CoastAdapt

Coastal sediments, beaches and other soft shores

Information Manual 8

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Acknowledgements

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Preface

In 2014, the National Climate Change Adaptation Research Facility (NCCARF) was commissioned by the Australian Government to produce a coastal climate risk management tool in support of coastal managers adapting to climate change and sea-level rise. This online tool, known as CoastAdapt, provides information on all aspects of coastal adaptation as well as a decision support framework. It can be accessed at www.coastadapt.com.au.

Coastal adaptation encompasses many disciplines ranging from engineering through to economics and the law. Necessarily, therefore, CoastAdapt provides information and guidance at a level that is readily accessible to non-specialists. In order to provide further detail and greater insights, the decision was made to produce a set of Information Manuals, which would provide the scientific and technical underpinning and authoritativeness of CoastAdapt. The topics for these Manuals were identified in consultation with potential users of CoastAdapt.

There are ten Information Manuals, covering all aspects of coastal adaptation, as follows:

1. Building the knowledge base for adaptation action
2. Understanding sea-level rise and climate change, and associated impacts on the coastal zone
3. Available data, datasets and derived information to support coastal hazard assessment and adaptation planning
4. Assessing the costs and benefits of coastal climate adaptation
5. Adapting to long term coastal climate risks through planning approaches and instruments
6. Legal risk. A guide to legal decision making in the face of climate change for coastal decision makers
7. Engineering solutions for coastal infrastructure
8. Coastal sediments, beaches and other soft shores
9. Community engagement
10. Climate change adaptation planning for protection of coastal ecosystems

The Information Manuals have been written and reviewed by experts in their field from around Australia and overseas. They are extensively referenced from within CoastAdapt to provide users with further information and evidence.

NCCARF would like to express its gratitude to all who contributed to the production of these Information Manuals for their support in ensuring that CoastAdapt has a foundation in robust, comprehensive and up-to-date information.

1 Introduction

This information manual, *Coastal sediments, beaches and other soft shores*, has been developed through the National Climate Change Adaptation Research Facility (NCCARF), particularly through the information and decision-support framework CoastAdapt.

1.1 Role of this manual within CoastAdapt

This manual has been written to support decision-makers when they are evaluating present and future management of soft shores, including beaches, foredunes, banks and coastal terraces, considering changing conditions due to climate change and sea-level rise. Although soft shores commonly have high amenity value in themselves, in many cases these features also provide primary protection to coastal land use and infrastructure, and their evolution is crucial to long-term coastal management and planning.

Public response to erosion of soft shores is often emotive and a powerful stimulus for coastal decision-making. However, responses to locally preserve the status quo will often act to transfer the problem elsewhere, and inappropriate actions may amplify the problem. Identification of appropriate actions requires knowledge of likely future coastal behaviour. This document provides guidance on the challenges of managing soft shores and guidance on information needs for effective coastal decision-making.

The purpose of the manual is to support decision-makers undertaking erosion hazard assessment and subsequent climate change adaptation planning.

The manual provides an overview of how coastal dynamics may be observed, interpreted and forecast in both high-level and detailed assessments. The benefits of using sediment compartments or sediment budget frameworks when evaluating regional coastal management are presented through some examples of practical applications.

1.2 How to use this manual

This manual has been prepared for coastal managers who need to make decisions about the management of soft shores in the context of potential adaptation to climate change. In particular, the role of soft coasts to provide coastal resilience is demonstrated, and approaches used for local and regional decision-making are presented.

The document structure is outlined in Table 1.1. Sections 2–4 are intended for the general reader; they describe adaptation planning on soft shores. Sections 5–7 contain most of the technical content and should be considered reference material for non-technical readers.

Table 1.1 Information manual sections

Section 2	Soft shores: Coastal management and adaptation	Outline of the management challenges presented to soft shores by climate change and the need for coastal adaptation planning
Section 3	What you can do to respond	An overview of coastal management roles and adaptation to climate change impacts for soft shores
Section 4	Tips and traps	Highlights key messages for coastal managers developing adaptation plans for soft shores
Section 5	Soft shore dynamics	Description of the characteristics and processes influencing the dynamics of soft shores
Section 6	Management of soft shores	A general approach towards adaptive coastal management on soft shores
Section 7	Using available information	A summary of some available sources of useful information for the management of soft shores

2 Soft shores: Coastal management and adaptation

2.1 Coastal sediments, beaches and other soft shores

Coastal sediments comprise pieces of solid material that may be moved due to water motion (waves or currents) but do not float (van Rijn 1998). Coastal sediments, commonly sand grains, occur along the entirety of the Australian coast, with a wide range of origins, structures, sizes and chemical compositions. Sediment may develop through weathering of rock, shells or shell fragments; organic debris; or chemical precipitation. They may be delivered to the coast by river flows, wave action or currents. At the coast, the decline of river currents as they enter the ocean and the landward push by waves determines that the coastal margin is a preferred location for coastal sediments to deposit.

Material accumulating near the coast is redistributed by waves, currents and tides. However, sediment accumulations may affect these water motions, and with sufficient feedback this provides the basis for development of coastal landforms (Woodroffe 2003). The most significant type of coastal landform-process interaction occurs at the shoreline itself, where the reduced mobility of sediment out of the water determines that accumulation often occurs horizontally, building soft shores, including beaches and low-relief coastal landforms, for example foredunes, banks and coastal terraces. Along parts of the Australian coast, these features are further mobilised by wind and colonised by vegetation, producing coastal dune formation and growth. A weakly defined boundary occurs offshore where the depth of the water limits the capacity for waves or currents to move sediment; this is termed the 'depth of closure'. The modern 'coast' is typically considered the area between the depth of closure and the crest of the coastal dune, when it is present.

Coastal sedimentary landforms are naturally dynamic, responding to variation of waves, winds, currents and water levels over a wide range of time scales. This sensitivity determines that they are among the first coastal features affected by natural or artificial change to existing conditions. The ability of soft shores to adjust to different conditions may provide a high degree of resilience to coastal change, provided land-use planning allows sufficient scope for coastal movement. The high amenity of soft shores and, often, the value of adjacent infrastructure, determine that perceived adverse impacts of coastal dynamics give high socio-political pressure for management responses. However, the spatial connections of soft shores determine that action without an appropriate understanding of coastal dynamics often leads to propagation or an increase of the problem.

This manual primarily focuses on those soft shores that occur on the open coast, which mainly occur as beaches and barriers, including coastal foredunes and dunes. Around the Australian coast, these mainly comprise sand-sized material that is not cohesive.

Some of the information contained herein is also relevant to the management of other soft shores, including estuarine shores and shoals, coastal terraces, banks and mangrove coasts. Although many of the general principles regarding management of sandy coasts also apply, these different shores are subject to different key physical and chemical processes. One of the most significant differences occurs on muddy coasts, where sediment dynamics are strongly influenced by cohesion between fine sediment particles.

2.2 Coastal planning and management

The coast is a dynamic environment, with active coastal processes including shoreline change, marine inundation and associated landform change. It is also a location of high amenity and ecological value, with pressure for competing land use. The interaction of a mobile coastal boundary and associated coastal hazards with intensive use provides challenges to coastal planning and management, further complicated by the capacity for human interventions to result in substantial coastal change.

Coastal planning refers to all types of planning that may be influenced by coastal dynamics. This may include statutory, environmental and facility planning, occurring over a wide range of time frames and spatial scales. The common factor is the need to respond to a mobile coastal boundary. Consequently, the interaction of a particular planning scale with the sensitivity of land use to coastal change affects perspectives of what comprises the coastal zone. In some cases, the effect of planned land use upon coastal dynamics may also need to be considered. In general, planning requires identification of the longest term land uses or those which are most sensitive to coastal change. Typically, times frames in the order of 100 years are used to manage freehold land. This includes potential for significant climate change and, therefore, substantial coastal dynamics.

Coastal management involves human use of the coastal zone, including marine access, recreation, adjacent land use, coastal facilities, ecosystem interactions and coastal stabilisation. As such, the various forms of coastal management may be integral tools for coastal planning, where they influence the relative distribution of assets and amenity, therefore affecting the consequences of any coastal change.

Soft shores are those coasts comprising sediments that may be moved through the hydrodynamics of waves and currents. Weather and climate variability causes movement of the shore position, which can be cyclic or progressive over time scales that vary from daily to millennia. Consequently, for any point near the coast, there is a possibility (likely or remote) of switching between marine and terrestrial conditions, which is therefore likely to substantially affect the amenity or structural requirements at that point. Examples include salinisation of coastal land, smothering of a port by alongshore sand drift (see section 5.2), or the more visual undermining of housing. Recognition of this potentially substantial change has long been incorporated into coastal management, generally through the use of risk-management principles. In many cases, this has led to the use of hazard avoidance, such as coastal setback, as the preferred form of mitigation, or setting of rarely observed design criteria, such as designing for a 100-year recurrence interval storm.

In situations where coastal mobility cannot be wholly managed through avoidance, most coastal planning approaches acknowledge that some stabilisation works may be necessary for effective management. The capacity for stabilisation of one section of coast to transfer pressure to adjacent areas of coast is normally recognised, typically established through observation of coastal dynamics and transport patterns. In order to limit economic costs and maximise coastal resilience, the strategy of nodal coastal development – where development is necessary – is preferred over piecemeal or continuous development.

2.3 Climate change and coastal adaptation

Climate changes, primarily as a result of increased greenhouse gas emissions, are projected to occur over the forthcoming centuries. These changes overlay historic variability of climate conditions. The combination of progressive change and variability is anticipated to increase the occurrence of unusual climate events (in the direction of climate trends) and ultimately cause conditions outside the range of the historic record.

Projected climate changes include sea-level rise and alteration of weather systems. Some of these impacts are described in greater detail in Information Manual 2: Understanding sea-level rise, with the anticipated response typically being one of increased tendency of progressive erosion. Uncertainty regarding how the coast will respond to climate change and regarding the projections themselves provides challenges to coastal planning.

Use of adaptive planning principles has been promulgated as the most effective means of managing coastal change in the face of high future uncertainty and high pressure for coastal use. Planning instruments to facilitate coastal adaptation are discussed in Information Manual 7: Engineering solutions.

2.4 Why are soft shores so important to coastal planning and adaptation?

Soft shores, including beaches, foredunes, banks and coastal terraces, are the features first affected by coastal dynamics, including climate change effects due to sea-level rise and change in weather systems. The processes of erosion and accretion may seriously affect coastal land use and amenity, from direct impacts on coastal infrastructure and other built assets through to collapse of ecosystem services associated with susceptible coastal landforms, such as fringing wetlands and coastal dunefields. Some changes to soft shores occur over long to very long time frames (decades to millennia), with substantial response expected to occur due to projected climate changes. Present-day variability of soft shores and their sensitivity to climate change determine that an understanding of coastal dynamics is essential to coastal planning and adaptation.

Coastal dynamics often demonstrate strong spatial relationships, which may result in the propagation or migration of coastal management issues. Intervention using traditional coastal engineering means (e.g. groynes and seawalls) may therefore have wider consequences than intended or may even exacerbate problems; they therefore require careful application. However, the ability of soft shores to adjust configuration in response to changing conditions may also provide opportunity for effective planning and adaptation, as careful site selection and coastal management may provide high coastal resilience.

Effective management of coastal dynamics may have important consequences. Although soft shores often have high amenity value in themselves, most clearly highlighted at the Gold Coast, Queensland, the perceived state of the coast has a strong influence on business and real estate investment. Adverse impacts of coastal dynamics commonly provide high socio-political impetus for decision-making, as seen in Seabird, Western Australia, but may also create community conflict where there are perceptions of a select group benefiting from the public purse (e.g. Glenelg West Beach Boat Ramp, SA), or where the intervention is likely to transfer problems within and between communities and local councils (e.g. Wonnerup, WA; Old Bar, NSW).

In many cases, coastal interventions have resulted in the transfer of erosion or accretion issues to the adjacent coast, which may have implications for neighbouring land managers. In some locations, this has resulted in expensive ongoing sand-bypassing activities to maintain navigation channels and limit downdrift impact, such as at Tweed River entrance, New South Wales; Nerang River entrance, Queensland; Mandurah and Dawesville channels, Western Australia; and Glenelg West Beach Boat Ramp, South Australia. Some of the questions regarding liability for transferred erosion impacts are discussed in Information Manual 6: Legal risk.

2.5 References

Van Rijn, L. C., 1998: *Principles of coastal morphology*. Aqua Publications, 730 pp.

Woodroffe, C. D., 2003: *Coasts: form, process and evolution*. Cambridge University Press, 640 pp.

3 What you can do to respond

3.1 Introduction

Coastal managers can provide essential input into the evaluation and interpretation of their soft shores regardless of their technical knowledge, data availability or budget. This may be achieved by developing an improved understanding of how the coast changes and a refined understanding of how coastal users may interact with possible future changes.

Practical steps to improve coastal planning and adaptation on soft shores may vary considerably between agencies, depending on their level of activity for different coastal management roles. The steps may typically include:

- data and information collection and storage
- study scoping and validation
- policy definition and implementation
- development planning and approvals
- facility provision and management.

In general, the capacity for successful adaptation is improved by applying the principles of resilience and flexibility to these steps. Further, the potential importance of locally relevant information and processes should be recognised when applying or interpreting generic systems of analysis or management.

3.2 Data and information collection and storage

Coastal data and information may be collected for a diverse range of coastal management issues on soft shores. In the context of this manual, a primary objective is to describe geomorphic change (coastal dynamics). However, data and information may also be relevant to human activities (beach use, navigation), environmental values (fauna, benthic vegetation, pollution) or coastal hazards (safe beach use, inundation, threat to infrastructure). This diversity creates various perspectives of what parameters should be monitored and therefore what is appropriate data or information for each objective.

In many cases, coastal parameters that are appropriately monitored for one objective may be useful for another target, although the frequency or coverage of monitoring may be different. The monitoring approach is normally determined by the agency with the greatest need for data at high frequency and broad spatial coverage. Other agencies rely on the lead agency to collect the information and then obtain a relevant subset through purchase or data agreements. Agency needs and pressures therefore require careful dialogue between agencies conducting monitoring (and data users) to limit duplication of effort and support wide application of coastal data.

The coastal monitoring system most applicable to management of soft shores focuses on identification of erosion, inundation and infrastructure risks. It operates within a wider coastal monitoring framework, which may include activities by federal and state governments and academic or industry agencies. International monitoring, such as satellite-based monitoring, is typically supplementary to this framework. The most common forms of data collection use a measure of the coastal position, winds, wave conditions and water levels – primarily because these data address numerical model needs.

Approaches towards monitoring of coastal erosion vary geographically (from the scale of nation or state down to local government area and local scale) and between types of institution (local government, state government, planning or engineering). However, the most important factor influencing a coastal monitoring approach is proximity of assets to the coastal hazard zone, which is itself a function of institutional practices for coastal hazard risk mitigation (see section 6.4). Depending on the proximity of assets of interest to the coast, monitoring may be to confirm that existing management practices remain valid, to estimate the time available before changing management, to identify the existing likelihood of hazard or to indicate whether certain management actions should be triggered.

3.3 Study scoping and validation

Local coastal managers are commonly responsible for commissioning professional coastal studies, including data analyses or modelling, which are then used to support coastal decision-making. This is a very important role, as:

1. definition of the study scope predetermines the study range and therefore potentially its outcomes
2. information provided by the coastal manager often affects study methodology and therefore outcomes
3. the context in which the study may be used or misused need to be understood by the coastal manager, particularly for any applications outside the scope of the study.

In many cases, local coastal managers defer to professionals in the definition of scope, information requirements and interpretation of study outcomes. However, commercial and time pressures on professionals mean that they typically apply a highly focused problem-solving approach. The local coastal manager is often in a better position to provide a wider perspective on the study needs, its validity and potential application.

It is commercially advantageous for external consultants to apply generic frameworks to a limited amount of information and to conduct minimal field work. This gives high potential for a mismatch of study scope to the problem being evaluated. Care should be taken by the coastal manager to ensure that the study approach is supported by available information. However, as there is a direct link between the study cost and the amount of information used to develop the study, provision of extraneous information to a consultant may have implications for the study budget.

The best action that can be undertaken by coastal managers is to develop a greater understanding of their coast, including establishing a history of its management. Where possible, this should be supported by a coastal monitoring system, which may include informal monitoring such as a regular site photographs. Typically, a local coastal manager will have an understanding of the coast that is built upon more frequent observations over a longer period and a wider area than considered by an external professional. In almost all cases, the historic behaviour is known for far longer than coastal measurements are available.

A schematic context for evaluating the scope of coastal studies, the information provided to support the studies and other information available for validation is shown by Figure 3.1. The selection of an analysis framework affects the study budget and determines what information is used (and therefore what information is neglected) and is available to validate the study outcomes.

Review of professional assessments by local coastal managers should ask:

- Are the study mechanisms of coastal change indicated by the study supported by the observed sequence of change (timing and pathways)?
- Is the coastal behaviour suggested by the study consistent with observations over longer time frames?
- Do the study results suggest behaviour that is inconsistent with the wider area?
- Are there other potential uses (or misuses) of the study?

