcrops intermittently in the lagoon waters.	An arcuate shallowly indented shoreline faces WSW. Beaches vary morphologically from reflected and transitional forms in the south to transitional types in the north.	The barrier is comprised of parabolic dunes and mobile sandsheets overlaying a prograded barrier. Vegetation of the low lying dunes of the cuspate foreland has been disturbed by a settlement and its access tracks. The foredune ridge around the foreland is cliffed along the beach and has 25 -75% vegetation cover. A mobile sandsheet abuts the beach in the central part and a small active parabolic dune is located in the northern third of the cell.

Cell	S	N	INSHORE	SHORE	BACKSHORE
18	Magic Reef	Wedge Island	Discontinuous limestone reef approximately 2km offshore and a lagoon are apparent in the inshore zone. Reef outcrops intermittently as pavement throughout the inshore waters.	The shoreline consists of three shallowly indented arcuate embayments formed by small salients landward of rock outcrops, including South Rocks. The beaches face S to SW. Their morphology changes from reflective to dissipative with an increase in exposure to the north. The cell terminates in a large cuspate foreland at Wedge Island.	Vegetation cover on the episodic, transgressive barrier is between 25 and 75% of the land surface. Large mobile sand sheets are present in the centre of the barrier at the heads of parabolic dunes originating in the southern half of the cell. The frontal dune complex is disrupted by ORV tracks and small blowouts but has >75% discontinuous cover.
17	Narrow Neck	Magic Reef	A narrow, discontinuous limestone reef approximately 800m offshore and a lagoon are apparent in the inshore zone.	The shoreline is arcuate and shallowly indented. Its SW facing beach varies from exposed, reflective to dissipative beaches with distance north. The cell terminates in a small tombolo at Magic Reef.	Vegetation cover on the episodic, transgressive barrier has been significantly disturbed by fire and mobile sandsheets occur in the central part of the barrier. Closer to shore the frontal dune complex has 50 to 75% cover. The foredune is cliffed in part and discontinuous elsewhere. Small blowouts are present in the southern third of the cell.
16	Dide Point	Narrow Neck	Discontinuous limestone reef approximately 800m offshore and a lagoon are apparent in the inshore zone. Reef outcrops irregularly throughout the inshore waters.	The shoreline is arcuate and shallowly indented. Its SW facing beach varies in morphology from a sheltered, rounded beach to the south to more exposed reflected and transitional forms in the north. The cell terminates in a small cuspate foreland at Narrowneck.	The episodic, transgressive sand barrier of the area has over 75% vegetation cover although a large fire scar is apparent. The frontal dune complex is narrow, commonly <200m and comprised of vegetated parabolic dunes. A foredune ridge is present along much of the shore.
15	Lancelin Island	Dide Point	The offshore area has two ridges of intermittent reef extending parallel to the shore. Closer to shore limestone outcrops as intermittent reef.	The shoreline consists of four shallowly indented arcuate embayments formed by small salients landward of rock outcrops at Virgin Reef, Bob's Corner and Dide Point. The exposed WSW facing beaches have reflective to transitional morphologies.	An episodic, transgressive barrier approximately 3.5km wide overlies an older barrier complex. There is between 25 and 75% vegetation cover on the barrier with mobile sandsheets in southern and northern areas at the heads of parabolic dunes. The frontal dunes of the three southern embayments have <25% cover and are disturbed by ORV tracks. Vegetation in the northern embayment is between 25 and 75%. The frontal dune has been eroded.
14	Edward Island	Lancelin Island	The cell is enclosed by a nearly continuous reef between Edward Island and Lancelin Island. The limestone reef is approximately 1km off shore and encloses a shallow lagoon.	The shoreline is comprised two arcuate shallowly indented embayments facing W to WSW. The beach is continuous, and because of the reef, its morphology varies from sheltered flat beaches in the south, to reflective beaches in the north.	Mobile sand sheets from the parabolic dunes sourced to the south have migrated northwards across a low marl surface immediately seaward of the frontal dune complex. This in an area of rural urban development between the mobile sandsheet and the shore. Landward of the mobile dunes, the episodic, transgressive barrier has greater than 75% vegetation cover.

