New geoscience

A geological framework for coastal planning

by Bob Gozzard

Abstract

Marine and coastal planning and management need a sound scientific basis. An important component of this involves the mapping of coastal landforms leading to the identification of coastal compartments and sediment cells along the coast of Western Australia. The approach is similar to that used for land systems and river catchments and involves the identification of a hierarchy of units based on natural coastal systems. This hierarchy provides a physical framework for a variety of applications. These include planning and management of natural resources within the nearshore marine and coastal environment, assessment of vulnerability to coastal hazards, climate change, and rise in sea level.

KEYWORDS: coastal features, littoral zone, geomorphology, coastal management, climate change, sea-level rise.

Introduction

The Intergovernmental Panel on Climate Change has released a number of reports detailing the extent of predicted sea-level rise throughout the 21st century (Pachauri and Reisinger, 2007). These and other scientific and research reports predict that southwest Western Australia is particularly at risk to the impacts of sea-level rise through climate change, principally because of the area's low tidal range and generally low, sandy coastline. Future coastal erosion potentially threatens coastal assets such as roads, urban, commercial and industrial development, as well as tourism and recreation.

Two projects being undertaken by State Government agencies are contributing to the identification and use of natural coastal units in a variety of marine and coastal planning and management applications. The agencies involved in these projects are the Geological Survey of Western Australia (GSWA), Department of Planning, Department of Transport, and Department of Environment and Conservation, who have identified marine and coastal planning units consistent with the hierarchy of scales currently used in land use planning. At each scale, the units are based on geological and geomorphological boundaries, and each unit includes a suite of landforms consistent with the landform classes represented in the State Coastal Planning Policy SPP 2.6 (Western Australian Planning Commission, 2003).

In a separate but related coastal mapping project, GSWA has gathered information supporting and extending the potential applications of the marine and coastal planning units (Gozzard, 2009). This project provides more-detailed descriptions of the landform attributes required for coastal hazard and risk assessment at specific sites and at broader scales.

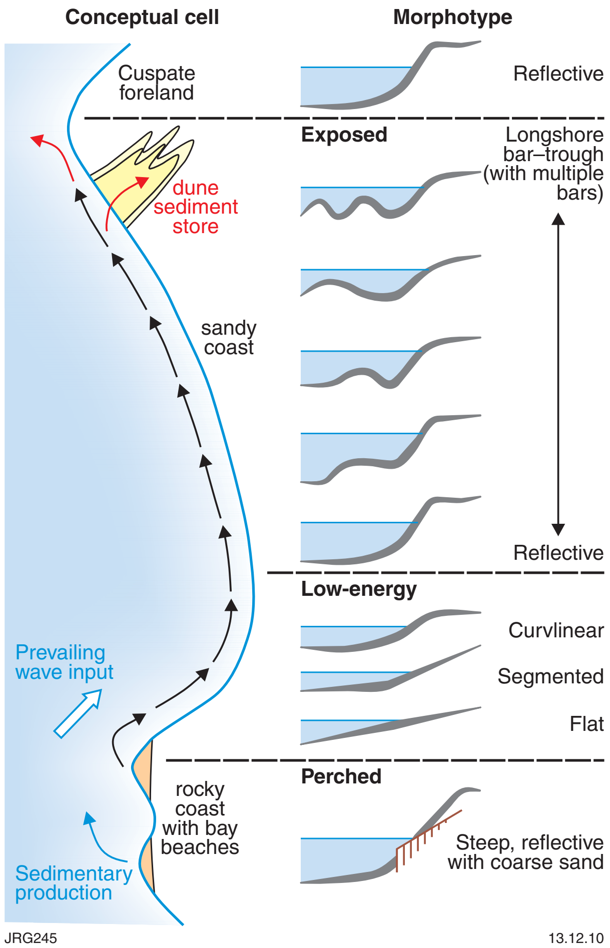

Figure 1. Conceptual model of a sediment cell (from Stul et al., 2007)

Planning units

In the past coastal planning and management in Western Australia has been based mainly on Local Government boundaries and other cadastral information, but as the pace of development increases, as projects get bigger, and as the threat to coastal infrastructure becomes more important