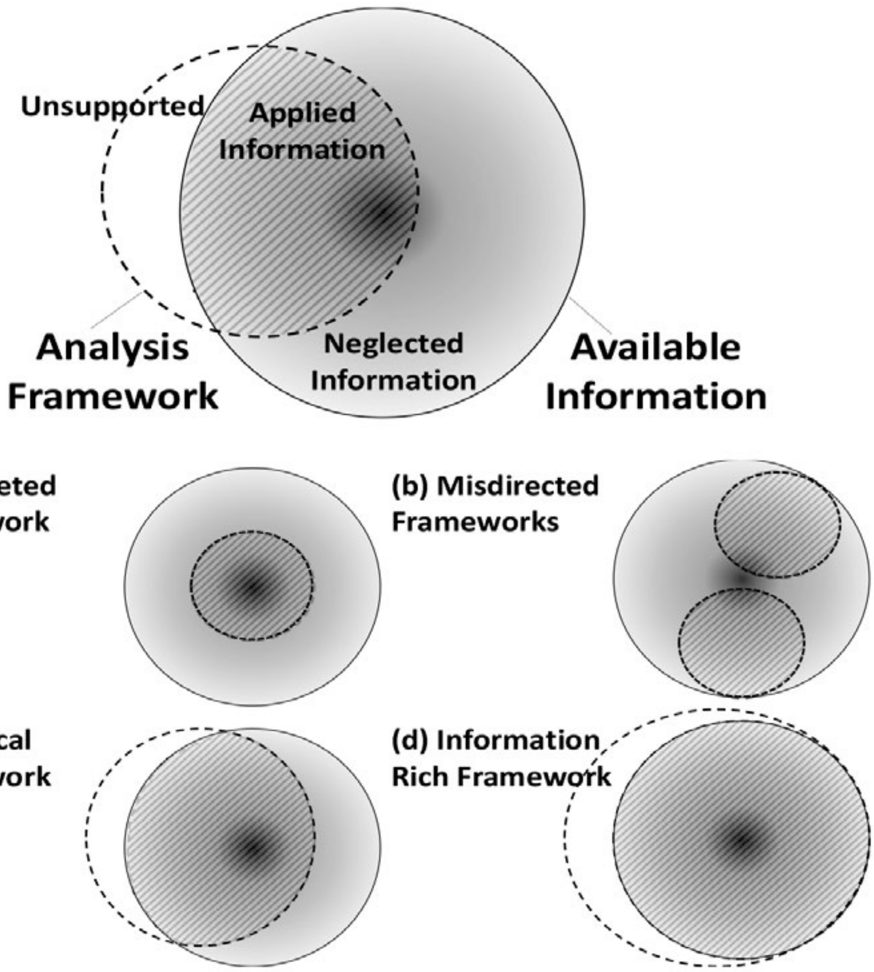

Figure 3.1 Information and analysis frameworks to assist evaluation of a study approach.

Note: Coastal managers should develop an awareness of neglected information and sections of the analysis framework that are unsupported. Targeted analysis frameworks are the most cost-effective, and information-rich analysis frameworks are the most comprehensive. Source: Developed by the author.

3.4 Policy definition and implementation, development planning and approvals

Major roles of coastal managers include policy definition and implementation, development planning and approvals.

To date, Australian coastal policy has been in the enviable position where development is sufficiently sparse that erosion hazard avoidance can be retained as the preferred means of mitigation, with comparatively limited use of engineering works to transfer or protect against erosion. However, as demonstrated in other parts of the world, increased erosion pressure, as may be expected due to sea-level rise, tends to cause increased proliferation of coastal protection works (Nicholls et al. 2013, Melius and Caldwell 2015). In some cases, broad planning strategies based on development renewal may need to be applied (Kousky 2014), but in most cases the shift from hazard avoidance to tolerance or use of protective works is largely a one-way change. By good planning and appropriate use of setbacks, there is great scope to widely delay this transition in Australia.

As a first step, it is generally appropriate for coastal managers to develop a strategic coastal adaptation plan. This involves:

- identifying the existing coastal management strategy
- reviewing whether the strategy is likely to remain effective in the future

- determining an alternative management strategy that may be appropriate under future conditions
- developing an indicator of when to change management strategy.

Although these steps are essentially straightforward, the implementation is inherently more complex. Key difficulties develop due to significant variation in coastal behaviour between locations over a range of different temporal and spatial scales. This means that generic frameworks will come up against almost as many exceptions to the rule as solvable problems in coastal erosion management.

The use of widely applied coastal strategies is challenged where the variability of erosion pressure along the coast is substantial, whether due to changing morphology or to the influence that coastal management activities have upon alongshore sediment supply and transport. Implicitly, this suggests that coastal management policies may need to make better use of coastal science, reducing sensitivity to coastal change through appropriate land use and intelligent siting and design of infrastructure. Revision and clarification of existing coastal planning policies is likely to be required to meet this need, although it is clear that hazard avoidance should remain a preferred strategy for hazard mitigation where it is feasible (WAPC 2013).

A shift towards adaptive management frameworks is widely considered to provide the most viable means of dealing with uncertainty, especially due to the anticipated responses to sea-level rise. This requires a significantly greater incorporation of coastal monitoring into coastal management activities, with decision-making frameworks developed to include monitoring-based triggers for coastal management. A key element of this framework must be the ability to distinguish between cyclic and progressive coastal change, to avoid short-term reactive responses or expensive temporary fixes.

The need to improve coastal policy through the inclusion of better science extends to development planning and approvals. A challenge presented by coastal dynamics, particularly in a changing coastal climate, is the reduced ability to use precedential coastal management practices for adjacent land uses or those within the same jurisdiction.

In many cases, preservation of the status quo with respect to existing land use will result in increased pressure elsewhere. A wider appreciation of consequences is necessary when providing development approvals, and an increased capacity to make tough socio-political decisions is likely to be required.

3.5 Facility provision and management

A necessary role for coastal managers is to provide facilities on the coast that support a wide range of human activities. However:

- potential conflicts may arise when protecting or relocating facilities on an eroding coast, particularly with decreasing areas of relative coastal stability
- the amount of effort and expense required to manage or maintain facilities increases as they are closer to the shore.

For these reasons, the capacity to effectively undertake coastal adaptation is significantly assisted by minimising the quantity and value of assets and infrastructure that may be exposed to coastal erosion hazard (see section 6.3). In general, providing coastal facilities only when necessary is the best approach towards promoting a resilient coast.

On soft shores, the ability to transfer erosion pressure along the coast means that adaptive capacity is greater when development is both further from the coast and sparser along the coast. As mentioned above, the approach of nodal coastal development is therefore preferable to continuous or 'strip' coastal development.

When a facility is necessarily located in the coastal zone, its key characteristics affecting adaptive capacity include:

- the anticipated structure life
- the capacity to cope with changing conditions, including practical limits for increased maintenance needs to support the existing facility
- possible pathways for structural modification, including new works to cope with changing conditions.

These pathways for adaptation at a facility scale are discussed in Information Manual 7: Engineering solutions.

3.6 References and further reading

Kousky, C., 2014: Managing shoreline retreat: A US perspective. *Clim. Change*, **124**, 9–20.

Melius, M. L., and M. R. Caldwell, 2015: California coastal armoring report: Managing coastal armoring and climate change adaptation in the 21st Century. Stanford Law School. Accessed 4 May 2016. [Available online at https://law.stanford.edu/publications/california-coastal-armoring-report-managing-coastal-armoring-and-climate-change-adaptation-in-the-21st-century/].

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4 Tips and traps

Several topics discussed in this manual contain key points for coastal managers. These are highlighted here as a set of 'tips and traps'.

TIP Expect (and possibly accept!) erosion and loss of land

Coastal dynamics are developed through the movement of sediment, creating both accretion and erosion. Although these are rarely balanced exactly, stabilisation of areas subject to erosion will reduce the occurrence of stable or accreting shorelines and may truncate sediment pathways which support the recovery of soft shores that have been subject to erosion events. Sea-level rise is further anticipated to tip the balance towards greater erosion, producing net recession of the coast and loss of land.

TRAP Dominance of policy solutions

Coastal planning policy has been developed around the strategy of avoiding erosion hazard; therefore, analysis techniques are appropriate for assets located some distance from the coast. The perceived need to be compliant with policy should not prevent the development and application of more advanced assessment techniques suitable for assets closer to shore.

TIP Work with nature as much as possible

Natural movements of sediment are substantial, both cross-shore and alongshore, and the costs of engineering works to achieve equivalent results could be financially implausible. Working with the natural pathways and variability of sediment dynamics provides the most effective means of managing soft shores.

TRAP Over-reliance on coastal modelling

Coastal modelling is a useful tool for coastal management decision-making. However, the relative expense of modelling and its associated uncertainty should be considered carefully, particularly when addressing simple questions. Model outcomes that state the obvious, for example 'further landward is less prone to erosion', are of little benefit. Cost-effectiveness should be evaluated carefully, as high costs may be incurred for small refinements of model uncertainty. Use modelling appropriately.

TIP Cope with changing policy and practices

Both natural variability of coastal dynamics and projected changes of climate are expected to place pressure on existing coastal management policies and practices. Increased flexibility of coastal management is required, potentially through the increased use of adaptive management frameworks and incorporation of greater use of coastal science and monitoring systems. Long lead times required to change policy and practice should be recognised at institutional levels.

TRAP Ignoring rock control – at one's own peril

The underlying geological framework may provide considerable influence on the pathways and distribution of coastal sediments. This can have impact at all scales, from coastal compartments down to storm erosion-recovery patterns. All coastal studies should carefully consider how the presence of rock may affect the processes inherent within the study techniques. Rock may provide a cross-shore limit to erosion in many locations.

TIP Use preferred coastal management strategies

Coastal dynamics are developed through backwards, forwards and alongshore movements of the shoreline, making the use of foreshore setbacks the most preferred means of mitigating coastal erosion hazard. However, in practice, active coastal land use requires some connections to the coast, which may need local coastal protection. The ability to manage pressure on these sites is affected by the extent of protection alongshore and its distance cross-shore. Consequently, preference should be given to strategies of nodal development and of limiting interruptions to alongshore sediment transport.

TRAP Developing blanket policies

Coastal management principles are often developed on a jurisdictional basis, using conservative assessment techniques such as the spatially uniform Bruun Rule. Natural coastal variability along the shore is high, whether due to compartment structure or sediment pathways; therefore, a broadbrush approach may limit the distinction between sites that are naturally more or less resilient in response to erosion pressure. More intelligent placement of coastal assets requires better identification of coastal variability.

TIP Develop a greater understanding of your coast

Each section of coast is unique. Consequently, coastal decision-making may be significantly improved through a strong local understanding, which may be developed through observation, monitoring and recording of coastal history. This knowledge should be used as a basis when engaging external professionals and is important when setting study scopes, providing information or interpreting study outcomes.

5 Soft shore dynamics

5.1 Coast types

Difference in forcing conditions, sediment type and the adjacent geological and hydrological frameworks determine that there are a number of ways in which coasts respond to change. The resulting different sets of coastal landforms and their interactions determine coast types. Although all coast types may occur around the majority of the Australian coast, their distribution can be broadly related to the marine climate regimes (IMCRA 1998).

Five broad classes of sedimentary coast occur around Australia, comprising more than 70% of the coastline:

- sandy beaches and dunes
- headland and reef-controlled beaches
- barrier systems
- tidal floodplains and mangrove coasts
- estuarine shores.

Within each of these classes, the behaviour may vary significantly due to differences in forcing or sedimentary characteristics. However, unifying patterns have been established for these classes, with the range of behaviour related to a few parameters. Beach types (the top two classes) have been related to wave and tide conditions (Short 2006, Figure 5.1). Estuary types have been related to waves, tides and streamflow (Boyd et al. 1992, Heap et al. 2001), although the structure and dynamics also show high dependence on geomorphic origins (Perillo and Piccolo 2011).

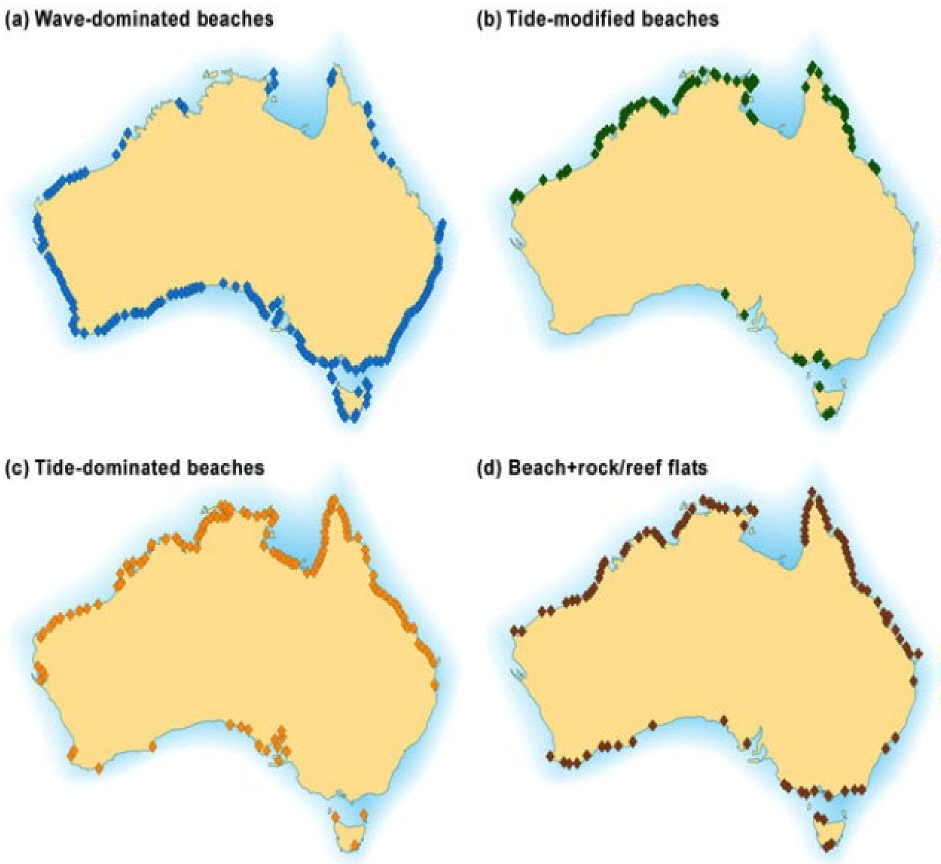


Figure 5.1. Australia beach-types distribution Note: Wave-dominated beaches prevail around the southern half of the continent, while tide-modified and tide-dominated are more prevalent across the northern half. Beaches fronted by exposed rock (at the intertidal level) can occur right round the coast, while those fronted by fringing coral reefs are restricted to the tropical northern half. Source: Short 2006; Short and Woodroffe 2009.

5.1.1 Sandy beaches

Sandy beaches and dunes occur where there is abundant mobile sediment accumulated near the coast, which is able to be moved by waves and currents (Short 2006). Typically, this coast type is responsive to variation of forcing conditions, particularly waves and water levels, but has a tendency to return to a position that is characteristic of the average conditions experienced. A unifying conceptual model for beach profiles has been developed based on particle size and density, wave height and tide range (Wright and Short 1984, Masselink and Short 1993). Coastal dynamics are mainly related to changes in the cross-shore (see section 5.2), particularly through storm erosion and recovery cycles. Variation to wave direction causes alongshore sediment transport, but often produces limited erosion or accretion, as the transport is nearly constant along the shore, due to gradual changes in beach profile and orientation. Over geologic time, there have been periods of mass onshore transport of sediment associated with glacial and interglacial cycles of sea-level change (McArthur and Bettenay 1974; Roy and Thom 1981; Roy et al. 1994, 1997).

The responsive nature of sandy beaches under changing conditions means that shoreline positions can only persist if there is an overall balance of sediment transported into and out of the beach (i.e. dynamic stability). This can even occur with very high rates of alongshore transport, provided there is a net balance.

5.1.2 Rock-controlled beaches

These beaches occur where a rocky feature provides local retention of mobile sediment by partly restricting or effectively preventing alongshore sediment transport. Features may intercept the shoreline (e.g. rocky headlands), limit the area of beach exposed to wave action (e.g. perched beaches), or provide local sheltering from waves (e.g. reef-protected beaches). Although the profile shape and cross-shore dynamics of rock-controlled beaches are sometimes similar to that of sandy beaches (Short and Masselink 1999), in many cases there is additional capacity for short-term variation due to alongshore transport, occurring as beach rotation on headland controlled beaches (Ranasinghe et al. 2004) or as instability on reef-sheltered forelands (Sanderson 1997).

The nature of rock-controlled beaches generally means that the capacity for alongshore transport is determined by the volume of sediment retained. This provides a way of self-stabilisation and may support persistence of sedimentary features even through periods of very low sediment supply. Headland bypassing may lead to a net loss of sediment in some situations. Reef-sheltered forelands are not subject to this form of self-stabilisation and therefore are often more dynamic than other types of rock-controlled beach.