Cell	S	N	INSHORE	SHORE	BACKSHORE
13	South Pacific Reef	Edward Island	Inshore comprises discontinuous limestone reef and lagoon. The NE trending ridge running from Web Reef to Mile Reef closes with the coast in the centre of the cell.	The uninterrupted shoreline faces SW and has two components. The southern part of the cell is sheltered by the off shore reefs and its beach morphology is mainly reflective. The northern section is more exposed and the beaches have transitional to dissipative morphology. The beach terminates in a cuspate foreland at Edward Island.	The episodic, transgressive barrier is comprised of parabolic dunes that have their source in the southern sector of the cell. The vegetation cover of the barrier is between 25 - 75% with disturbances from roads, tracks and a golf course. In the southern part of the cell there is over 75% vegetation cover. This contrasts to the North where discontinuous frontal dunes with less than 25% vegetation cover.
12	Ledge Point	South Pacific Reef	Inshore comprises discontinuous limestone reef and lagoon. It is an area of major change in the orientation of the reef from NW to NE trending ridges and there is a broad salient along the 20m isobath.	The WSW facing shoreline is comprised of 3 shallowly indented arcuate segments that decrease in size with distance North. Beaches vary in width by 30 to 80m with distance N in each segment and the morphology ranges from reflective to transitional.	The episodic, transgressive barrier is comprised of 2 types of dunes. Older blowout dunes on the barrier extend up to 4km landward. They have a W to E orientation and >75% vegetation cover. Mobile sandsheets and parabolic dunes with a S to N orientation occur closer to shore. There is >75% vegetation cover on the frontal dune complex.
11	Green Reef	Ledge Point	The inshore is characterised by two lines of limestone reef and a shallow lagoon approximately 2.5km wide between Green Reef and Home Reef off shore. The lagoon closes with the coast off Ledge Point.	The WSW facing shoreline is comprised two arcuate shallowly indented embayments facing SW. The beach is continuous, widening from approximately 30 to 80 m with distance North. Beaches are transitional with rip currents apparent.	An episodic, transgressive barrier with nested blowout dunes extending up to 2km landward and overlying older dunes. The barrier dunes have greater than 75% vegetation cover and the discontinuous frontal dunes have between 25 and 75%. Several small blowouts are apparent in the frontal dune ridge.
10	Manakoora Sand Patch	Green Reef	The inshore has intermittent limestone reef. More extensive limestone outcrops occur as platforms immediately N of Manakoora Sand Patch.	A continuous WSW facing sandy shoreline extends from South Ledge 1 to Green Reef. The beach widens to the North and has a transitional morphology.	An episodic, transgressive barrier with approximately 2 m wide blowout dunes overlying older dunes that extends up to 3.8km landward. Mobile sandsheets over 0.5km wide extend for over 60% of the coast. The frontal dues are discontinuous with less than 25% cover with evidence of ORV tracks.
9	South First Bluff	Manakoora Sand Patch	Intermittent reef with outcrops of limestone pavement and platform are common features of the shore	The straight WSW facing coast has small shallow embayments between rocky outcrops. Perched beaches with reflective profiles commonly occur in association with rock platforms.	An episodic, transgressive barrier overlies a discontinuous bedrock surface. The barrier is comprised of nested blowout dunes with greater than 75% vegetation cover extending up to 1.2km landward over older parabolic dunes. The frontal dunes, particularly near First Bluff, have 25 - 75% vegetation cover.