Figure 2. Main coastal morphologies along the southwest coast of Western Australia:
a) rocky coast in gneiss at Cape Naturaliste; b) rocky coast in calcarenite at Cape Peron; c) mixed sand and rock coast at Green Head; d) perched beaches at Trigg; e) barrier system along the Yalgorup coast; f) tombolos at Albany

to the State's continued development, it is more appropriate to identify natural risks and use these to define a hierarchy of natural coastal units at scales that closely match planning scales currently adopted by the Western Australian Planning Commission. At the same time there is the need also to recognize adverse threats to various parts of the coastal system by inappropriate development. Each level in the hierarchy should be linked to and limited by the type of information and detail required for the type of planning to be undertaken. Higher levels in the hierarchy can be used to determine broader, more general policy settings, whereas the lower levels are more suitable for the preparation of detailed management plans for specific sites. At each level in the hierarchy the scale of key landforms is matched with meteorological and oceanographic processes at related scales and linked to the major environmental risks for the appropriate coastal unit.

The concept of coastal compartments and littoral sediment cells and subcells has been adopted world-wide as the basis for coastal management and planning, especially in North America and Europe (Hansom et al, 2004; May and Hansom, 2003). In Western Australia, Sanderson and Eliot (1999), Searle and Semeniuk (1985) and Stul et al. (2007) employed a similar approach between Busselton and Geraldton and identified several primary sediment cells and numerous nested secondary cells. However, the sediment-cell concept has yet to be consistently incorporated into coastal management and planning in Western Australia.

Segmentation of the coast

Coastal compartments are large, regional-scale (i.e. tens to hundreds of kilometres), structural features primarily related to the regional geology — which exerts structural control on the shape of the coastline. The direction the coast faces (coastal aspect) and large coastal landforms such as deltas and cuspate forelands visible at a scale of 1:250 000 are secondary factors in determining the boundaries of coastal compartments. Each compartment encompasses the terrestrial coastal zone and the intertidal zone as well as the waters of the inshore and inner continental shelf.

In contrast, sediment cells are three-dimensional units that incorporate both nearshore terrestrial and marine environments and are usually smaller than coastal compartments. They are defined by the movement of unconsolidated sediments between source areas and deposition sites within geological and geomorphological boundaries identifiable at scales of 1:50 000 or larger (Fig. 1). A sediment cell can be relatively self-contained with regard to the movement of sediment, acting as a closed system with little exchange of sediment between adjacent cells (Komar, 1996). However, not all cells are discrete segments of the coast, and in Western Australia open-cell circulation involving sediment exchange between adjacent cells is not uncommon. Rocky headlands or man-made structures usually represent fixed-cell boundaries, whereas sandy promontories that move with changing wave conditions form migratory boundaries to sediment cells.

The classical approach to the identification of sediment cells (Gelfenbaum and Kaminsky, 2010; Hansom et al., 2004) is based on the principle of a complete sedimentation cycle in which sand is brought to the coast by rivers and streams, carried along the coast by longshore currents, and lost to sediment sinks such as submarine basins. In Western Australia generally, and southwestern Western Australia in particular, this classical approach requires modification, principally because of a lack of major rivers contributing sediment to the offshore (Fig. 2). On the west coast, the main sediment sources are the extensive sand flats, seagrass meadows, and offshore calcarenite reefs, and the major sediment sinks are the extensive dune barriers found along the whole coastline. The inherited geological framework, as, for example, where barrier systems are perched on older lithified sediments, is also more influential in the identification of sediment cells along the west coast than it is in classical models.

Eliot et al. (2010) identified a hierarchy of compartments for the whole of the Western Australian coast at three levels — primary, secondary, and tertiary (Fig. 3). There are thirty-six primary compartments, which have been grouped into 13 coastal regions, and there are 114 secondary compartments, and 242 tertiary compartments.

Tertiary compartments have been further subdivided into a hierarchy of sediment cells. The subdivision of tertiary coastal compartments into sediment cells is determined by the presence of geological controls, such as headlands, a change in beachface and nearshore sediment characteristics, a change in wave climate, and the presence of man-made structures such as groynes, breakwaters, and marinas (Fig. 4). The use of high-resolution LiDAR (Light Detection And Ranging) data and detailed nautical charts is particularly useful in