5.1.3 Barrier systems

Barrier systems develop where there is deposition of sediment at the coast through marine or aeolian (wind-driven) processes to form a ridge that is higher than the ground to landward. These features are commonly associated with sandy beaches, when developed through dune building (Short 2010), although other processes may form coastal barriers, including spit growth, storm wave deposits or response to rock features, creating a beach and barrier system that is distinct from a sandy beach. Very large barrier systems in Australia include those in Gippsland, Victoria; Coorong in South Australia; and the massive dune barrier islands of south-east Queensland. Sand ridges occur as localised barriers (including cheniers) in tidal floodplains of the Pilbara and Gulf of Carpentaria and along many of the estuary shores around the southern half of Australia. The barrier origin is often a significant factor in determining how it may respond to interventions or future change, typically requiring stratigraphic analysis to determine. A classification scheme for barrier structures based on landform type and determined by drilling and dating was developed for the New South Wales coast (Chapman et al. 1982, Roy et al. 1994). This classification may provide a basis for understanding the availability of sediment for future shoreline changes as forcing conditions change.

Dynamics of barrier systems are often strongly related to the cross-shore and alongshore dynamics of beach systems immediately adjacent to them. However, they may also be subject to additional mobility under high wave or water level conditions, with overtopping of the barrier potentially causing barrier migration or breaching (Donnelly 2006). The stability of barrier systems is therefore affected heavily by projected climate changes to extreme storm events and sea-level rise. However, under conditions of adequate sediment supply, the barrier may simply adjust by growing in elevation.

The continuity of barrier systems is influenced by the nature of alongshore sediment supply and transport, balanced by the ability of either tidal or fluvial processes to develop and sustain channels. Channel-forming processes are enhanced in regions of high tidal range or wet season flood discharge (FitzGerald 1996, Eliot and Eliot 2012).

5.1.4 Tidal floodplains and mangrove coasts

Tidal floodplains occur where the geomorphic origin (due to sea-level history), and modern low wave energy supports building of low relief coastal landforms that may be flanked or overtopped by high tides. This occurs extensively along the northern coast of Australia, from Carnarvon to Weipa, and is further supported by mangrove colonisation (Davies and Woodroffe 2010). Smaller scale tidal floodplains also occur for the remainder of the Australian coast, particularly near estuaries.

Coastal dynamics are developed through the interaction of tidal waters with the adjacent landforms, requiring channel structures that are capable of transporting sediment in either direction to convey the water both landward and seaward across the intertidal area. The dynamics of tidal floodplains can be extremely complex, often displaying interactions with the vegetation, variability of sediment composition or the influence of run-off pathways (Fagherazzi et al. 2008, Perillo 2009).

Tidal floodplains are generally expected to move upward in elevation with sea-level rise, with the sediment required to cause this adjustment being drawn from the coast via tidal channels or supplied from river run-off (Woodroffe et al. 1993, FitzGerald et al. 2008). On mangrove coasts, part of this adjustment may be provided by the detritus produced by the mangroves and associated fauna. However, existing coastal lagoons on parts of the coast and areas of observed wetland salinisation (Winn et al. 2006) suggest that in some cases an alternate response to sea-level rise will be drowning of the tidal floodplains (Semeniuk 1996).

5.1.5 Estuarine shores

Estuaries are the interface between fluvial and marine systems, and therefore may be subject to the delivery and movement of sediment by waves, tides and run-off. The presence of estuaries is strongly related to the relative sea level, and therefore they are relatively recent features in a geomorphic sense. The location of the majority of present-day estuaries was determined by the modern sea level, which steadied approximately (within several metres) 6,000 years ago (Woodroffe et al. 1993, Lambeck and Chappell 2001). They have subsequently evolved in response to the deposition of river sediments, influx of coastal sediment, colonisation by vegetation and human interventions. This pattern provides a basis for an 'evolutionary' classification scheme, which describes the extent to which the original basin has infilled (Figure 5.2, Ryan et al. 2003). A key difference is related to whether the estuary primarily receives sediment supply from the coast (i.e. it is a sediment sink to the wider coast) or whether it supplies terrigenous or estuarine sediments to the coast.

The basic model for evolution is further complicated by differences in forcing conditions, with coastal waterways showing an array of forms that lend themselves to a classification based on waves, tides and river run-off (Roy 1984, Dalrymple et al. 1992). Application of this classification to the Australian coast has been undertaken and is further supported by the development of conceptual models related to the geomorphology, which describe typical hydrodynamics and sediment dynamics (Figure 5.3, Heap et al. 2001, Ryan et al. 2003).

Although the nature of sediment dynamics may vary considerably between different estuarine types, they commonly have much lower wave action and often reduced tidal conditions than the open coast. This supports greater stability of vegetation, both on the margins and the bed of the estuary itself, and therefore may provide far greater interplay between vegetation and hydrodynamics. Estuarine wetlands, including sedge communities, provide significant habitats, particularly for shellfish and waterbirds. The differences in sediment

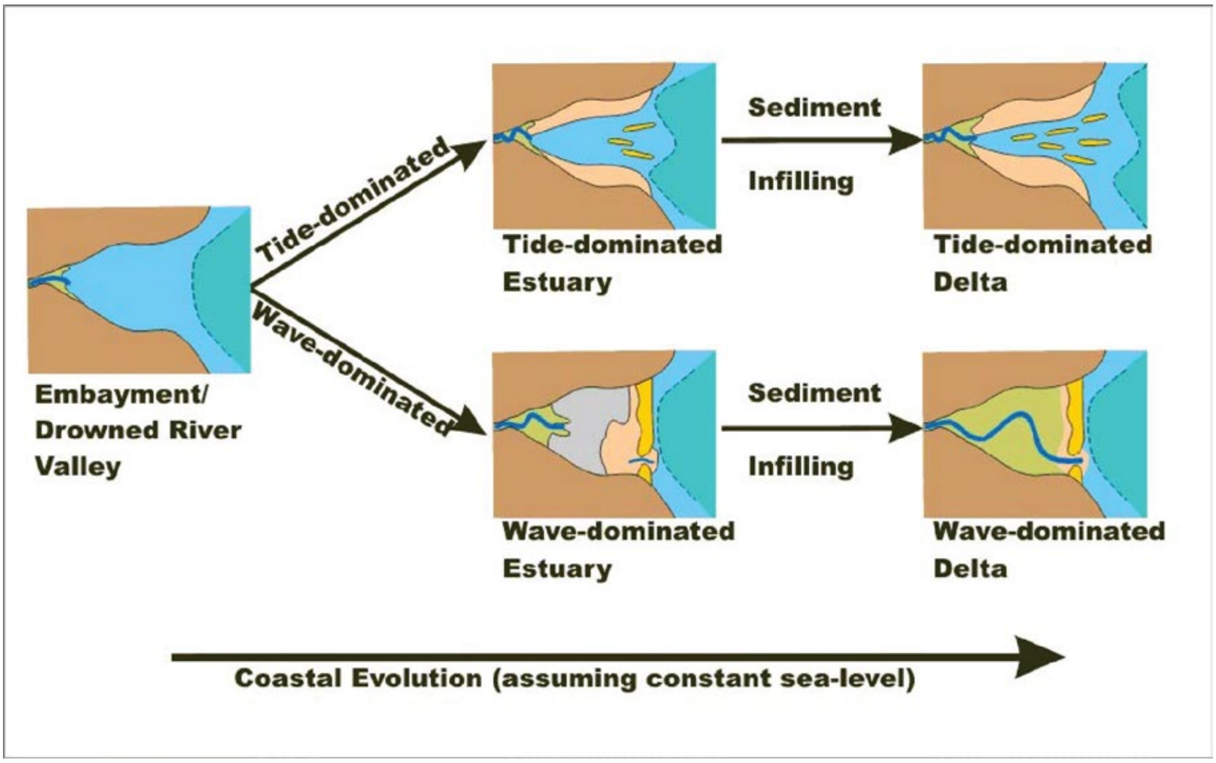


Figure 5.2 Evolutionary 'family tree' for Australian coastal waterways Note: This shows infill pathways for wave-dominated and tide-dominated systems (coastal lagoons, strandplain-associated creeks and tidal creeks have been omitted due to low fluvial sediment input). Source: Ryan et al. 2003 © Commonwealth of Australia (Geoscience Australia) 2016.

origins, chemical properties and productivity support greater presence of cohesive sediments than typically occur on the open coast. This manual focuses on coastal sediments; therefore, decision-makers will require further information for interpretation when considering the management of estuarine shores with cohesive sediments.

Estuarine shores are often more complex than open coast beaches, as differences in wave fetch across estuary basins may provide substantial local variation of wave climate. The dynamics are further complicated by the roles of vegetation and currents, including eddy structures (Hunter and Hearn 1987). Beaches inside estuaries often differ in form and structure from those on the open coast (Nordstrom and Roman 1992, Freire et al. 2013); for example, a widely occurring characteristic on estuarine beaches is the presence of subtidal terraces. These can physically separate erosion and recovery sediment pathways and often result in limited beach recovery after storm events, unless there is a sediment source (possibly riverine) that is active under prevailing conditions.

The expected response to estuarine systems as a result of sea-level rise is one of increased sedimentation from marine sources. This is anticipated to cause increased erosion stress on the coasts adjacent to estuary entrances. However, as demonstrated by the existing morphologies, this is not always expected to keep pace with the rate of sea-level rise, and for particularly constrained entrances the change is likely to be mainly related to deepening of the estuaries themselves (FitzGerald et al. 2008).

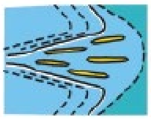
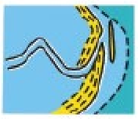
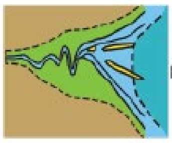
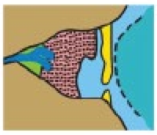
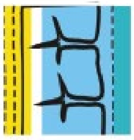
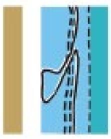
Type of Coastal Environment	Sediment Trapping Efficiency	Turbidity	Circulation	Habitat Loss due to Sedimentation
 Tide-dominated Delta	Low	Naturally High	Well Mixed	Low Risk
 Wave-dominated Delta	Low	Naturally Low	Salt Wedge/ Partially Mixed	Low Risk
 Tide-dominated Estuary	Moderate	Naturally High	Well Mixed	Some Risk
 Wave-dominated Estuary	High	Naturally Low	Salt Wedge/ Partially Mixed	High Risk
 Tidal Flats	Low	Naturally High	Well Mixed	Low Risk
 Strand Plains	Low	Naturally Low	Negative/ Salt Wedge/ Partially Mixed	Low Risk

Figure 5.3 Estuarine systems in relation to some key management implications. Source: Heap et al. 2001 © Commonwealth of Australia (Geoscience Australia) 2016.

5.2 Causes of coastal dynamics

Soft shores comprise coastal sediments, which by definition may be moved by waves, winds and currents. Coastal dynamics are a result of three-dimensional sediment movements over time, driven by waves, currents and winds, which are themselves influenced by the shape of the sediment mass, being the landform (or landform assemblage) that defines the configuration of any given section of coast.

Landforms may persist over time either when their features (e.g. beach slope or aspect) limit the capacity for sediment transport (stability) or when similar rates of sediment supply to and loss from the landform occur over a perspective timescale, typically annual (dynamic stability). However, forcing conditions experienced at the coast vary continuously through changes in weather, tides and human or ecological processes. Where varied conditions cause opposing directions of transport, a state of equilibrium can be reached if transport in opposite directions is balanced. Equilibrium is mostly a theoretical concept, as variation of forcing conditions occurs over many different scales, from the effect of a single wave, through daily or seasonal fluctuations, to long-term changes in climate, but it is a useful tool to convey understanding of coastal system behaviour. In practice, a position of dynamic equilibrium can often be considered for coastal landforms, which is a modal configuration about which fluctuations (e.g. shoreline position) occur. A resilient soft coast may be one in which the modal position of the shoreline is sustained, even where substantial variation occurs due to forcing conditions.

The concepts of equilibrium and sediment transport are often considered either relative to coastal cross-section or relative to coastal plan form, termed cross-shore or alongshore behaviour respectively (Figure 5.4).

The concept of equilibrium has been variously applied to describe the way in which landform structure is related to the hydrodynamics, including the effects of waves, water levels and currents. Key hydrodynamic characteristics may include:

- wave energy (parameterised by wave height and period)
- wave direction (incoming direction and spread)
- water level, which may include tide, mean sea level, storm surge and long wave effects
- currents (including speed and direction).

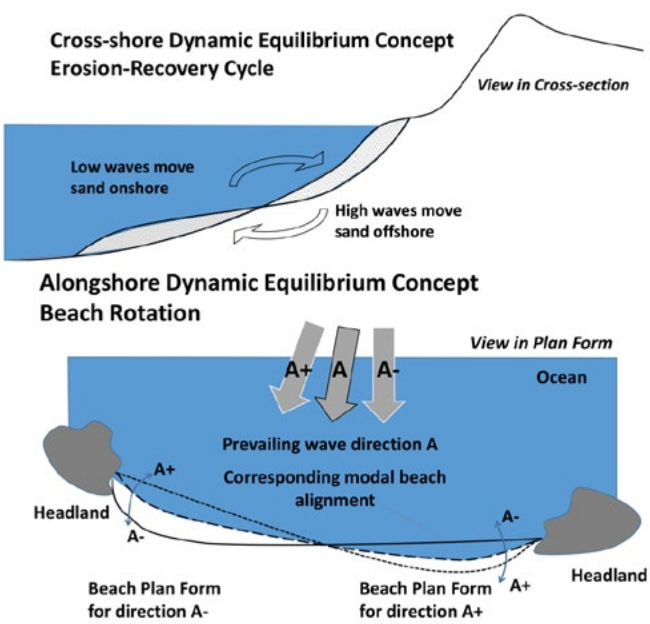


Figure 5.4 Cross-shore and alongshore concepts of dynamic equilibrium. Source: Developed by the author.

In a general case, the cross-shore configuration is mainly influenced by the wave energy and the water level range (Wright and Short 1984, Masselink and Short 1993). The alongshore configuration can most generally be associated with the wave direction, with a 'stable' shore typically facing straight towards the modal wave direction. Shelter provided by rock headlands, reefs or the influence of seabed features on wave conditions may alter the modal direction, providing characteristic curvilinear shorelines, including zeta-form bays and cuspate forelands (Silvester et al. 1980, Woodroffe 2003). Nearshore currents may also influence both the cross-shore and alongshore configuration, although this influence varies substantially according to the nature of the current and, in most situations, is a secondary process.

Sediment transport involves interaction of hydrodynamic forces (waves, water levels and currents) with bodies of sediment. This interaction leads to morphodynamic adjustment of form and process (Wright and Thom 1977, Wright 1995). Changes in hydrodynamic energy will alter the rate and direction that sediment is entrained, transported and deposited. Consequently, acute coastal change is commonly associated with severe storms, which have high wave energy; these storms can approach from a direction which differs markedly from modal conditions and occur at unusually high water levels through associated storm surge. However, coastal change may be induced by all changes in coastal forcing, including the effects of tide, weather systems or seasonal fluctuations, as well as inter-annual fluctuations such as those associated with El Niño–Southern Oscillation (ENSO) events or projected long-term climate change.

Coastal sediment transport tends to alter the coast by redistributing sediment in the cross-shore and alongshore directions. This change is typically towards a new configuration that has greater stability (resistance to change) under the active conditions. In many cases, conditions are not sustained for a long enough duration to wholly achieve stability, and therefore coastal morphodynamics typically involves constantly adjusting sediment redistribution, often cyclic in nature. As redistribution affects sediment transport for subsequent conditions, coastal behaviour is influenced by the sequence of forcing conditions.

A resilient shore is one that has the capacity to fluctuate around a modal position, implying that sediment availability and transport within the coastal system are sufficient for the coast to accommodate changes in forcing conditions. This implies that the coastal configuration developed under unusual conditions (typically storms) supports change towards the modal position under prevailing conditions. Substantial movements of sediment outside the influence of prevailing conditions, whether alongshore or cross-shore, therefore cause coastal change. If there is loss of sediment availability following a cycle of storm and post-storm recovery, the position of the shoreline will recede landward. Conversely, the shore will move seaward, or accrete, if there is an increase of available sediment within the system. However, when considered at a larger scale and across the entire depth of the active coast, sediment must move from one location to another, meaning that erosion and accretion must ultimately balance. Where adjacent landforms simultaneously respond in an opposite manner to forcing conditions, a form of balance may occur through sediment exchange between landforms. The most prevalent example is cross-shore exchange between the beach/dune area and the nearshore zone (Figure 5.4).

Natural interactions between forcing conditions and landforms determine that the coast is changing almost continuously over different characteristic timescales (Gallop et al. 2015), with:

- coastal fluctuation caused by short-term variations (hours to weeks) of environmental forcing, particularly due to storminess
- progressive change due to variation of prevailing conditions, including seasonal and inter-annual coastal fluctuations
- longer term landform evolution in response to prevailing environmental conditions, usually related to the landform origin, with change over decades through to millennia
- change imposed by human interventions to the coast.