Cell	S	N	INSHORE	SHORE	BACKSHORE
8	Second Bluff	South First Bluff	Discontinuous reef outcrops as islets and reefs approximately 2.5km off shore. The largest of the outcrops comprise the Dragon Reef and Platform Reef-Big Horseshoe Reef complex. The two reefs are separated by Windmill Passage which leads to a 15m deep inshore basin.	An uninterrupted rhythmic shoreline facing SW consists of three very shallow embayments. The width of the reflective beach varies with distance North. It is at a maximum on the Southern side of low amplitude salients tied to outcrops of inshore reefs.	Episodic, transgressive barrier of moderate height and width of approximately 3.5 m. The mainland barrier comprised of nested parabolic dunes with more than 75% vegetation cover. Ridge crests have a low vegetation cover. The centre of the cell has discontinuous foredune ridges and the frontal dunes have 25 - 75% cover.
7	Eagles Nest Bluff	Second Bluff	The Leschenault Reef and One Mile Reef become discontinuous approximately 2km south of Eagles Nest Bluff, and a third line of shore parallel reef occurs approximately 500 m offshore and closes with the shore in the vicinity of Second Bluff. Irregular rock outcrops as apparent as The Lumps in the inshore waters, shoreward of Dragon Reef.	A narrow reflective beach is continuous along the straight WSW facing shore and is generally less than 25m wide.	A narrow episodic, transgressive barrier with nested blowouts extending up to 1.3km landward. The dunes are fully vegetated. A fully vegetated foredune abuts a low rocky cliff.
6	Seabird	Eagles Nest Bluff	There are two lines of limestone reef off Seabird: the Leschenault Reefs form a continuous line of reef approximately 5km offshore; and the One Mile Reef is a discontinuous reef approximately 1.5km offshore. Irregular rock outcrops, The Lumps, together with sand patches and seagrass occur in the troughs separating the reefs the lagoonal waters closer to shore.	The shoreline faces WSW. It is generally straight with very shallow arcuate embayments tied to rocky headlands. A continuous reflective beach increases in width from 0.2 to 0.5km to the North. Sections of the beach are perched on rock platform.	Episodic, transgressive dunes extend approximately 2.6km inland as nested blowouts with >75% vegetation cover. The foredune is discontinuous with 25 - 75% vegetation cover. The foredunes are absent in the North where the beach abuts a low cliff.
5	Moore River	Seabird	A continuous limestone reef and lagoon parallel the shore. Irregular rock outcrops and sand patches occur in the inshore waters.	Two shallowly arcuate beaches facing SW. The exposed reflective beaches are <2km wide and segmented by rock outcrops along the coast	A receded barrier up to 3km but generally <1km wide is perched on a discontinuous rock surface. It has >75% vegetation cover. Approximately 50% of the shore abuts low rocky cliff.
4	South Moore River	Moore River	Continuous limestone reef approximately 4km offshore impounds an inshore lagoon with a rocky substrate and sand patches. The seabed has >50% intermittent reef and sandy patches.	The shoreline faces SW and is apparently unbroken by rock outcrops. It is rhythmic in plan form and has an exposed reflective beach up to 0.5km wide.	The episodic, transgressive barrier is approximately 5.5km wide in the central part of the cell and has >75% vegetation cover. The frontal dune ridge is comprised of nested blowouts, including active dunes associated with tracks. Some instability is associated with the discontinuous foredune located seaward of the frontal dune.

Cell	S	N	INSHORE	SHORE	BACKSHORE
3	North Two Rocks	South Moore River	Continuous limestone reef impounds an inshore lagoon with a rocky substrate and sand patches. The sand patches are elongate and parallel in the vicinity of the offshore reef but are more irregularly distributed closer to shore. The seabed has >50% intermittent reef and sandy patches.	A straight shoreline faces SW with some small arcuate embayments less than 1km long. Reflective beaches are up to 0.5km wide. Small shoreline salients are associated with inshore rock outcrops.	The 3 -4km wide episodic, transgressive barrier decreases in width and is less than 0.5km wide where it closes with the shore at South Moore River. The barrier has >75% vegetation cover and small mobile dunes. The foredune is discontinuous and cliffed.
2	Two Rocks	North Two Rocks	Continuous limestone reef impounds an inshore lagoon with a rocky substrate and sand patches. The sand patches are elongate and parallel in the vicinity of the offshore reef, but are more irregularly distributed closer to shore.	Three arcuate beaches facing WSW are within a 5km long embayment. The beaches are up to 0.5km wide and have a reflective morphology. The northern & southern beaches are perched & topographically controlled	An episodic transgressive barrier overlies older blowouts that extend approximately 5km landward. The frontal dune ridge is approximately 0.5km wide and comprised of nested blowouts. It is scarped along the shore such that foredunes are either absent or discontinuous. Mobile blowouts on the ridge are associated with beach access tracks. The main barrier has 25 to 75% vegetation cover and mobile dunes particularly in the northern sector.
1	Wreck Point	Two Rocks	Continuous reef approximately 4km offshore encloses an inshore lagoon with water up to 10m deep. The seabed has >50% intermittent reef and sandy patches.	The WSW facing, arcuate and shallowly embayed shore between the Wreck point cuspate foreland and a small salient at Two Rocks is divided into two parts by the Two Rocks Marina. South of the marina a 100m wide beach is on the north flank of the cuspate foreland, North of the marina the sheltered beach is perched on a rock platform.	An episodic transgressive barrier with a frontal dune ridge of nested blowouts to the north and a narrow foredune plain to the south overlies older blowouts that extend up to 4km landwards. Settlement at Two Rocks obscures the vegetation in the central part of the barrier. The 25 to 75% vegetation cover on the frontal dunes is discontinuous due to access tracks and small blowouts.