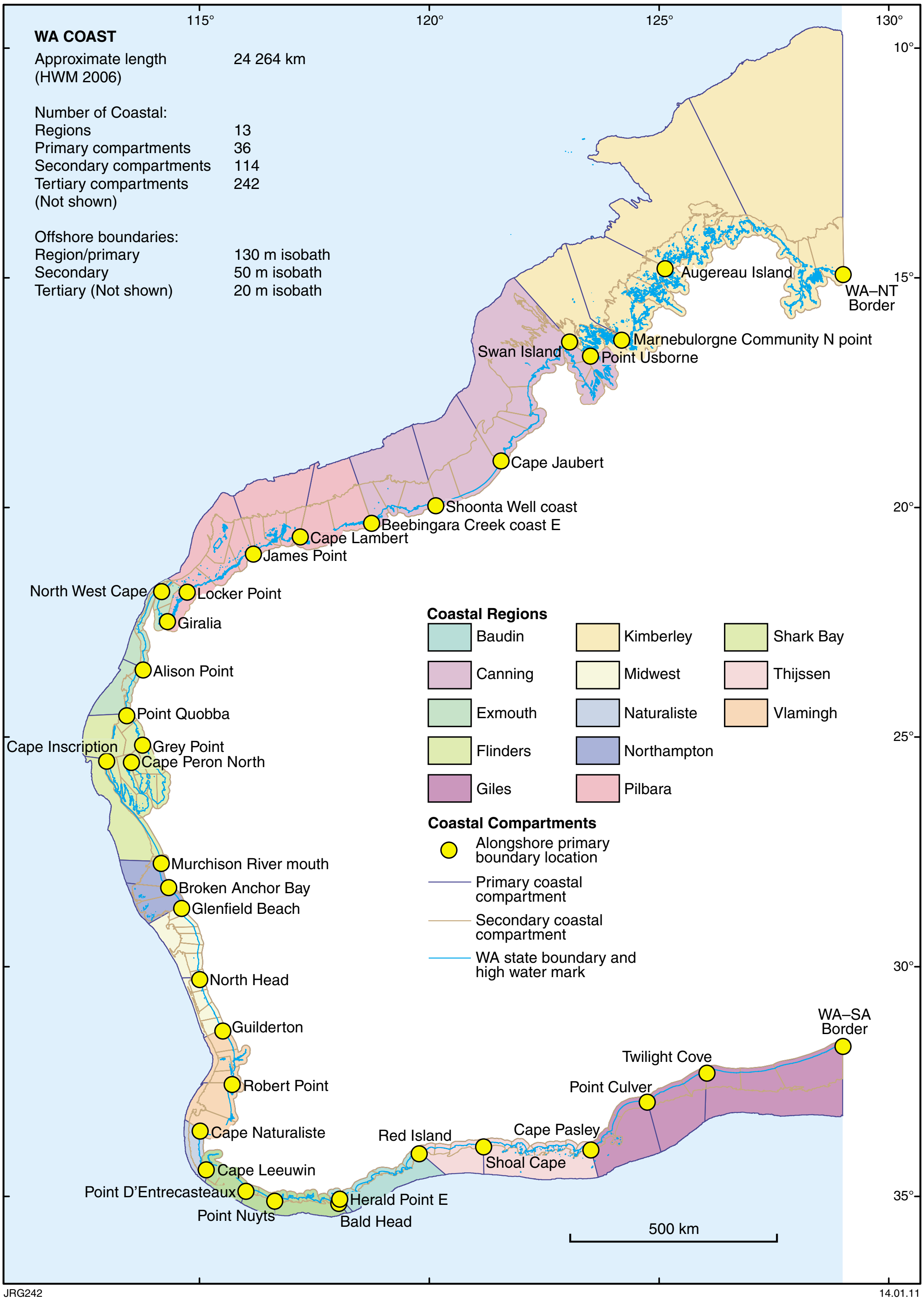

Figure 3. Coastal compartments recognized along the Western Australian coast. Data sources are GSWA, Department of Conservation, Damara Pty Ltd

discriminating sediment cell boundaries. Stul et al. (2007) suggested that the exchange of sediment between sediment cells is likely to be greater than that between compartments because compartment boundaries tend to be rocky headlands or man-made structures whereas sediment-cell boundaries are more susceptible to wave conditions.