Distinction between the three 'natural' mechanisms for change (1–3) is predominantly made by considering the rate and direction of sediment exchange. Short-term coastal processes typically cause large rates of sediment movement mainly in a cross-shore direction, that is, between the beach/dune area and the nearshore area. Seasonal and inter-annual changes typically involve smaller rates of transport, distinguished from the short-term fluctuations by considering alongshore changes. Evolutionary behaviour occurs through slow rates of net transport, changing the volume of available sediment. Where prevailing conditions are otherwise unchanged, this change in volume is often accommodated by a cross-shore movement of the coast.

In many cases, the effect of short-term coastal processes is temporary, as much of the change is related to profile or plan form adjustment that is reversed following a return to prevailing conditions. The capacity for recovery needs to be considered when decision-making, as stop-gap responses have often resulted in high and unnecessary expense. Cycles of storm erosion and subsequent recovery are commonly described phenomena within many types of sandy beach systems. Recovery normally comprise short-term recovery (within a week or two) and more gradual recovery (seasonal), although much slower recovery is possible after extreme storm events (Thom and Hall 1991). Understanding and modelling of recovery processes is less well established than for erosion.

5.2.1 Coastal change terminology

Erosion and accretion may have substantially different management implications depending on the persistence of coastal change and the physical extent of change relative to the original shore. This results in terminology to support distinction of impacts.

In general, changes that do not affect vegetation or infrastructure (i.e. they only move coastal sediment) are considered fluctuations. These are predominantly short-term changes over time scales from days to months, sometimes longer where no adverse impact is perceived. Fluctuations may include cross-shore sediment exchange due to typical storm and recovery cycles, or alongshore movements, including the effect of seasonal changes in wave direction.

Erosion is most typically considered to occur where there is a loss of vegetation, impact to infrastructure or loss of amenity. Erosion is further distinguished by the speed of development, with rapid (acute) erosion or progressively developing (chronic) erosion. For coasts where acute erosion is largely caused by a single storm system, the erosion is sometimes termed storm bite and is typically parameterised according to storm severity (Thom and Hall 1991, Mariani et al. 2012). Storm bite is typically described in terms of sediment volume loss from above water level.

Where conditions cause a net loss of sediment, the coast experiences sustained change. This is normally termed recession to distinguish it from shorter term change. In many situations, coastal recession approximately corresponds to a landward movement of the previous beach profile. The corresponding term for sustained accretion is progradation. Coastal response to climate change, including sea-level rise, is expected to cause recession along much of the Australian coast.

Change in the form of the coast, whether the cross-shore profile or the shoreline configuration, also has terminology related to the time scale over which change is sustained. A change that occurs over less than a year is normally considered a fluctuation. Over annual to decadal time scales, it is typically termed a change of state. Over longer time scales, change in form is commonly described as evolutionary, although it may be cyclic in nature.

5.3 Cross-shore and alongshore coastal dynamics

The distinction between cross-shore and alongshore dynamics is largely one of convenience. This distinction is supported by cross-shore configuration largely responding to waves and water levels, while the alongshore configuration largely responds to wave direction. There is also a distinction of scale, as a small volume of cross-shore change may be sufficient for beach slope adjustment, while it requires a large volume of alongshore change to cause an adjustment of beach aspect. A result of these distinctions is that observed change in the cross-shore typically occurs at a much faster rate, therefore providing a convenient separation for modelling of coastal change. In reality, the distinction is less discrete, as there are some adjustments to shoreline configuration which require only small volumes of material transport, including the formation of scarps, bars and beach cusps.

Cross-shore coastal dynamics are strongly related to the way in which the beach face dissipates wave energy. On a steeper face, the effect of plunging waves creates greater sediment mobility and may drag beach material offshore as the wave withdraws. This process is enhanced in situations where wave-induced rip currents form. The offshore movement of sediment creates a flatter beach profile, which allows the beach to better dissipate wave energy.

Under calmer conditions, spilling waves percolate through the beach sediment; therefore, the offshore flow as the wave withdraws is much reduced compared with a plunging wave. This helps provide a gradual landward movement of sediment, which supports the beach building towards a steeper profile, depending in part on sediment grain size and tidal conditions (Wright and Short 1984, Masselink and Short 1993).

Alongshore coastal dynamics are mainly related to changes in the direction of wave or current motion relative to the shore. Shore deflected water flows, including wave-driven nearshore currents, combined with sediment suspension in the water column generate alongshore sediment transport (van Rijn 1989). The capacity for transport is significantly increased nearshore, where the shallow depth of the water and turbulence due to wave breaking enhance sediment suspension. The dependence of alongshore transport on coastal positon determines that stability (in the short term) can be increased through change in beach alignment (rotation). The response generally depends on the length of the coast, with shorter segments more likely to rotate, although considerable change in mobility may also be introduced by micro-features such as beach cusps.

Alongshore transport is often considered as an alongshore transport rate, which is the accumulation or loss of sediment volume from a defined area within a certain amount of time. Most commonly, the rate is identified through accumulation at a sediment trap (e.g. within a dredged basin) or loss from a designated area (USACE 2001, Cooper and Pilkey 2004). Alongshore transport rates are a notional concept, as they typically comprise the total change produced by many backward and forward movements of sediment, and therefore vary with time scale. Observed rates of transport are also affected by the configuration of the feature being measured and the nature of supply; they therefore may require careful interpretation (Rosati 2005).

The relative influence of waves and currents on alongshore transport varies significantly between locations, resulting in a number of different formulations for alongshore sediment transport (Table 5.1). These differ in terms of the mechanisms considered for both sediment suspension and water movement. Both the key active processes and coastal geomorphology to be represented should be considered when selecting an appropriate modelling method. In most cases, the modelling is subject to considerable manipulation through selection of parameters, and therefore distinction between model calibration and validation may be required (Pilkey and Cooper 2002).

In general, the ability for waves to generate alongshore transport is substantially related to their direction of approach, which is in turn strongly influenced by the process of wave refraction. Waves arriving at an angle to the shore can generate both sediment suspension and alongshore currents, and therefore wave-only model formulations are often used for 'open coast' scenarios.

Waves arriving normal to the beach have less capacity to generate alongshore currents and therefore cause low rates of alongshore sediment transport. These waves do create high sediment suspension due to wave breaking turbulence, but this is usually transported in the offshore direction by rip currents (Harley et al. 2011, Loureiro et al. 2014).

Table 5.1 Some formulations for alongshore sediment transport modelling

Formulation	Processes	Morphology
CERC Formula (USACE 1984)	Waves only	Not considered (integrated)
Kamphuis et al. 1986	Waves only	Considers beach slope only
Bijker et al. 1976	Currents and simplified waves	Almost planar bed
Fredsoe et al. 1985	Waves and simplified currents	Bed roughness and almost planar bed
van Rijn 1989	Waves and currents	Bed roughness and sloping bed

5.4 Sediment redistribution

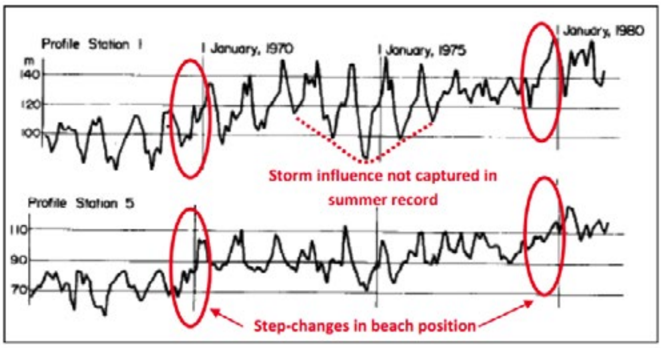
The mechanisms of cross-shore and alongshore sediment transport provide a high capacity for soft shores to adjust to a more stable configuration under more energetic (storm) conditions by moving sediment offshore or alongshore. Material that moves offshore or alongshore away from the beach causes net erosion, with the soft shore assuming a new configuration that is determined by the reduced volume. Commonly, this will be similar to the previous configuration, but shifted to landward.

Importantly, the eroded sediment must have been redistributed. In cases where it has been moved offshore, it may progressively return onshore during calmer conditions. The nature of recovery is determined by how far offshore the material has moved; if it is transported into a nearshore bar, then recovery can be within weeks to seasons, while for transport further offshore, recovery may take a number of years. This point has been well documented by the time series measurements of beaches north of the Moruya Airport on the New South Wales south coast (Thom and Hall 1991, McLean and Shen 2006).

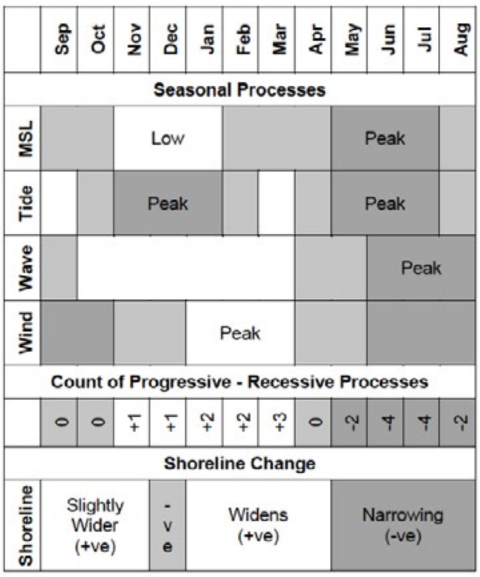
Where sediment has been moved alongshore, particularly if it has bypassed headlands or other barriers, recovery may require resupply from the net onshore drift. This can be a much slower process than cross-shore recovery, although on a beach partitioned by coastal headlands or structures, recovery can be rapid if the storm response merely involves beach rotation rather than a loss of volume.

The resulting patterns of change are cycles of erosion and recovery (Komar and Enfield 1987, Boak and Turner 2005), which typically include short-term responses to storms, substantial seasonal fluctuations in response to changed conditions, inter-annual variations in response to sediment supply, and slower changes in storminess or sea level (Figure 5.5). The nature of these variations is effectively unique to each shore, depending on the forcing conditions, sediment supply and morphology.

At Scarborough Beach, WA, beach widths were measured monthly over a 19-year period (Figure 5.5a), demonstrating a strong seasonal variation and the effects of variable storminess and mean sea level (Clarke and Eliot 1983, Eliot and Travers 2011). Comparison of the time series with further environmental parameters revealed additional shoreline responses due to daily tide range, mean wave conditions and alongshore wind (Figure 5.5b). A simple count of whether these processes are in progressive and recessive phase helps to explain the observed patterns of change on a seasonal basis (Eliot and Travers 2011).



(a) Scarborough monthly beach width 1965-1984



(b) Seasonal processes influencing beach width

Figure 5.5 Coastal behaviour identified from beach width at Scarborough, Western Australia
Source: Eliot and Travers 2011, with 1965-1984 beach width data from Clarke & Eliot 1983.

5.4.1 Transfer of coastal stresses and beaches as stress-damping mechanisms

The coupled nature of erosion and accretion means that any effort to stabilise a section of soft coast effectively reduces the quantity of sediment supplied to another, usually adjacent, section of coast. The most commonly described result is the effect of downdrift erosion, which occurs by interrupting the net alongshore sediment transport, such as through the installation of coastal groynes (Figure 5.6). In practice, the effect is partly mitigated by the capacity for sediment to bypass the structure, and therefore is influenced by the cross-shore length of the feature and the rate of sediment supply.

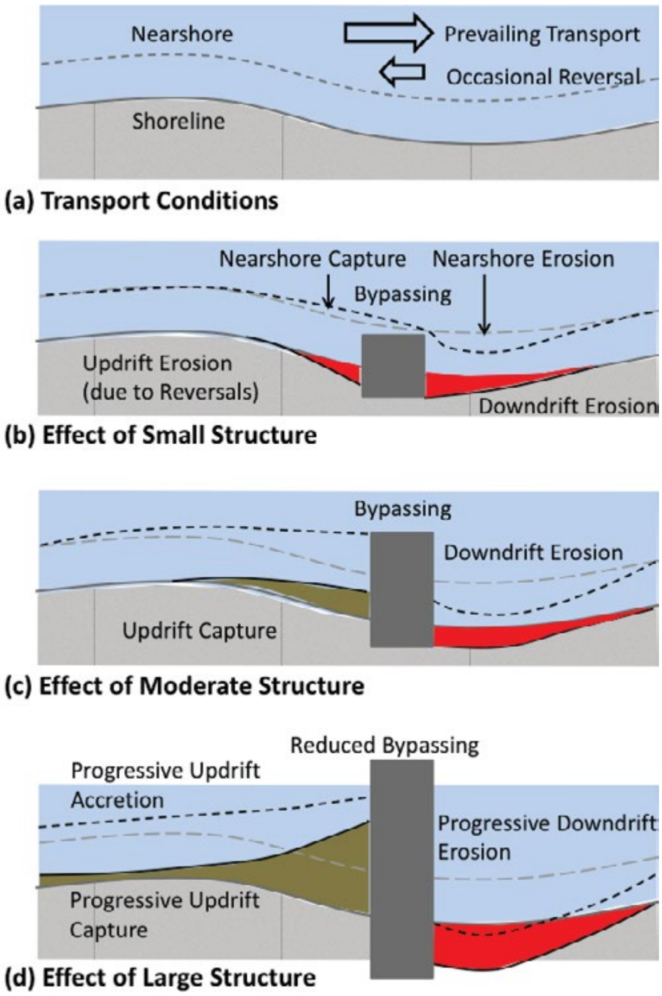
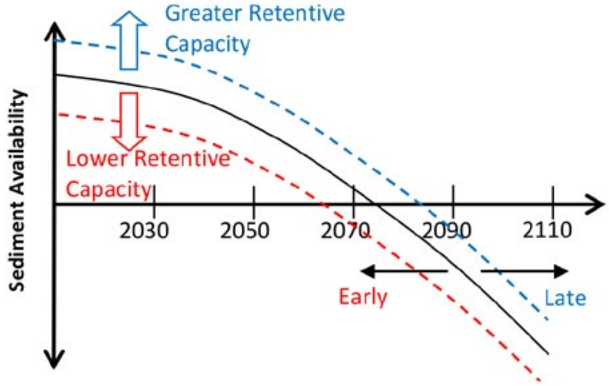


Figure 5.6 Response to coastal structures (groyne effect). Source: © Damara WA Pty Ltd 2015.

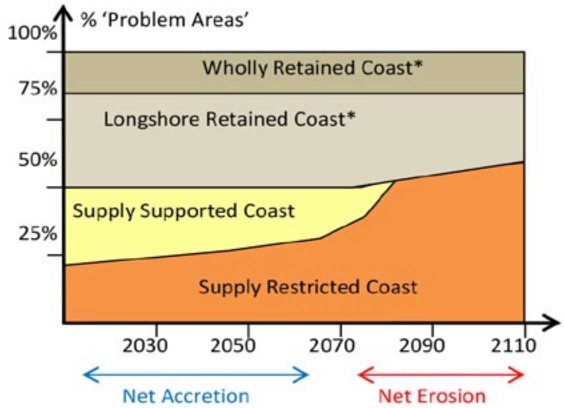
Other types of erosion pressure may occur through natural variations in alongshore sediment transport (low supply conditions) or periods of high storminess. As a soft coast subject to erosion pressure assumes a configuration that reduces its tendency to erosion, the effect of erosion is commonly to reduce the net alongshore transport. This propagates downdrift, reducing the alongshore supply and therefore effectively transferring the erosion pressure.

Along a soft coast, the relative capacity for retention of coastal sediment varies spatially according to the presence of alongshore controls (natural or artificial), sources of sediment (river inputs or coastal sand feeds) and the coastal configuration (morphology). An adjustment in the availability of sediment, due to changes in storminess or a longer term adjustment due to sea-level rise, causes changes in the balance of sediment volume and transport rates between sections. For those sections which are subject to alongshore retention, the relationship between volume change and bypassing determines that they effectively 'borrow' sediment from less-retained sections, specifically beach sections (Figure 5.7). As a consequence, the volume of sediment in the beach system may act as a buffer to coastal erosion for a far greater length of coast than the beach itself.

Figure 5.7 illustrates a conceptual analysis of the Cockburn Sound, Western Australia, foreshore, which is supplied by a limited volume of sediment from outside the Sound. Historical management has involved the use of retentive structures to manage this supply, with about 30% of the shore requiring external sand supply to retain its existing position, and about 20% of the shore with no external sand supply (i.e. supply restricted). The supply is presently considered adequate for the Sound beaches to build over time, largely keeping pace with sea-level rise over the twentieth century. However, under projected rates of sea-level rise, the supply is considered to be inadequate for stability (Figure 5.7a). Over time, a shift in coastal behaviour within the Sound from net accretion to net erosion will lead to effectively zero external supply, creating widespread erosion (Figure 5.7b) A change to the coastal management strategy within the Sound is projected to be required.