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Appendix E Coastal Rankings and Implications for Coastal Planning and Management for Each Cell

THE SUSCEPTIBILITY AND INSTABILITY RANKINGS SHOULD NOT BE USED INDEPENDENTLY. BOTH ARE BASED ON SEVERAL CRITERIA AND ARE GUIDES TO THE VULNERABILITY ASSESSMENT

No.	S	Lon	Lat.	Susceptibility		Instability		Vulnerability			
				Rank	Implications	Rank	Implications	Rank	Constraint	Implications	Coastal Planning and Management Recommendations
36	South Fisherman	115.002981	-30.148595	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched barrier has a low susceptibility to long-term change although the shore is exposed to major storms.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough). A low-to-moderate level of dune instability apparent in the cell.	L	Coastal risk is unlikely to be a constraint for coastal management.	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
35	Sandy Point	114.992182	-30.18326	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The zeta-form bays of the cell have a moderate susceptibility to long-term change with some exposure to major storms.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough). Eroded frontal dunes in the southernmost embayment have been disturbed by ORV tracks but have more than 25% vegetation cover.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
34	Sandland	114.992702	-30.207597	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The cuspate forelands and pocket beaches have a moderate susceptibility to long-term change with a high exposure to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Moderate levels of landform instability are apparent on the dune and barrier. A mobile sand sheet is located at the head of a long parabolic dune extending from the south of the Sandland foreland. It is located approximately 0.6km landward of Sandy Point.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
33	North Head	114.99522	-30.233045	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The perched barriers and pocket beaches have a low-to-moderate susceptibility to long-term change with a high exposure to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Moderate levels of landform instability are apparent overall. Vegetation cover in the 500m landward of the shore is between 25 and 50% but is markedly affected by ORV tracks in the southern part of the cell.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

No.	S	Lon	Lat.	Susceptibility		Instability		Vulnerability			
				Rank	Implications	Rank	Implications	Rank	Constraint	Implications	Coastal Planning and Management Recommendations
32	Pumpkin Hollow	115.014151	-30.233373	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched tombolo has a low susceptibility to long-term change.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough). Low-to-moderate levels of landform instability are apparent on the dune and barrier overall. However, there are numerous ORV tracks in the area and mobile dunes, including an active parabolic dune in the centre of the embayment.	L	Coastal risk is unlikely to be a constraint for coastal management.	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
31	Middle Head	115.038131	-30.258439	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched barrier has a low susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Moderate-to-high levels of landform instability are related to scarping of the foredunes and frontal dunes.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
30	Island Point	115.020491	-30.317242	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. Island Point is a cuspate foreland with a moderate-to-high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Moderate levels of landform instability are related to inshore and foreshore instability as well as scarping of the foredunes.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
29	South Booka Valley	115.042812	-30.349115	H	Natural structural features are extensively unsound. Major engineering works are likely to be required. The southern flank of the cuspate foreland has a high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Unconsolidated inshore sediments, an active beach and blowouts, as well as scarping of the frontal dunes indicate an overall moderate level of instability.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

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				Rank	Implications	Rank	Implications	Rank	Constraint	Implications	Coastal Planning and Management Recommendations
28	South Hill River	115.050051	-30.421746	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The shallow embayment contains the wave dominated delta of the Hill River. It is susceptible to long-term change and has a high exposure to major storms.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton). The inshore substrate, beach and frontal dune systems all have bare sand surfaces and eroded landforms with a moderate-to-high level of instability.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
27	Black Head	115.062796	-30.455586	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. Much of the barrier dune system is perched and has a low susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Although there is evidence of scarping of the frontal dune complex the dunes overlying the Hill River delta have a moderate level of stability.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
26	Thirsty Point	115.057865	-30.510757	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The northern flank of the cuspate foreland has a moderate susceptibility to long-term change and a moderate-to-high exposure to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Landforms of the cell uniformly have a low-to-moderate level of instability. In the northern part of the embayment, the frontal dunes have been disturbed by access tracks and their vegetation cover is discontinuous.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
25	Hansen Head	115.075551	-30.52408	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The southern flank of the cuspate foreland of Thirsty Point has a high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Landforms of the cell uniformly have a low-to-moderate level of instability. The moderate ranking related to inshore instability.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