All levels in the compartment and sediment-cell hierarchy use a standardized nomenclature for coastal landforms that can be used for a variety of shoreline types. The classification is simple and yet comprehensive enough to encompass landforms that are found at a range of scales in the landscape as well as those landforms that are more scale-specific. For each of the primary, secondary and tertiary compartments the geology and dominant landforms have been identified at a level appropriate to the compartment scale. For example, the Swan primary compartment (Vlamingh Region, Fig. 4), which is bounded by Guilderton in the north and Robert Point, Mandurah in the south, is wholly contained within the Phanerozoic Perth Basin and contains offshore limestone reefs, tombolos, beaches, and dunes. It has been subdivided into three secondary compartments. The coastal landforms associated with primary, secondary, and tertiary sediment cells have been identified as part of the WACoast project (Gozzard, 2009).

WACoast — coastal geology and landforms

There have been many studies undertaken along the coast of Western Australia for the purpose of identifying and mapping the geomorphological components of the coast in detail and assessing the response of the coast to potential future sea-level rises (Green, 2008; Travers, 2007). However, it can be difficult to compare the results from different studies, even when two areas are apparently very similar. For example, the results from one section of rocky calcarenite coastline cannot always be

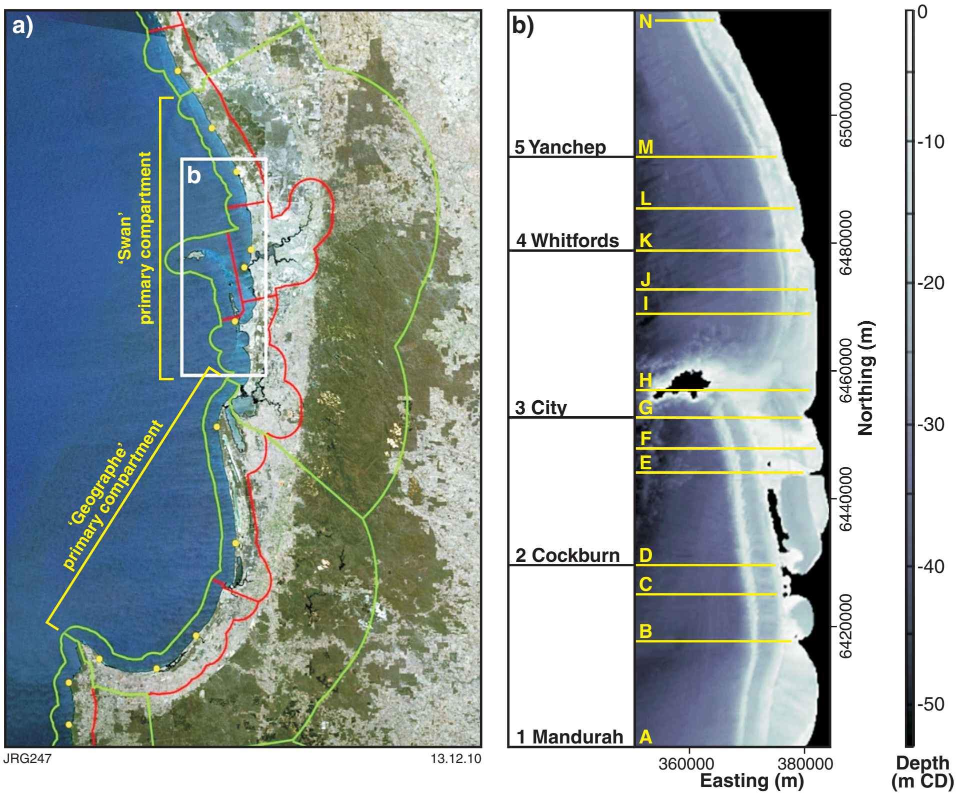

Figure 4. Subdivision of compartments into sediment cells (cells from Stul et al., 2007). mCD = metres Chart Datum