(a) Projected Change in Sediment Availability



(b) Change in Coastal Behaviour

Figure 5.7 Notional change in sediment availability and coastal behaviour. Source: Coastal Zone Management Pty Ltd et al. 2013 © Cockburn Sound Coastal Alliance 2016.

5.4.2 Dune management

Coastal dunes provide an important barrier to storm events, including the effects of wave run-up and erosion. They can also provide important ecological roles, particularly where they act as faunal refuges along urban or peri-urban coasts. The consequences of dune destabilisation can threaten houses and roads, with sand sheets associated with blowouts able to travel hundreds of metres inland. As a consequence, effective coastal dune management is a substantial activity for many coastal managers, which typically includes planting and other works to assist in the stability of sand surfaces from extreme wind and wave attack.

However, coastal dunes also have a significant role as additional storage of coastal sediments landward of the beach. Under periods of high stress, sediment eroded from coastal dunes may act as an important source of material for the coast, enhancing the capacity for recovery of the adjacent coast. The intermittent need for sand from coastal dunes, often in response to long-term cycles of erosion and recovery, determines that they should be managed with considerable care. In general, an understanding of the capacity for a beach and dune system to act as a valuable source of material during times of coastal stress should be recognised by the coastal manager.

5.5 Large-scale coastal dynamics

Beaches and other forms of soft shore form the majority of the Australian coast (Woodroffe 2003, Short 2006, Short and Woodroffe 2009), although they typically overlay and interact with rock structures that comprise the Australian continent and its shelf margins. Although some sediment loss is believed to occur, mainly through shelf canyons (Harris et al. 2003), the origin and behaviour of coastal sediments is generally treated as a result of processes on the continental shelf and coast, with some input from Australia's river systems over geologic time (Roy and Thom 1981, Prosser et al. 2001).

The rapid nature of cross-shore movements, particularly due to storm erosion and recovery, promotes the concept that the coast should *on average* be close to a state of cross-shore stability (de Vriend et al. 1993). In contrast, the occurrence of net alongshore transport sustained over long time scales suggests that the section of coast is *not* in a state of alongshore stability, and therefore implies that large-scale coastal dynamics, at the scales of decades and kilometres, is largely an alongshore process. Over longer time scales, changing climate and sea-level conditions will also cause changes to the cross-shore configuration, requiring a balance from either alongshore or cross-shore sources. An understanding of long-term, large-scale dynamics provides a simple conceptual model for large-scale coastal change. Interpretation of this conceptual model has varied both globally and around Australia, with three major frameworks applied to assess large-scale change: enclosed, continuous or compartmentalised.

The *enclosed* approach assumes that each section of coast is effectively discrete, although variation to supply or loss alongshore might be considered. A major focus for assessment involves looking at how the volume of coastal sediment may be redistributed through changing conditions. A typical approach involves definition of a sediment cell, within which the patterns of alongshore transport cause areas to act as a source of sediment (eroded), a pathway for sediment transport, or a sink for sediment (accreting). Changes to the overall cross-shore configuration, such as due to sea-level rise, are typically considered locally through a volume loss from the nearshore. The enclosed approach is popular with numerical modellers due to the convenience of a potentially confined model area, particularly at smaller scales. It is likely to be appropriate where there is limited change over time to the *net* sediment supply.

Application of the enclosed approach to larger physical scales generally takes the form of a sediment budget, which is based on the concept that erosion and accretion must ultimately balance (Rosati 2005). This involves consideration of sediment volumes and exchange, both onshore into dunes and tidal inlets, and offshore (Figure 5.8). Rates of alongshore sediment transport can be estimated through modelling or observed patterns of shoreline change.

Balancing the sediment budget may require consideration of river run-off and shelf sediment supply, including that from biota (such as shells), dunes and floodplain sediment storage. The relative capacity for each of these components to supply or remove sediment from the coastal system varies significantly around Australia, suggesting that substantial variation in the conceptual models is appropriate for evaluation of long-term coastal response to sea-level rise (Eliot 2013).

Examples of sediment budget derivation are presented in Mariani et al. (2013), where the components have been developed from a range of studies (Figure 5.9). An outcome of the study was to highlight differences in forecast response to sea-level rise between Avoca Beach, which is effectively enclosed, and Cabarita Beach, which is part of a wider sediment transport system.

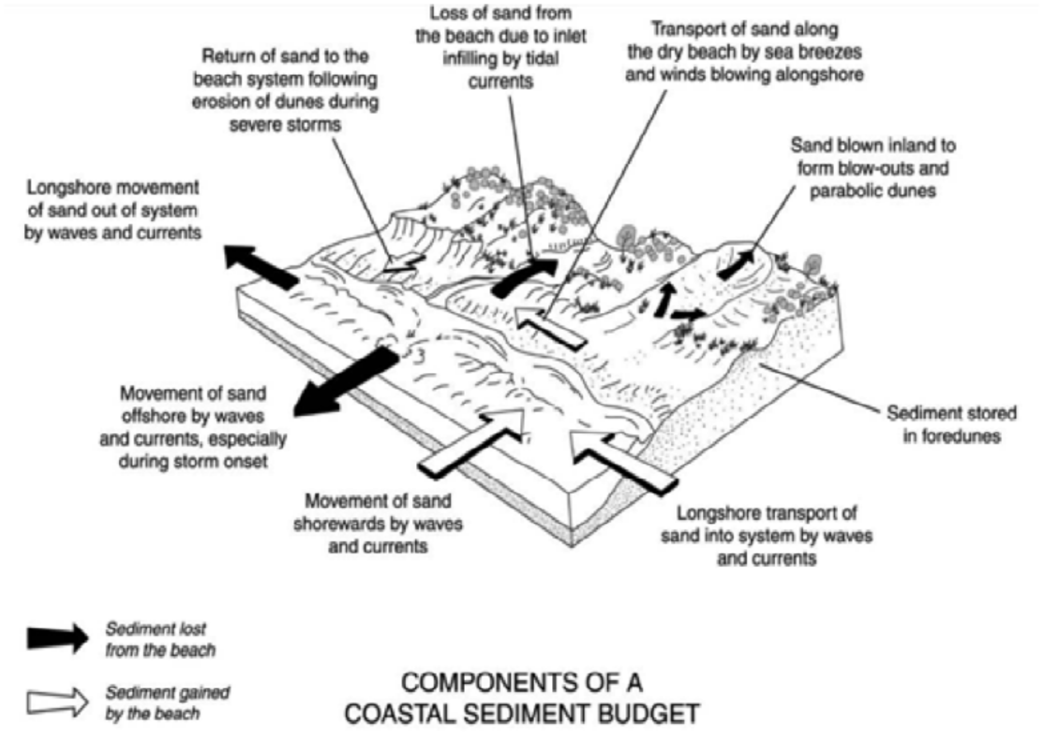


Figure 5.8 Sediment cell figure (simple). Source: WAPC 2003 © Government of Western Australia.

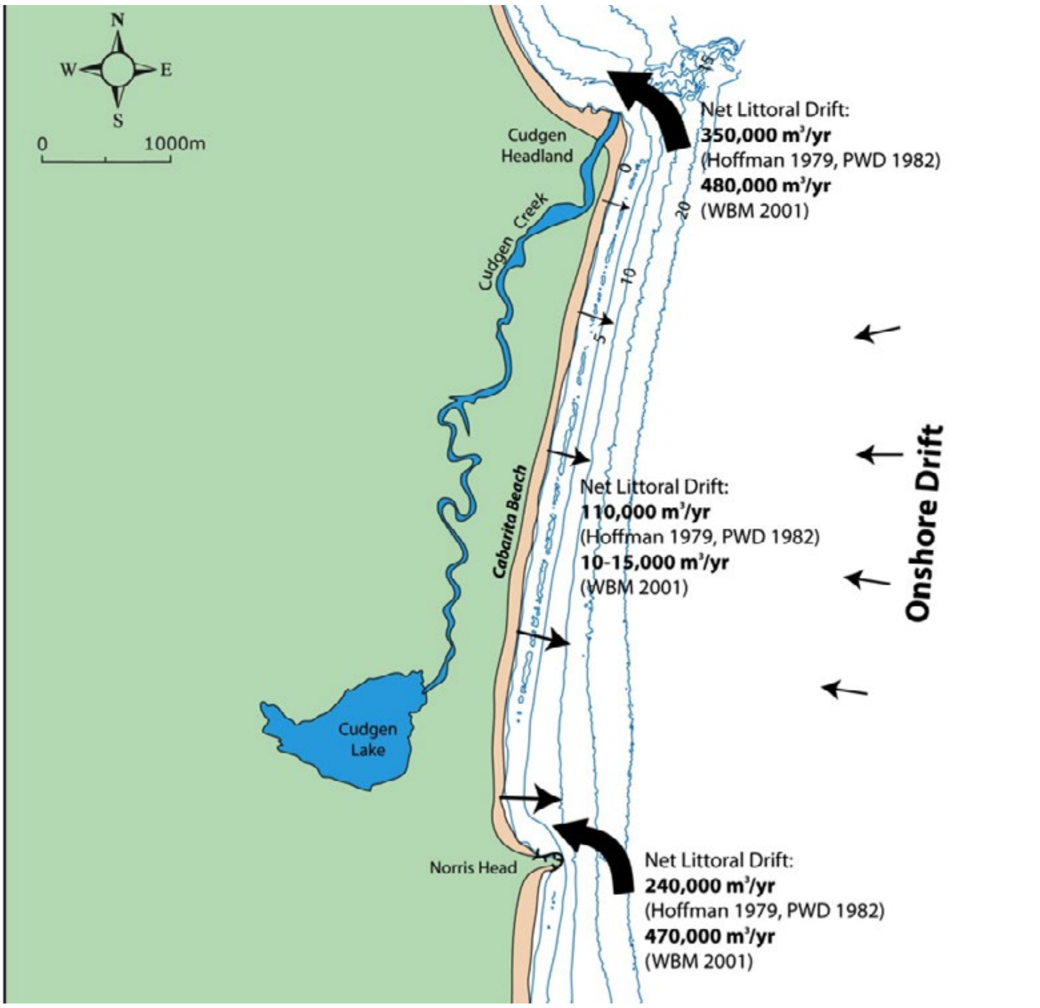


Figure 5.9 Cabarita bathymetry and conceptual sediment budget model. Source: Mariani et al. 2013.

The *continuous* approach towards long-term coastal dynamics is partly a notional concept, originally developed for very large scales. It relies on an assumption that alongshore coastal dynamics are developed through the distribution of large-scale sources of sediment, and therefore it is relevant along sections of coast with high input of river sediment. The supplied sediment is distributed alongshore through marine processes, with local-scale processes and human interventions acting to modify the net supply. This framework was used to develop the 'River of Sand' concept for the east coast of the United States, which was essentially a communication tool to indicate the influence that coastal structures could have on downdrift coasts by transferring erosion stress. The mechanics of coastal sediment transport differ considerably from this concept (Tanner 1987).

The framework of *coastal compartments* considers that coastal dynamics can be considered neither wholly discrete within sections of the coast nor wholly continuous along the coast. The approach considers that although common behaviour occurs within discrete sections of coast, there are relationships between these sections, which may result from restricted sediment transfers that occur between sections. In this way, the coastal compartments framework may provide bridging across scales of assessment.

Use of coastal compartments to support understanding of coastal dynamics has previously occurred along a number of parts of the Australian coast, for a number of different purposes. The relevance of this approach to coastal management, particularly when operating at multiple scales, has subsequently been recognised and has recently resulted in a program to describe compartments spatially across Australia (Figure 5.10).

The potential complexity of sediment dynamics at the scale of sediment compartments is illustrated by the seabed features apparent from high resolution Light Detection and Ranging (LiDAR) imagery. Regional differences in the manner in which the coast behaves were highlighted through comparison of seabed and coastal landforms in the southwest of Western Australia and along the Pilbara coast.

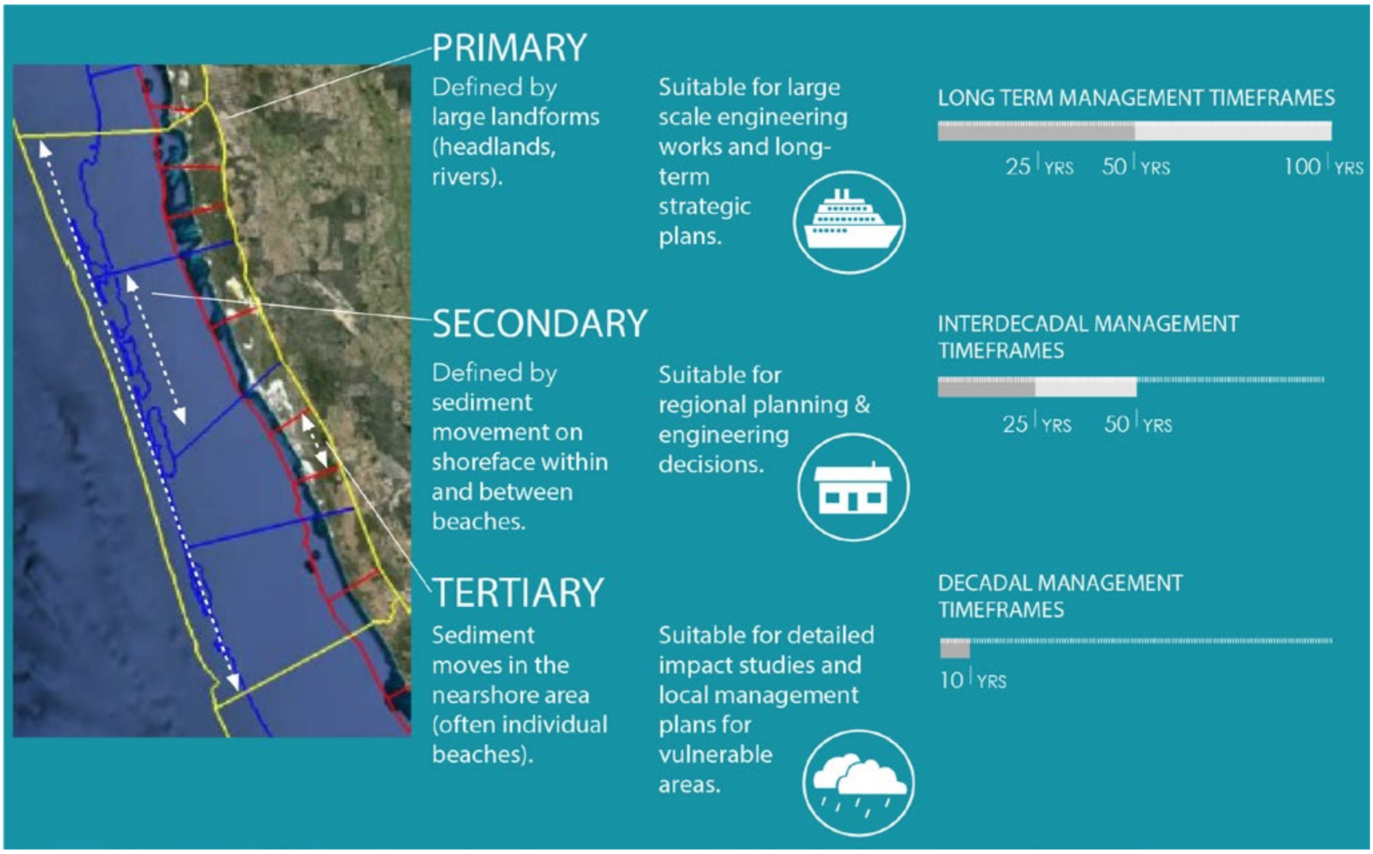


Figure 5.10 Coastal compartments scales, uses and time frames. Source: Thom 2015 © Commonwealth of Australia 2016.

The seabed structure at Mandurah, Western Australia (Figure 5.11) indicates that sediment transport may occur in discrete pathways, both cross-shore and alongshore, with adaptation to coastal change requiring an understanding of these pathways and how possible interventions may affect the continuity of supply. Following analysis of the seabed structure, these sediment pathways were interpreted as to how they may affect the coastal response to sea-level rise, including the difference in response by spatially disparate compartments:

- The south-west coast is strongly influenced by the presence of offshore reefs and alongshore headlands. These features control the delivery of sediment from both offshore and alongshore in discrete pathways and therefore are expected to develop spatially variable erosion responses to future sea-level rise.
- In contrast, the Pilbara coast is strongly affected by intermittent sediment supply from rivers and has irregular tidal network connections to extensive coastal floodplains. These features suggest that the major coastal change will occur on the floodplains, affected by proximity to rivers and connection to the coast. Weakly connected lagoons are expected to 'drown', while tidal flats with extensive creek networks are likely to grow in elevation but experience tidal creek extension.

The significant (alongshore) spatial variation of shoreline response to sea-level rise is inconsistent with widely used generic models for long-term coastal change. The difference is illustrated by comparison of a generic behavioural model (Figure 5.12a) with one developed for the south-west of Western Australia (Figure 5.12b), which incorporates the anticipated influence of sediment pathways identified specifically for this section of coast (Eliot 2013).