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24	Kangaroo Point	115.087658	-30.578274	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The Kangaro Point foreland has a moderate susceptibility and the northern part of the cell a moderate-to-high susceptibility.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Landforms in the cell have a moderate ranking due to foredune instability in the northern part of the cell and a mobile sandsheet is located in the centre of Nambung Bay.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
23	Boggy Bay	115.107175	-30.61319	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The forelands and transgressive barriers of the cell have a moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The cuspate forelands of the cell have landforms that are moderately unstable including eroded foredunes, a mobile sand sheet and fire damage to the vegetation.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
22	Grey	115.133758	-30.666648	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. Much of the transgressive barrier is perched and has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Landforms in the cell have a moderate ranking due to foredune instability and blowouts in the frontal dunes.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
21	South Grey	115.159379	-30.728533	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The transgressive barrier is perched and has a low susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Mobile sandsheets occur at the northern and southern boundaries of the cell. The foredune is eroded and the fontal dune complex has discontinuous vegetation cover. It is traversed by numerous ORV tracks.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).

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20	North Wedge	115.17289	-30.753204	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The transgressive barrier is perched and has a low susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The overall ranking is moderate. However landform components comprising the cell are variable with the exposed beaches and frontal dunes having a moderate-to-high ranking.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
19	Wedge Island	115.189975	-30.825341	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The northern flank of the cuspate foreland has a moderate-to-high susceptibility to long-term change and a moderate to a high exposure to major storms.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton). The cell has a high instability ranking due to disturbance of vegetation of the low lying dunes by access tracks; cliffing of the foredune ridge around the foreland; and a mobile sandsheet.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
18	Magic Reef	115.242935	-30.868997	H	Natural structural features are extensively unsound. Major engineering works are likely to be required. The southern flank of the low-lying cuspate foreland has an overall high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Large mobile sand sheets are present at the heads of parabolic dunes originating in the southern half of the cell and the frontal dune complex is disrupted by ORV tracks and small blowouts.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

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17	Narrow Neck	115.268221	-30.912125	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The transgressive barrier is partly perched and has a moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The foredune is cliffed in part and discontinuous elsewhere; small blowouts are present in the southern third of the cell and the vegetation has been damaged by fire.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
16	Dide Point	115.289658	-30.945199	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The transgressive barrier is mainly perched and has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The narrowness of the frontal dune complex and fire damage contributes to the moderate instability ranking of the cell.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
15	Lancelin Island	115.322871	-31.005492	H	Natural structural features are extensively unsound. Major engineering works are likely to be required. The transgressive barrier and forelands overlie weakly cemented lagoonal sediments and are moderate-to-highly susceptible to change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The overall moderate ranking is related to a lack of cover on the frontal dune complex of the three southern embayments and their disturbance by ORV tracks.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
14	Edward Island	115.326486	-31.026878	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The transgressive barrier and forelands overlie weakly cemented lagoonal sediments and are moderate-to-highly susceptible to change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The cuspate forelands of the cell have landforms that are moderately to highly unstable including eroded foredunes and a mobile sand sheet.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

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13	South Pacific Reef	115.347416	-31.063903	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The transgressive barrier is perched and has a low susceptibility to long-term change although the shore is exposed to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Exposed beaches and active blowouts in the frontal dune complex have a moderate-to-high instability ranking.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
12	Ledge Point	115.370944	-31.109603	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The salient and perched barrier has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Mobile sandsheets and parabolic dunes are common in the frontal dune complex. Together with exposed beaches and scarped foredunes these landforms contribute to the moderate instability of the cell.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
11	Green Reef	115.387591	-31.140096	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The perched transgressive barrier has a low-to-moderate susceptibility to long-term change with a high exposure to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Active blowouts are present in the frontal dune complex. Together with exposed beaches and scarped foredunes these landforms contribute to the moderate instability of the cell.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.