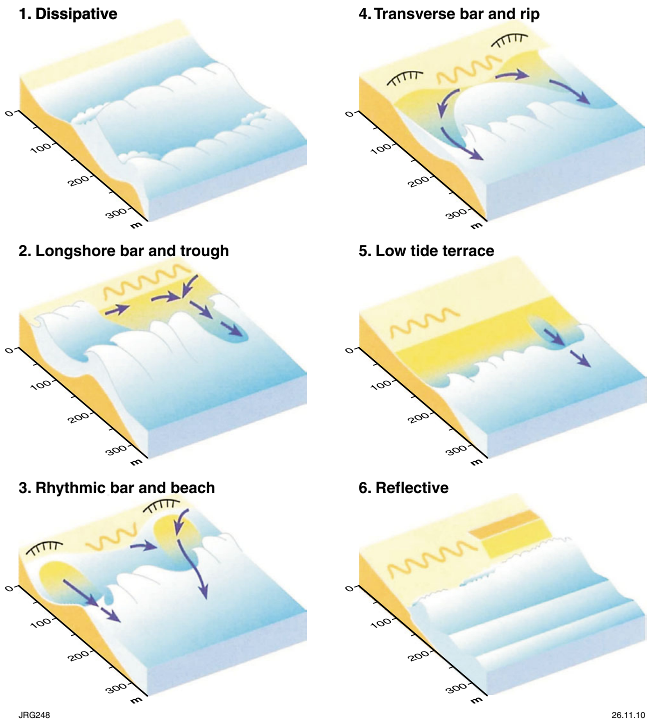

Figure 5. Classification of nearshore and foreshore morphologies (from Short and Woodroofe, 2009)

compared in a meaningful way with those from another similar section of rocky calcarenite coastline because both the classification of landform types and the modelling approach used were often too different.

The WACoast project, which covers Rottnest Island and the 1010 km of open coastline between Cape Naturaliste and Kalbarri, was completed in 2010 (Gozzard, in press a,b,c). The aim of the project was to collect fundamental, baseline geological and geomorphological data for the entire open coastline and create a highly detailed coastal geomorphological dataset using consistent landform classifications. The method adopted followed the 'Smartline' mapping concept of Sharples et al. (2009). Using this approach the coastline can be divided into a number of tidally defined zones — nearshore, foreshore, and backshore. The **nearshore** is permanently inundated by the sea and, for the purposes of the project, was defined as being immediately seawards of the foreshore zone, but may extend to an arbitrary distance of approximately 500 m offshore. The **foreshore** is the intertidal zone, including beaches. The **backshore** can be further divided into proximal and distal zones: the proximal backshore is immediately landward of the foreshore, and the distal backshore is the hinterland landward of the proximal backshore and for the purposes of the project was considered to extend an arbitrary distance of approximately 500 m inland.

Each of the four tidally defined zones was mapped using established published classifications. For example, for sandy shorelines the classification of Short (1999) was used to describe nearshore and foreshore (beach) morphologies (Fig. 5), that of Hesp (1999) to describe proximal backshore landforms (Table 1), and that of Chapman et al. (1982) to describe distal backshore barrier systems (Fig. 6). In addition, coastal exposure and the geological substrate of the coastline were also classified. From these six data layers the whole coastline can be represented in a single GIS polyline layer with multiple attributes attached to each segment.

All 468 beaches and intervening sections of rocky coastline in the study area were identified, mapped, and attributed using data collated from Short (2006). Each beach was characterized at one or more locations in the field. As well as data describing each tidally defined zone, coastal exposure, and geological substrate, four context photographs were taken at each location, two at the backshore looking left and right along the beach, and two at the proximal foreshore looking left and right along the beach.

There is also a map of the geomorphology of the coastline, which shows landforms within three kilometres inland of the coast. This map is based on field data, high-resolution orthophotographs, a high-resolution digital elevation model, and Landsat TM multispectral data.

Oblique aerial photographs of the whole coastline were taken from a fixed-wing light aeroplane. To view these photographs, an interactive map-based viewing system is being developed by GSWA that allows users to access the photographs by either overview or in detail, to zoom in and out of each photograph, and to activate an animated sequence of photographs.

Conceptual mapping of the coast

The work carried out so far on coastal compartments and sedimentary cells and WACoast provides detailed data and information on the cross-shore and alongshore structure of the coast at regional to local, site-specific scales. However, planners and managers also need a clear understanding of the processes that might present a threat to existing or future infrastructure, fisheries,