5.6 Impacts of coastal dynamics

The most dramatic effects of coastal dynamics are commonly illustrated by the collapse of housing that has been undermined by storm erosion (Figure 5.13a) or where severe erosion clearly threatens beach infrastructure (Figure 5.13b). The perceptible cost and rapid nature of such change typically conveys a sense of importance for the management of coastal erosion. However, in most cases such impacts only follow progressive changes, which may be less visually confronting without the presence of significant infrastructure. Even a coast that has been eroded periodically, but at an average rate of approximately 1 m per year, may appear largely stable under ambient conditions (Figure 5.13c).

In most cases, progressive coastal erosion may be directly associated with a corresponding volume of accretion (Figure 5.13d). In situations where this accretion is perceived to have a positive benefit, whether amenity, ecological or as an improved erosion buffer, there is often debate about whether to intervene by transporting some of the accreted sand to the eroded area to replenish beach loss. The case not to intervene is typically supported by the high costs of human intervention, the uncertainty of effectiveness and the likelihood of conditions recurring. However, in areas of high population and demand for beach use, such as in Adelaide or near the Tweed River entrance, benefits of action have been shown to outweigh the cost of inaction.

Impacts due to small volume or subtle coastal dynamics may occur if changes to sensitive coastal features affect coastal and estuarine habitats. Rapid switching from marine to estuarine conditions may occur for intermittently closed and open lakes and lagoons (Gale 2006) if the entrance bar is destabilised. Other situations where a relatively small coastal change may have a significant impact include dune destabilisation (Sloss et al. 2012), the formation or collapse of bars or spits affecting wave conditions (Hollings 2004) and smothering or erosion of coastal wetlands through washover processes accompanying storm surge.

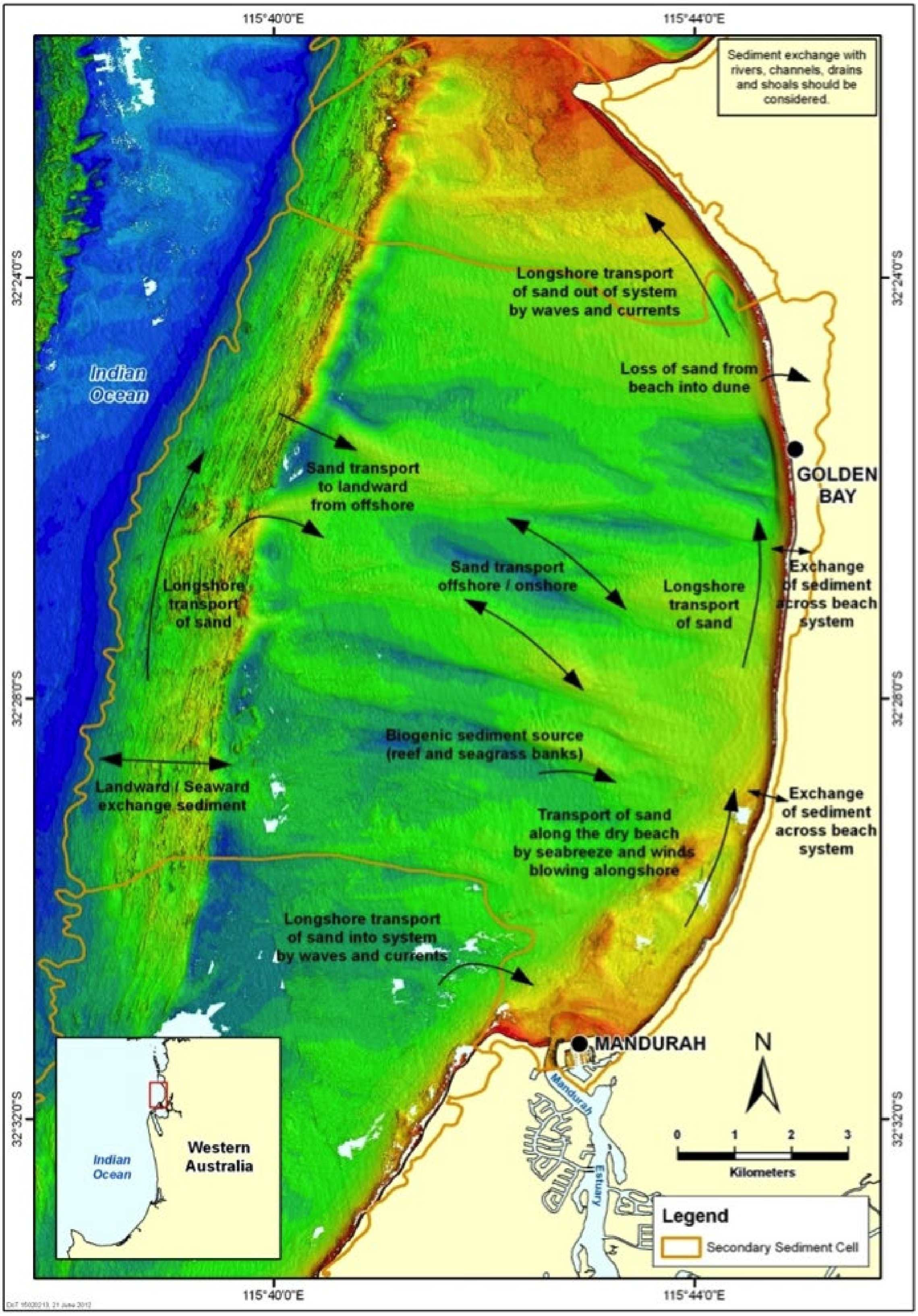


Figure 5.11 Interpretation of LiDAR Bathymetry near Mandurah, WA. Source: Stul et al. 2015 © Government of Western Australia.

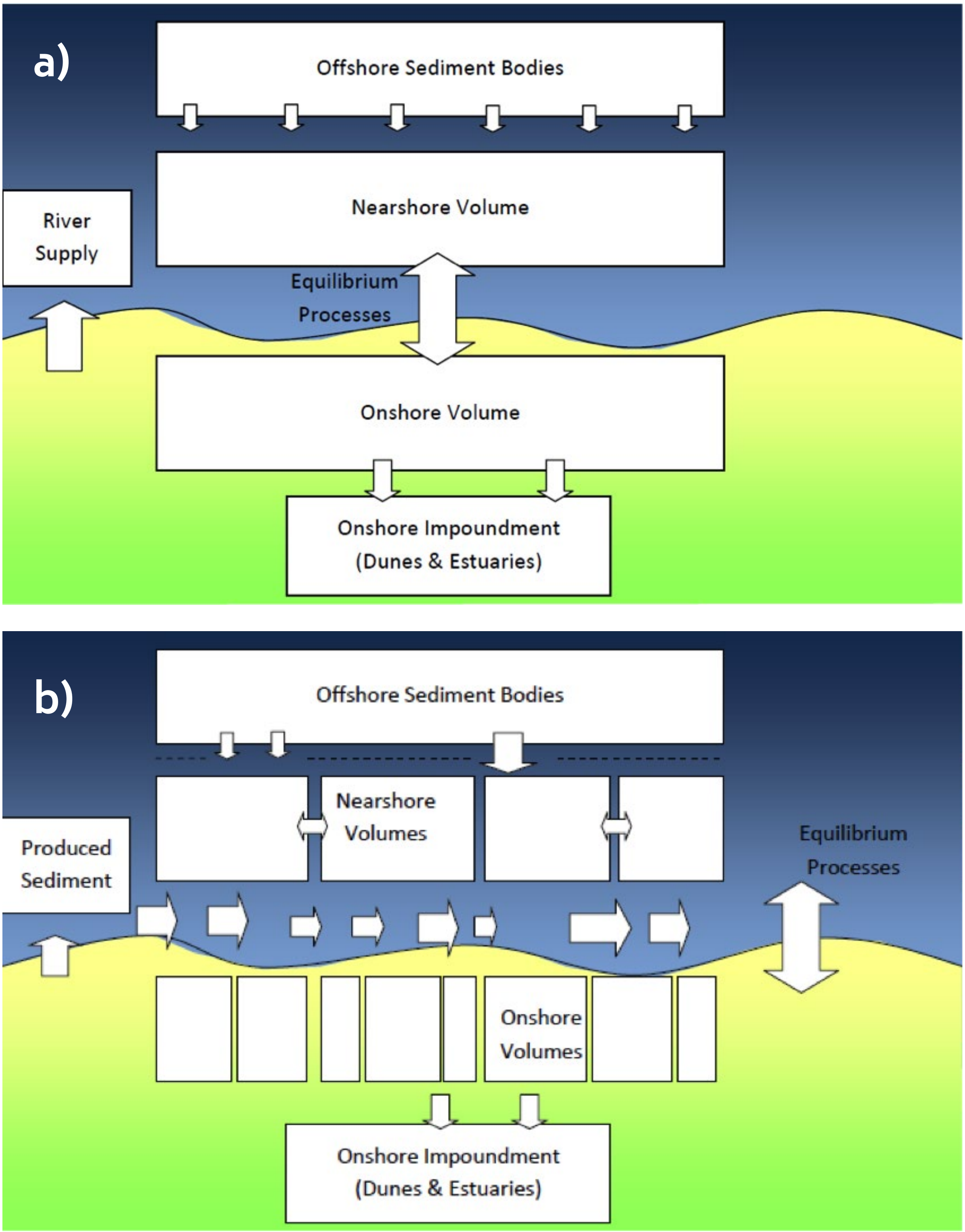


Figure 5.12 Schematic behavioural models for coastal dynamics.

(a) Commonly used model based on cross-shore balance;

(b) Model for Naturaliste to Lancelin Coast, WA, based on extensive nearshore reefs and coastal rock features. Produced sediment is from rock erosion and biogenic production, including seagrass and epiphytes. Source: Eliot 2013.

Figure 5.13 Illustration of various forms of coastal dynamics.

(a) Undermining of a house due to storm erosion at Collaroy, NSW. Photo: © Angus Gordon.

(b) Storm erosion on South Narrabeen Beach, NSW. Photo: © Andy Short.

(c) Long-term eroded shoreline near Quindalup, WA. Source: Image courtesy of the Geological Survey of Western Australia, Department of Mines and Petroleum © State of Western Australia 2016.

(d) Foredune development in response to harbour works, Two Rocks, WA. Source: image provided by Peron Naturaliste Partnership.

5.7 References and further reading

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6 Management of soft shores

The Australian coast is heavily used for human activities. In many urban and peri-urban centres, particularly our major cities, the coast is subject to intensive infrastructure development. Although much of our coastal use involves recreational or residential amenity, there are also substantial transport, commercial and industrial uses, including ports, aquaculture, desalination plant or cooling water intakes and wastewater outfalls. How these human activities and infrastructure interact with the dynamics of soft shores is an important aspect of coastal management.

6.1 Approaches to coastal management

Three major approaches to coastal management exist, relating to how natural hazards impacting on soft shores are dealt with:

- avoidance – hazards are identified, with land use planned to avoid likely risk over an identified time frame
- tolerance – negative impacts of the erosion or accretion are accepted as a limitation to land use, typically with reactions to mitigate consequences
- protection – hazards are identified, with interventions undertaken to prevent likely risk over an identified time frame.

In general, population pressure, economic drivers and degree of governance are influential on the approach preferred by different coastal managers (Figure 6.1). All Australian state governments have planning policies identifying that the preferred means of avoiding erosion hazard is through coastal setbacks, providing a buffer to erosion (Walsh et al. 2004). Examples of erosion hazard avoidance, tolerance and protection are shown in Figure 6.2.

The recognised need to develop coastal nodes and the presence of fixed land-use boundaries on evolving coasts has historically resulted in a blend of approaches on urban coasts, with a tendency for increased use of protection where there are industrial or commercial works. There is generally a greater use of hazard avoidance or tolerance on rural or peri-urban coasts, although there are many examples along the Australian coast where protection has been applied by landowners, sometimes with acceptance by local authorities. The approach used in any particular case is typically a result of relative values placed on the land use, the perceived consequences of hazard mitigation and political will to enforce policy guidelines.

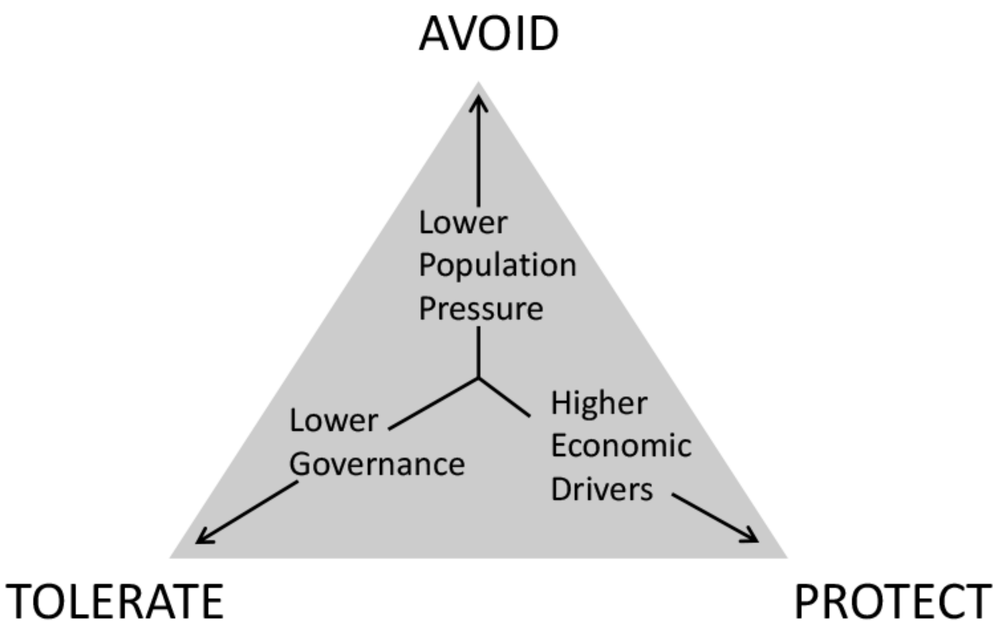

Figure 6.1 Typical drivers of coastal hazard mitigation approach. Source: © Damara WA Pty Ltd 2015.

Figure 6.2 Examples of avoid, tolerate and protect approaches to erosion hazard.

a) Avoidance, using a wide setback at Karratha in the Pilbara. Photo: Image courtesy of the Geological Survey of Western Australia, Department of Mines and Petroleum © State of Western Australia 2016.

b) Tolerance, by using low-cost infrastructure (caravan park) to limit erosion impact at Guilderton. Photo: Image courtesy of the Geological Survey of Western Australia, Department of Mines and Petroleum © State of Western Australia 2016.

c) Protection, using a seawall at Busselton. Photo: Provided by Peron Naturaliste PartnershipPeron-Natualiste Partnership.

The length of time over which a section of coast has been developed may also influence the coastal management approach. For an evolving coast, fixed land-use boundaries may conflict with coastal change, particularly under a situation of recession. This produces greater pressure for the use of coastal protection. On coast perceived as stable, land value is generally higher, resulting in increased justification for coastal protection, with values typically increased in areas that are protected by coastal works (i.e. reinforcing the justification).

Adaptation to erosion hazard involves a change in the type of mitigation used. This has occurred historically in Australia where coastal evolution caused loss of setback buffer, requiring a change from avoiding hazard to tolerating or protection against erosion. In situations of a near balance between erosion and accretion, coastal amenity provided by each of these adaptation pathways may be similar, and therefore protection was widely applied on the Australian coast through to the 1970s. More recently, the need to more carefully consider future adaptation on soft shores has been highlighted by the issue of sea-level rise induced by greenhouse gas emissions (Titus and Barth 1984). The coastal response is anticipated to cause a substantial increase in the proportion of coast experiencing erosion pressure (Sorensen et al. 1984, DCC 2009).

Generalised frameworks for adaptation to sustained erosion on soft shores have typically focused on three targets for the shoreline position: advance, retreat or hold the line.

A target of **advancing** the shoreline from its present position is rarely practical, although it may be appropriate in situations where storm hazards affect existing coastal amenity or infrastructure.

Retreat requires identifying ways to remove or relocate existing land uses landward from the present shoreline position (Kousky 2014). This is most easily managed where avoidance has been the main technique for coastal hazard mitigation, although in many cases existing development buffers only serve to defer the erosion threat to existing facilities by several decades. Practices to tolerate erosion hazard, such as housing with deep-piled foundations, become increasingly expensive with coastal retreat, and in most cases this increased cost has been used as argument to switch to coastal protection.

The target of **holding the existing shoreline** in its present position provides the least challenge to the status quo of land ownership. However, it is commonly associated with a high level of engineering with potentially significant capital and maintenance costs. These must be sustainably borne into the future. There is generally some loss of coastal amenity associated with change to an engineered coast, but the greatest adverse impact usually occurs through the alongshore transfer of erosion, which typically affects the adjacent land. The technique of beach nourishment offsets erosion by introducing a new source of sediment, but generally comes with high ongoing costs and difficulty establishing a sustainable economic source of material.