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10	Manakoora Sand Patch	115.396492	-31.164603	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The perched transgressive barrier has a moderate susceptibility to long-term change with a high exposure to major storms.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton). This is a highly unstable section of coast. Mobile sandsheets over 0.5km wide extend for over 60% of the coastal length; frontal dunes are discontinuous, with less than 25% cover and there is evidence of ORV tracks.	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.	It is advised that detailed consideration of the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on the site be completed before development proposals are formulated. Advisedly, preliminary investigations including a full geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) would be completed before a development proposal is formally lodged. The next step would be a full hazard and risk assessment provided the Department of Transport is satisfied with the results. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Advisedly, any subsequent development proposal would include strategies to respond to metocean events (such as storms), and other site disturbances, of various frequencies and magnitudes. Required stabilisation works (such as structures or bypassing) should be identified, costed and long-term management responsibility addressed. The Department of Transport's operational policy for coastal protection (DPI 2006) indicates that the State has not provided erosion protection for private property, and has no general obligation to do so. The authority to assist local government with finance for coastal protection works is only through ministerial direction. Advisedly, proposed developments should not devolve responsibility for protection works, or ongoing maintenance (such as bypassing), to the State or Local Government. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
9	South First Bluff	115.398926	-31.17932	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The perched transgressive barrier has a low susceptibility to long-term change although the shore is exposed to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Landforms in the cell have a moderate ranking due to the foredune instability and scarping of the frontal dunes between rock outcrops.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
8	Second Bluff	115.41359	-31.208243	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low susceptibility to long-term change although the shore is exposed to major storms.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). Ridge crests on the main part of the barrier have a low vegetation cover. Closer to the coast the cell has discontinuous foredune ridges and the frontal dunes a highly varied vegetation cover.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
7	Eagles Nest Bluff	115.42412	-31.232782	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low susceptibility to long-term change although the shore is exposed to major storms.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough). Overall the cell has a low instability ranking because the perched dunes of the barrier are dunes are fully vegetated, as is the foredune abutting a low rocky cliff.	L	Coastal risk is unlikely to be a constraint for coastal management.	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).

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6	Seabird	115.440333	-31.276128	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The transgressive barrier has a moderate-to-high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The cell has a moderate instability ranking due to erosion of the frontal dunes. Instability is indicated by the discontinuous to absent character of the foredunes.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
5	Moore River	115.499348	-31.353982	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised. The transgressive barrier has a moderate-to-high susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The cell has a moderate instability ranking due to erosion of the frontal dunes. Instability is indicated by the discontinuous to absent character of the foredunes.	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.	Detailed consideration is recommended for the potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall) on unsound natural structural features on the site proposed for development, including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) and coastal sediment budget assessment (approximate volumetric rates of sediment transport including sources and sinks) where appropriate. Advisedly, any subsequent development proposal should include strategies to respond to metocean events, and other site disturbances, of various frequencies and magnitudes. Completion of a hazard and risk assessment for the site prior to potential application of SPP 2.6, is advised where appropriate. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour). Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised.
4	South Moore River	115.550399	-31.427374	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The frontal dune ridge is comprised of nested blowouts, including active dunes associated with access tracks. Some instability is associated with the discontinuous foredune.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
3	North Two Rocks	115.564262	-31.465072	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The discontinuous and cliffed foredune and frontal dune complex indicate a moderate level of instability.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).

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2	Two Rocks	115.581103	-31.489246	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low-to-moderate susceptibility to long-term change.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay). The frontal dune ridge is narrow and comprised of nested blowouts. It is scarped along the shore where foredunes are either absent or discontinuous. Mobile blowouts on the main frontal dune ridge are associated with beach access tracks.	L-M	Coastal risk may present a low constraint for coastal management.	The site contains elements of low-to-moderate integrity of natural structures, elements of limited natural resilience or elements requiring management.	Detailed consideration of potential impacts of metocean processes (waves, winds, water levels, tropical cyclones, rainfall), including geotechnical survey (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique) where appropriate, is recommended as a precursor to development of a planning proposal. Particular attention should be given to the potential impacts of extreme metocean events (such as storms) on elements of low to moderate integrity of natural structures or limited natural resilience. Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).
1	Wreck Point	115.585362	-31.502327	L	A mainly structurally sound geologic or geomorphic feature likely to require limited investigation and environmental planning advice prior to management. The perched transgressive barrier has a low-to-moderate susceptibility to long-term change.	L	Resilient natural system occasionally requiring minimal maintenance (eg. Alfred Cove, Milyu Reserve & Scarborough). The cell has a low instability ranking although vegetation cover on the frontal dunes is highly variable due to access tracks and small blowouts.	L	Coastal risk is unlikely to be a constraint for coastal management.	The site has a good combination of integrity of natural structures, natural resilience and low management requirements.	Compliance with State Planning Policy (SPP 2.6) and associated guidelines with respect to setback and environmental considerations, as well as other relevant state, regional and local policy and plans is advised. A hazard and risk assessment is also advised. This assessment includes risk identification, risk analysis (likelihood and consequence) and risk evaluation for each coastal hazard (eg. unstable limestone cliff) and action (eg. interruption of alongshore sediment transport due to the construction of a harbour).