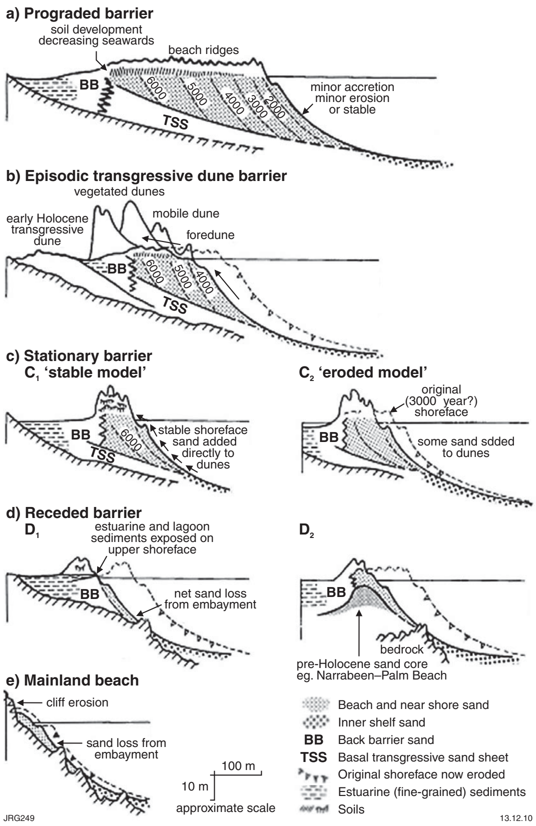

Figure 6. Conceptual models of various barrier types (from Chapman et al., 1982)

conservation areas, or marine habitats, and this can be provided in conceptual models of coastal behaviour. Concept mapping was chosen as the most effective method of modelling the collected information.

Concept maps are graphical tools for organizing and representing knowledge (Cañas et al., 2004). They use boxes or circles to represent concepts which, in the current context, are geological or geomorphological components of the coast. Connecting lines link concepts to indicate the relationships between them.

Conceptualizing coastal systems is a two-stage process. The first stage identifies the individual components (concepts) of the study area and the interactions between these components. Figure 7 is a concept map of Geraldton using data collected during the WACoast project and using CMapTools software (available from <*http://cmap.ihmc.us*>). Large-scale features, in this case two bays, a tombolo, a headland, and a river, are shown as white rectangles. The natural elements comprising each feature are shown as white ovals, and man-made features such as groynes and port facilities are shown as black rectangles. Solid lines represent sediment transport pathways and are helpful in understanding the sediment budget system. Dashed lines represent an influence link that does not involve sediment transfer.

The second stage of the process is the detailed analysis of the links between coastal components to provide a quantitative measure of the sediment budget in a particular geomorphological setting. Curtin University and the Department of Transport are jointly undertaking detailed offshore mapping to determine sediment budgets and, when available, these data will be incorporated into the concept mapping.

Potential applications

GSWA's geological and geomorphological mapping of the coastline has been done in consultation with the Department of Planning, Department of Transport, and Department of Environment and Conservation with the aim of providing consistent information readily usable by those responsible for coastal planning, risk assessment, and management. Local Government agencies have also been included in the process.

The hierarchical approach to characterizing the coast in terms of functional compartments and sediment cells has significant benefits for a wide range of applications, including risk management. Two factors are involved in assessing coastal risk: instability, or the changes taking place under existing conditions; and susceptibility, or the potential for change under different sea-level and climatic conditions. Risk can be assessed at any level in the hierarchy by combining instability and susceptibility in a matrix based on landforms.

Table 1. Terminology of backshore landforms (from Hesp, 1999)

Term	*Mode of formation*
Berm	Swash-deposited terrace, sand and/or gravel or shingle ridge
Beach ridge	Swash- and storm-wave deposit or ridge, sand and/or gravel or shingle
Storm ridge	Storm or high-energy wave-built ridge
Shingle ridge	Shingle or cobble or gravel (wave-built) ridge
Chenier	Storm wave-built ridge (sand, shell), often formed in mud-dominated environments
Beach-foredune ridge	Swash-deposited terrace or ridge with eolian capping
Foredune	Eolian sand deposited in vegetation at rear of backshore