Alongshore transfer of erosion means an approach of holding the line for one location must effectively accelerate the retreat in another adjoining or downdrift location. This is similar to historic coastal engineering practices, but requires a greater proportion of coastal land to be affected by erosion. In this regard, coastal resilience may be enhanced through:

- nodal coastal development, allowing sufficient space between nodes to support the redistribution of erosion pressure if protective works are required; with
- placement of nodes strategically along the coast at points of relative stability, to maximise the effective use of natural sediment transport patterns.

Although these two principles are incorporated within most state and regional coastal planning documents, their implementation is rare. Major reasons for this failure relate to the inertia associated with historic development, competing interests of separate coastal landowners and the importance of other development criteria. However, the difficulty of generically defining how to identify appropriate coastal nodes is a further possible reason for failure to apply these principles. In many cases, the default position of relying on precedent has supported the alongshore propagation of coastal defence structures or has resulted in progressive infill development that limits the capacity of minor works to locally transfer erosion stresses. Sediment compartments have been identified as a framework that may better support implementation of nodal development policy.

6.2 Decision-making on soft shores

Decision-making on soft shores in Australia is undertaken by a range of agencies, each with different responsibilities, jurisdiction and management tools. Typically, the key agencies are environmental or facility managers, engineers and planners from local or state government, who are generally interested in different time frames for decision-making (Table 6.1). An added layer of complexity comes in situations where there is high socio-political pressure. Political decision-making may over-ride the technical and bureaucratic processes.

The time frame of interest strongly affects the perceived importance of either storm erosion or progressive change. Illustrated simply, in a situation where there is potential for 20 m erosion in a single storm and 1 m/year progressive erosion, then viewed over five years, the storm determines 80% of the possible shoreline response; whereas over 80 years, the storm is only 20% of the response; and over 20 years, they each hold equal significance in determining the position of the shoreline.

Opinion regarding process importance is also influenced by uncertainty and the risk-averse or risk-tolerant perspective of the coastal decision-makers. In planning, the relative difficulty of withdrawing a decision is often a reason for adopting a risk-averse position. However, uncertainty regarding future coastal change, particularly change related to projected sea-level rise (see Information Manual 2: Understanding sea-level rise), and the time available to intervene at a later date are often used as arguments to adopt a risk-tolerant position. Policy positions and standards, particularly where they are subject to limited discretion, therefore provide a crucial tool for planning decision-makers.

For facility managers and engineers, the location of amenity or works is already determined, and therefore decision-making is commonly viewed in a cost–benefit framework (see Information Manual 4: Costs and benefits). Within this framework, the relative unlikelihood of experiencing extreme events (say the 100-year event) makes it difficult to justify expenditure to adapt existing facilities, often requiring a risk-tolerant position to be adopted.

Threats posed by coastal hazards vary over time and are influenced by weather conditions, the shore conditions, the assets or amenity which may be affected, and human interventions. Following the implementation of environmental risk-management frameworks (Standards Australia/Standards New Zealand 2006), practical methods to deal with changing risk can be either to adopt a conservative initial position or to use an adaptive management approach (see Information Manual 1: Building the adaptation case). Adaptive management provides advantages when dealing with an uncertainty of timing, and therefore is particularly valuable when dealing with response to sea level rise and its high uncertainties. The need for adaptation implies that there is a change of state in coastal parameters (Figure 6.3), and all types of coastal managers may require a method for adaptation.

Table 6.1. Objectives, tools and time frames for typical coastal decision-makers.

Key role	Objectives	Management tools	Time frame
Facility manager / Environ. manager	Manage existing amenity or works	Maintenance or defence	1–5 years
Engineer	Determine works to be constructed	Infrastructure capacity	5–30 years
Planner	Location and type of works to be determined	Zoning, approval conditions	30–100 years

Adaptive management on soft shores aims to identify those steps that may need to be undertaken following a forecast change of state, but which may not be presently appropriate. For a facility manager, adaptation may mean shifting from beach restoration to beach protection; engineers may need to accommodate new design criteria via structural modification; while planners may need to redefine zone boundaries.

Use of the adaptive framework requires an understanding of the time before conditions requiring change may occur, considered in the context of the time (and method) required to identify the need for change and implement adaptation. Where a change of state can plausibly occur faster than it can be identified and mitigated, there may be grounds for early implementation.

6.3 Defining a coastal hazard zone

A widely used tool used for coastal decision-making is definition of a coastal hazard zone, which marks the width of coast potentially affected by coastal erosion over a time frame of interest. International approaches towards evaluating coastal hazard zones over long time frames have gradually converged towards a similar approach, which forms the basis of Australian policies (NSW Government 1990; Komar et al. 1999; Healy and Dean 2000; Walsh et al. 2004, Woodroffe et al. 2012). Common elements in Australian state government policies to assess coastal hazard zones for soft shores include:

- short-term (acute) storm erosion, or storm bite
- short- to moderate-term beach realignment (rotation)
- progressive underlying recession due to sediment deficit or accretion
- recession due to projected sea-level rise
- instability of coastal landforms, including dunes and inlets.

Techniques to assess each of these components may vary between locations, according to the site characteristics. In most states, techniques are not set by policy but are strongly based on precedent.

The nature of the information required to support coastal decision-making varies according to the position of the assets of interest relative to existing and forecast hazards (Figure 6.4).

Applying the time series concepts in Figure 6.3 to coastal erosion, three physical zones are determined:

1. An existing hazard zone occurs within the potential reach of storm erosion for present-day conditions. Assets located in this zone are already at risk, and knowledge is required to determine the likelihood of adverse impact on the asset.
2. A forecast hazard zone occurs within the potential reach of storm erosion under future conditions, following a projected change of state. Assets located in this zone are not yet at risk. Awareness of the change of state necessary to develop risk (i.e. the long term trend the shoreline is following) should be developed, and a forecast of when such conditions are likely to be reached may be useful for planning.
3. Locations landward of the forecast hazard zone are considered not to be at risk. However, this may be subject to the forecast change of state, or trend. Information should be obtained to confirm that the forecast is adequate or conservative.

An approach promoted by the Intergovernmental Panel on Climate Change (IPCC) to look at vulnerability to climate change and sea-level rise is to apply a series of increasingly complex assessments, with reducing spatial scales of application (Table 6.2). Each level of assessment effectively provides screening for the next level of assessment (IPCC 2014). Similar approaches have been applied to parts of the Australian coast at different phases of the IPCC (Kay et al. 1996, Waterman 1996, DCC 2009).

Establishing the risk level or forecasting the time frame in which an asset may be at risk can be undertaken with various levels of information. Information needs are usually increased if the value of the affected asset is high, it is expected to be used for a long time or if mitigation of the erosion threat is likely to adversely affect other assets. Typical information may derive at one level from desktop assessment or at another level from landform analysis (geomorphology), with or without numerical modelling or field programs. More complex questions, particularly such as the provenance of a sand supply over the late Holocene, may require detailed stratigraphic and radiometric analyses, both onshore and offshore.

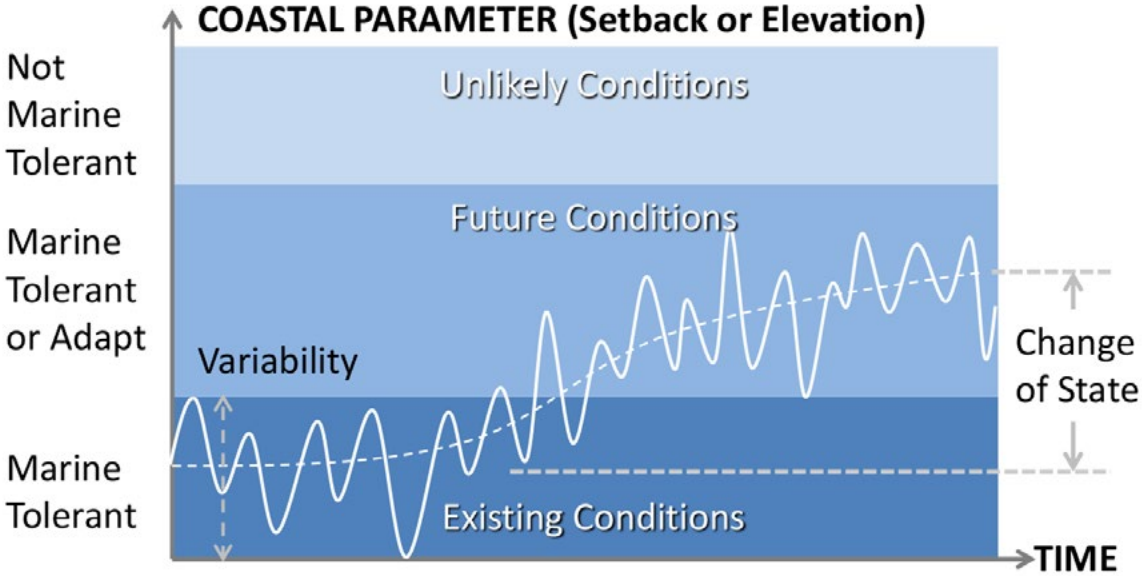

Figure 6.3 Concepts defining the role of adaptive management. Source: © Damara WA Pty Ltd 2015.

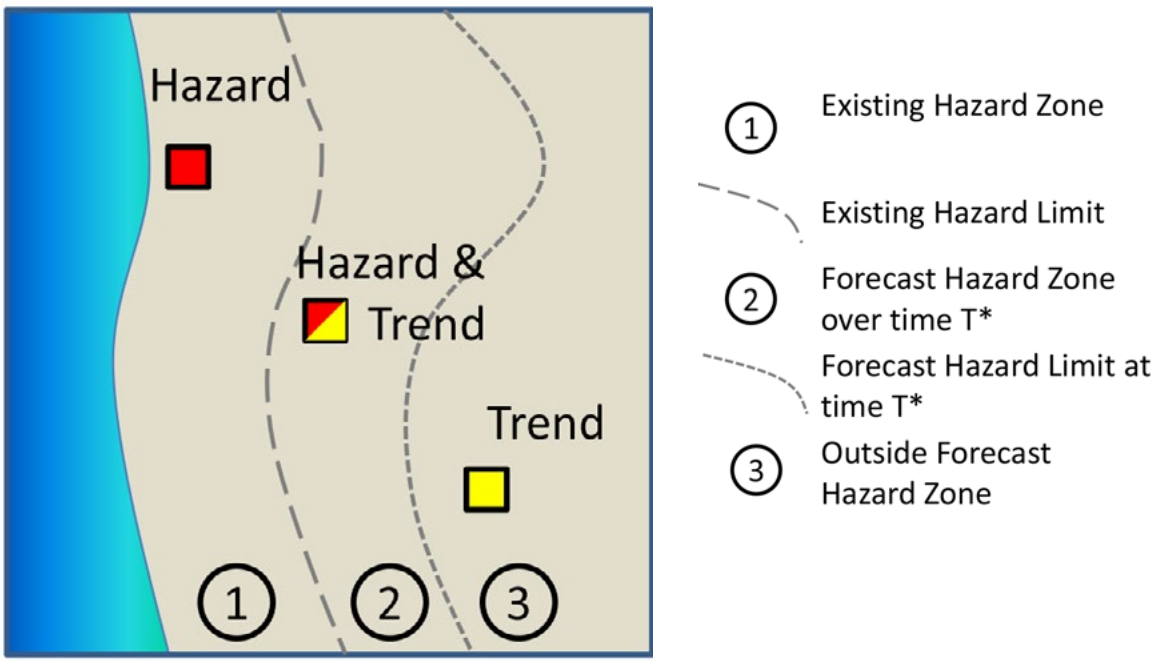

Figure 6.4 Influence of infrastructure position on coastal monitoring focus.

Note: The time frame of interest T* is usually determined by the lifetime of the asset, which in planning terms is commonly 100 years. Source: © Damara WA Pty Ltd 2015.

Table 6.2 Levels for coastal vulnerability assessment to climate change.

Level of assessment	Timescale required	Precision	Prior knowledge	Issues considered
Screening assessment (initial issue scoping)	2–3 months	Lowest	Low	Define the key issues and directions of change in broad qualitative or semi-quantitative terms. Strong focus on sea-level rise.
Impact assessment (initial impact and adaptation assessment)	1–2 years	Medium	Medium	Building on the screening assessment, impacts are quantified, including the possible role of other climate change and non-climate drivers. Adaptive capacity should be considered.
Planning assessment (linking to wider coastal management)	Ongoing (part of an adaptation process)	Highest	High	Building on the impact assessment, more comprehensive assessments are conducted, considering all relevant drivers (using multiple scenarios to explore uncertainty). Adaptation (see section 6.1 is an integral part of the assessment.

This implies that decisions must be taken at an early stage as to the level of detail required to inform decision-makers of the conditions likely to affect assets over time along soft shores in their locations. An indicative set of different information levels are suggested by Table 6.3, although it is noted that in most cases a range of information is used. The cost of developing a suitable level of information increases substantially from Level 0 up to Level 5, and the more expensive methods for evaluation (Levels 3–5) are usually reserved for the management of expensive assets, where refinement is perceived as adding value.

6.4 Coastal erosion monitoring

Coastal erosion monitoring involves time series measurement of the position of the shore, to detect erosion. This has an important role in helping to identify the most appropriate set of responses, through identifying active processes, trends and risks and determining whether management triggers have been reached. Coastal monitoring is a fundamental tool for informed decision-making in coastal management. Monitoring is therefore a function of which issues the coastal manager faces and what opportunities there are for action. Coastal monitoring objectives may be associated with broad levels of coastal management (Table 6.4), with increased resources required for both monitoring and management at higher levels.

Table 6.3 Information levels to support coastal decision-making.

Level	Main source of information	Comment
0	Policy position or generic analyses	Suitable for assets landward of the forecast hazard zone (i.e. setback definition). Based on the principle that development further landward reduces the risk of erosion hazard and increases the time before progressive erosion influences the asset. Usually overstates erosion hazard.
1	Desktop analysis	Conventionally uses analysis of historic aerial imagery (and relevant coastal data) to describe the observed erosion and accretion patterns. This can be used to support estimation of acute and progressive erosion behaviour.
2	Landform analysis	May support identification of active processes (guiding analysis methods), including apparent connections between adjacent landform and landform units.
3	Numerical modelling*	Typically required to estimate short-term erosion response if there is limited measurement of severe storm erosion. May be appropriate to assess progressive changes, particularly those related to proposed coastal protection works.
4	Field program (coastal dynamics, both onshore and offshore)	Confirms active processes and may be used to quantify coastal sensitivity to storms or changing conditions. May be appropriate for validation of numerical modelling.
5	Field program (stratigraphic and sedimentologic, both onshore and offshore)	May be appropriate to resolve patterns of progressive erosion or accretion, particularly in situations where a substantial trend may be considered subject to change.

Table 6.4 Management levels and corresponding monitoring objectives.

Management level	Description	Monitoring objectives
0. Reactive	Confirm that reactive management remains feasible	Confirm that reactive management remains feasible
1. Planned	Foreshore reserve used to provide buffer against coastal fluctuations	Allow forecast of effective time frame for buffer to be viable
2. Prioritising	Isolated management activities undertaken, including storm clean-up, dune revegetation or armouring	Provide measure to assist decision-making
3. Adaptive*	Management activities deliberately varied according to conditions and width of foreshore reserve	Identify the need to change management effort
4. Active	Using sand management or structures to distribute erosive or accretive pressures	Quantify management actions

* Note that an adaptive management level has a wider context here than adaptation to climate change (i.e. it includes shorter time frames).

Despite their potential importance, major changes due to sea-level rise are decades away, implying that the main objective for coastal monitoring (in an adaptation context) is to provide a baseline for comparison of future conditions. However, the occurrence of shorter term fluctuations in prevailing coastal conditions may also result in large behavioural changes, particularly the changes in coastal flooding associated with El Niño – La Niña climate cycles.

In most cases, state-changes indicating the need for adaptive decision-making should not be determined using the same set of coastal state indicators used to describe year-to-year coastal change (van Koningsveld et al. 2005, Payo et al. 2016). This is either because small progressive changes are obscured by more frequent fluctuations, or because changes caused by extreme or anomalous conditions may be more clearly identified by the associated meteorological or oceanographic parameters, which can potentially be used to establish event likelihoods. Defining a separate set of long-term coastal state indicators is presently a topic of scientific research. However, improved capacity to use existing short-term or local coastal state indicators for identification of state-changes may be developed through greater spatial awareness or by modifying the derived analysis parameters.

Spatially derived indicators for state-change associated with medium-term (5–10 years) coastal dynamics may include:

- change developing outside the notional depth of closure (Hallermeier 1981), which potentially indicates a shift in the balance of cross-shore sediment transport processes
- change to the apparent retentive capacity at cross-shore structures, which indicates the relative capacity for bypassing (e.g. updrift accumulations or headland connected spits)
- spatial variation of sediment cell accretion and erosion patterns that suggest change to the relative distribution of stresses (see Figure 6.6). At the smallest scale, this may involve comparing adjacent sediment cells, while for larger time and space scales, the behaviour of cells within a regional-scale coastal unit may need to be considered. State indicators may simply involve a count of erosion (or accretion) on a cell-by-cell basis, or (less simply) provide an interpretation of how the regional distribution of erosion and accretion may indicate reliability of alongshore sediment supply.