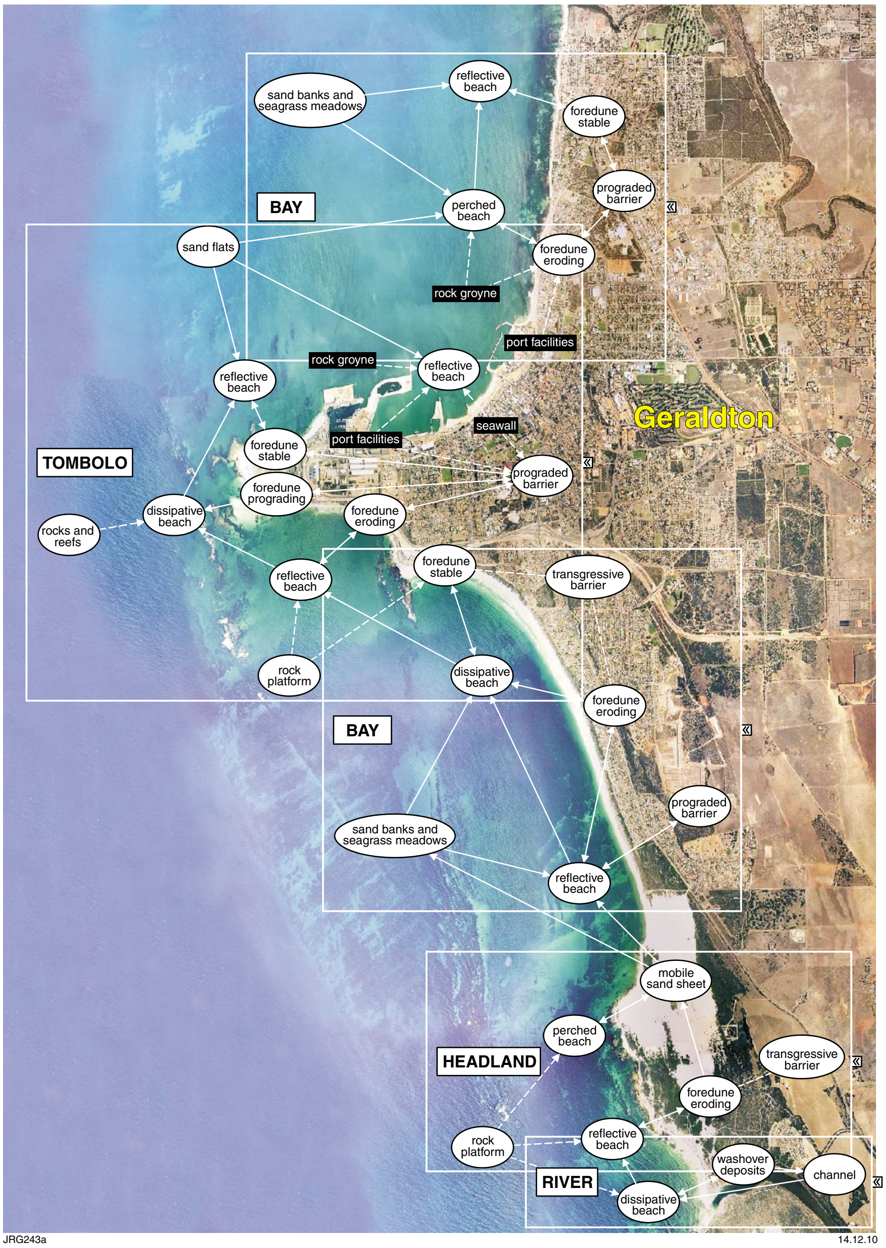

Figure 7. Concept map of the Geraldton coast. The individual components (concepts) of the coast and their interactions are shown. Natural elements are shown as white ovals and constructed features as black rectangles. Solid lines represent sediment transport pathways. Dashed lines represent influence links. The concepts occur in five natural groups represented by white rectangles.

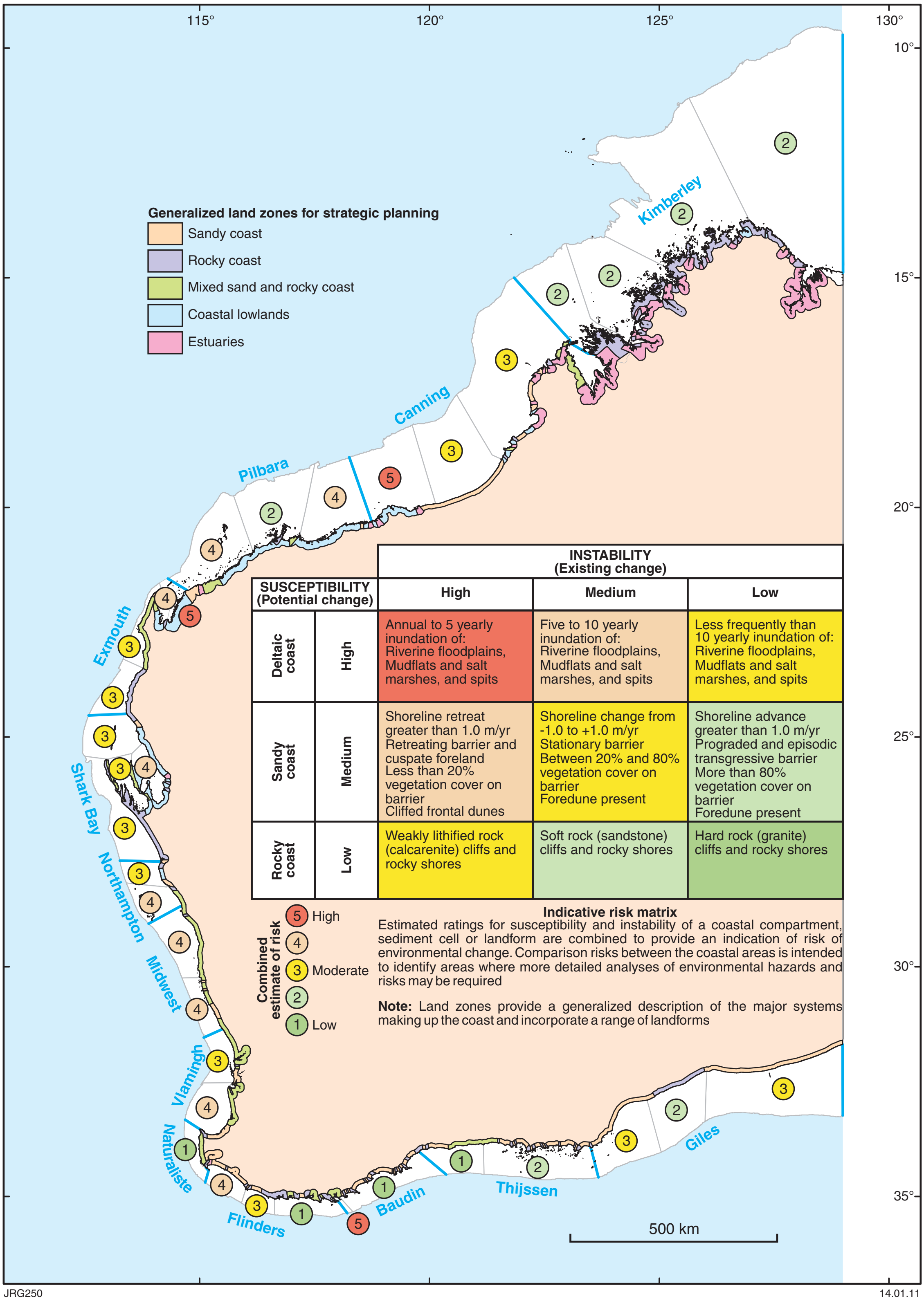

Figure 8. Coastal land zones and indicative risk for the Western Australian coastline. Data sources are GSWA, Department of Conservation, Damara Pty Ltd

At the primary compartment scale susceptibility to change is the primary factor; it relates to the structure of rocky coasts and the morphology of landforms. Instability describes the current state of the land surface and is secondary to susceptibility. Considered together, susceptibility and instability provide a broad indication of the level of potential risk (Fig. 8). A higher number represents a higher potential risk. At the most detailed levels in the sediment-cell hierarchy WACoast data can be used to develop indicative risk matrices for specific landform patterns such as, for example, episodic transgressive dune barriers and perched beaches on intertidal rock surfaces.

Other applications for the data include coastal planning for infrastructure and urban development, and natural resource management for determining marine conservation areas, sanctuary zones, and ecologically based fisheries management.

Conclusions

Coastal processes are not controlled by man-made administrative boundaries but by geology, geomorphology, meteorological, and oceanographic processes. The sediment-cell concept has become an essential part of proactive coastal management in Europe and North America, and its acceptance in Western Australia will represent a significant advance over existing approaches.

Breaking the coast up into compartments and cells based on geology, geomorphology, and marine processes provides a framework of coastal and nearshore management units that will enable managers and planners to understand coastal problems and potential solutions in terms of natural features and processes, which will allow them to anticipate the consequences of changes in coastal behaviour, whether man-made or natural, so that they will be better able to make informed strategic decisions in a wider context than has previously been the case.

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