Sensitivity-based indicators for state-change associated with medium-term coastal dynamics include:

- coastal segments displaying seasonal state-switching, which may indicate almost balanced alongshore transport, even for moderately biased forcing. The relative prevalence of one state (e.g. northward or southward transport) may provide a useful indicator of coastal state-change
- areas that are 'lagged' with respect to the sediment supply pathway, and therefore may show increased signs of delayed recovery after acute erosion events. This is anticipated at locations immediately downdrift of a series of compartments, which 'normally' bypass.

A whole-of-region monitoring approach is recommended as a means of obtaining sufficient information to evaluate these spatially derived and sensitivity-based indicators for state-change. Information developed should be suitable to provide a baseline for ongoing assessment and to help identify coastal variability. Where there is large spatial dependence on connected sediment transport networks (e.g. a weakly compartmentalised coast), region-based monitoring may provide better warning of future decline of sediment supply, in cases where reduced sediment availability propagates alongshore.

As described by Figure 6.4 and associated text, the objectives for coastal monitoring change from identifying *likelihood* of risk to determining when an asset is considered to be at risk. Monitoring to determine the likelihood of risk is herein termed *monitoring for coastal erosion hazard*, and monitoring to determine the timing of future risk is herein termed *monitoring for coastal trend*. The importance of this distinction for coastal erosion monitoring is that different, albeit similar, information is used to establish the acute coastal response or coastal trend (Figure 6.5).

Coastal erosion occurs through a range of processes, which may occur rapidly or more progressively (Komar and Enfield 1987). Change may also occur as a trend, cycle or through a shift in coastal state.

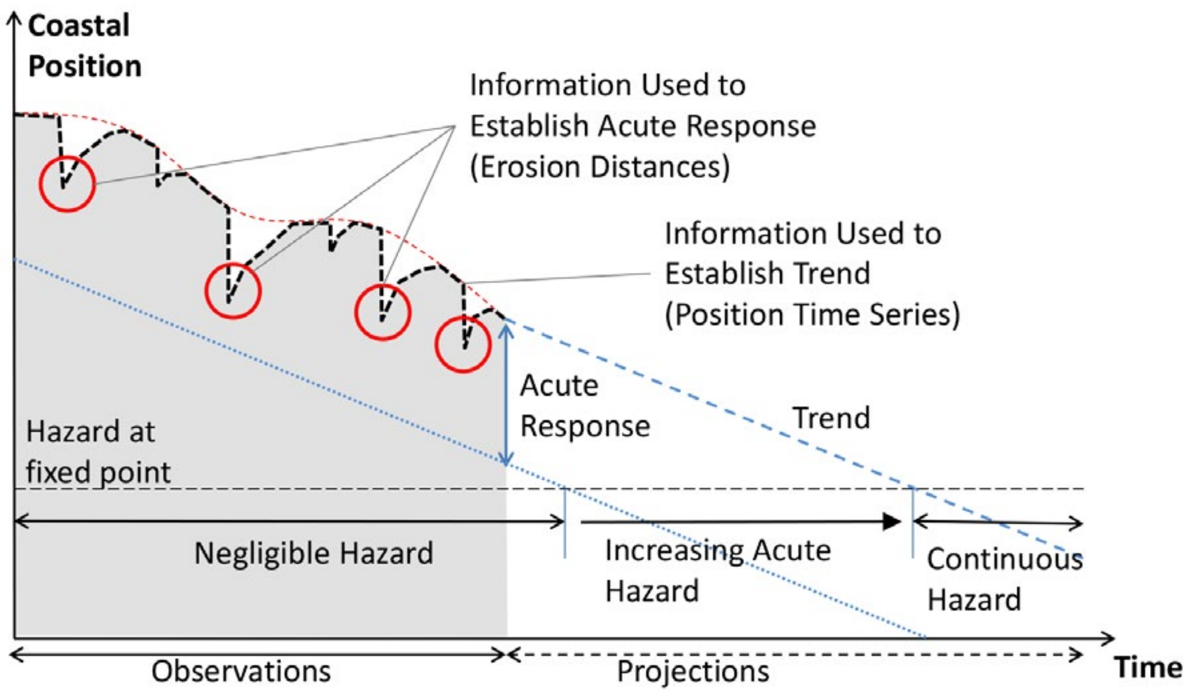

Figure 6.5 Schematic sketch showing the information used to define hazard and trend. Source: © Damara WA Pty Ltd 2015.

6.4.1 Monitoring for coastal erosion trend

Coastal trend analysis focuses on identifying the time available before a change in coastal management is necessary, normally the transition from negligible hazard to exposure to acute hazard (Figure 6.5). The forecast time is often estimated by the distance by which a foreshore reserve ($W_{reserve}$) is wider than the allowance for acute erosion (S_1), divided by the average rate of coastal change (dW/dt).

$$T\ forecast = (W_{reserve} - S_1) / \frac{-dW}{-dt}$$

The key dataset required is a time series of coastal position, from which a trend may be established. However, for many coastal measurements, short-term acute erosion events (storm bite) or moderate-term effects of variation in storminess affect observations. These fluctuations can significantly bias estimated trend, requiring monitoring in the field combined with historical analysis of shore position. Consideration should be given as to the confidence with which a trend may be established, taking into account the length of the observation dataset and its variability. Typically, a minimum of 40 years of observation is required to identify trends, which in many cases includes the effect of human interventions.

The simple time forecast suggested above may also require further interpretation on the basis of a spatial distribution of coastal change. Further thought may be required at the scale of a single council area or between adjoining councils in some situations:

- Presence of alongshore controls, such as rock headlands or groynes, may effectively provide a limit to erosion or accretion, after which dW/dt changes.
- On a coast with alongshore transport, coastal position may reflect the relative volume of a sediment sink or a source and the consequent availability of material.
- A mixture of erosion and accretion may suggest coastal rotation at a beach or cell scale, which tends to reduce the future rate of change, or be subject to reversal.
- The influence of migratory landforms, such as sand waves or pulses, can be significant at a local scale.

6.4.2 Monitoring for coastal erosion hazard

Coastal hazard evaluation, which focuses on the immediate threat of episodic coastal erosion, requires an understanding of the present state of the coast and an understanding of the likelihood of acute erosion. The key information to support coastal hazard analysis is a set of measurements of acute coastal response, typically storm events, with which a likelihood of acute erosion may be established. Historical records may assist in this regard. This is often presented as an erosion distance (sometimes area or volume) with an *n*-year average recurrence interval, being the distance of erosion that occurs on average once per *n* years.

In most cases, there is insufficient information to *establish event recurrence*, which is instead parameterised by coastal variables such as wave height, water level or storm persistence. The corresponding response is determined by numerical modelling, usually based on cross-shore profile models such as SBEACH or 3D models such as XBEACH. This approach has been widely adopted in planning policy as a general means for estimating storm erosion likelihood (Walsh et al. 2004). Generic cross-shore storm erosion allowances have been derived for different beach types around Australia, subject to different wave and water level regimes (Mariani et al. 2012). Further work is necessary to characterise response for different coastal configurations or to establish erosion likelihood relationships.

Field monitoring of acute response requires either frequent coastal measurement or a program of occasional coastal measurement combined with post-event measurements. In either case, it should involve corresponding meteorological and oceanographic monitoring to support evaluation of acute erosion likelihood and will typically require coastal modelling.

Monitoring to support identification of key processes and enable validation of coastal modelling is generally not required by regulatory agencies. Although such refinement could be in the order of 20 m, it is not crucial to coastal management because:

- on undeveloped shores, it is a small component relative to the allowances for long-term trends
- for developed shores, active management requires the ability to respond to extreme events, regardless of their estimated likelihood.

However, situations in which a strong understanding of acute response is required are largely restricted to those cases where coastal erosion management requires short-term preventative actions (e.g. sand-bagging or temporary removal of foreshore infrastructure). Following risk-management principles, this type of management should only correspond to low value coastal assets.

Monitoring for coastal hazard typically requires a higher level of monitoring effort than monitoring for coastal trend. In particular, higher frequency information is usually required to gain an appropriate understanding of erosion response and subsequent recovery.

6.4.3 Wider scale evaluation of coastal erosion

Coastal change includes alongshore movements of sediment in response to both short-term weather events and prevailing weather conditions. For much of the Australian coast, this is dominated by seasonal movements (Short 2010). In some locations, coastal monitoring has also shown the importance of decadal-scale shifts in storminess or prevailing winds (Thom and Hall 1991, Eliot and Travers 2011). The resulting sand movements back and forth along the coast influence the relative abundance of sediment adjacent to coastal control points, such as groynes or rock headlands. In turn, these affect the rates of 'natural' sand bypassing and the abundance of sediment along the adjacent downdrift coast. The capacity for bypassing is enhanced under very strong or sustained conditions for coastal segments where controls can be classed as 'leaky'.

On a compartmentalised coast that is closed to sediment transfer between compartments, fluctuations of alongshore transport may cause material to move from one end of the compartment to another (i.e. beach rotation). This will produce erosion at one end of the compartment and accretion at the other. In most cases, this pattern of behaviour suggests a limited need for intervention, as a return to prevailing conditions is also likely to cause the sediment to largely return to its original position. However, situations where this may not occur include those where:

- an unusually high volume of bypassing has occurred, which affects the availability of sediment within the compartment (i.e. a feature controlling shoreline in the compartment is intermittently leaky, such as river mouths)
- sediment movement has caused disruption or formation of features that reduce the volume of available sediment substantially, such as infilling of a large previously existing depression or inlet, loss into mobile dunes or formation of an offshore sandbar that is subsequently slow to move back onshore to restore beach and foredune volumes.

Coastal monitoring along an entire compartment, even qualitatively, is therefore essential as a means of identifying whether recovery after an erosive episode is likely (McLean and Shen 2006). An understanding of spatial sediment transfers developed through coastal and estuarine systems mapping (CESM) as related to driving processes may help identify this likelihood (French and Burningham 2009, French et al. 2016, http://www.channelcoast.org/iCOASST/introduction/ - accessed 4 May 2016). Littoral cells or sediment cells identified for some parts of Australia (see Section 7.5) indicate some of the scales to consider, based on apparent barriers (or impediments) to alongshore transport or the existence of other mechanisms of sediment loss.

Spatial connectivity also applies to adjacent cells. In most cases adjacent cells experience similar coastal forcing, therefore, comparing the similarity of behaviour between adjacent cells is one means of distinguishing whether the erosion is a local or regional issue (Figure 6.6). However, as adjacent cells and the coastal barriers that define them are rarely of similar configuration, the pattern of response and rate of bypassing is not usually identical. Local erosion may therefore occur when loss from one cell has not been balanced by supply from the updrift cell or, in the case of a closed cell, there is a lag in the recovery from offshore or loss into dunes or inlets. A decision regarding intervention to address erosion should consider the availability of sediment from updrift if the driving conditions continue. Information regarding compartment behaviour is available at large scales through the Coastal Compartments Project (section 7.5), with smaller scale information, suitable for looking at sediment cells, being more commonly defined in local-scale consultant reports.

Illustration of how to use spatial behaviour to assist with selecting coastal management focus is suggested by Figure 6.6. Four scenarios are presented:

- If there is variability in erosion and accretion trends within a single sediment compartment, then there may be opportunity to locally use alongshore sediment transfer to balance out the two. This is a conventional coastal engineering approach for a relatively stable shore.
- If there is variability in erosion and accretion trends between adjacent sediment compartments, then management at the boundary of the two compartments may be used to balance the supply.
- If erosion occurs over the majority of a cell that is not substantially losing sediment, then focus should be on increasing the capacity for onshore sediment movement, including dune management.
- If erosion occurs over multiple compartments, suggesting a net loss of material, then any attempts at stabilisation will amplify the erosion problem elsewhere. Redistribution of sediment requires careful trade-offs and therefore involves strategic coastal planning.

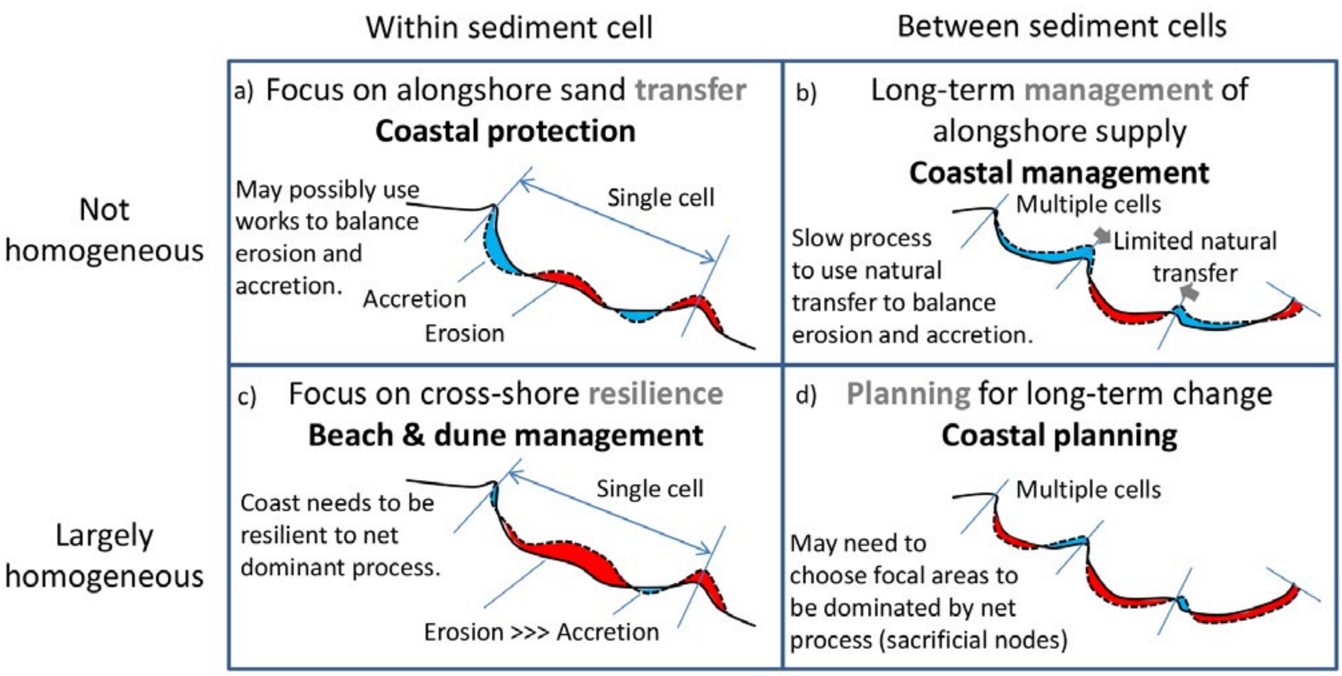

Figure 6.6 Indication of coastal management focus suggested by spatial patterns of change.
Source: Stul et al. 2015 © Government of Western Australia.

Connectivity between a series of compartments also occurs. Depending on the sediment demand and the balance of transfers between compartments, this may create preferential areas for erosion, sometimes termed erosion hotspots (McNinch 2004). A typical occurrence is where a severe storm causes sand to be moved offshore along multiple compartments – some will recover much faster than others. The recovery rate is generally related to the origin of sand supply and its pathway, with those compartments closest to the source being most capable of recovery and those further along the path experiencing lagged recovery and possibly enhanced downdrift erosion. A similar mechanism is likely to occur over longer time scales in response to changing prevailing conditions, including sea-level rise (Eliot 2013).

Different levels of spatial coherence for coastal behaviour determine that there may be several indicators of potential natural erosion mitigation (Table 6.5). Decision-making regarding coastal recession is therefore best informed by coastal monitoring that captures both a local and a wider regional perspective.

Consideration of potential cross-shore transfer is commonly applied to coastal management decision-making and is a major cause of increased nearshore monitoring for coastal managers who undertake active coastal management, such as sand bypassing. However, consideration at larger scales has been less targeted, with most understanding developed through site inspection or via vertical aerial photographs. A hierarchical sediment cells framework has been developed for several parts of Western Australia (Stul et al. 2015) to support spatial interpretation, with different levels of the framework applicable depending on the time scale or physical scale of the coastal disturbance (e.g. severity of storm erosion or the size of a constructed facility).

Table 6.5 Areas related to indicators of potential erosion mitigation.

Area considered	Indicator of potential natural erosion mitigation	Speed of response
Cross-shore	Presence of nearshore bar	Fast: much of the recovery may occur within the same season
Within cell	Equivalent accretion at other end of cell	Moderate: recovery typically requires seasonal reversal
Adjacent cell (updrift)	Sand bypassing imminent	Moderate: recovery is usually partial and typically requires seasonal reversal
Updrift cells (from source)	Adequate sand available updrift and bypassing occurring	Slow: may take several years for recovery to occur

6.5 Erosion monitoring for adaptive management triggers

A key application of coastal erosion monitoring in the context of climate change is through the identification of management triggers for an adaptive management framework. The existing coastal position is interpreted through a model for coastal change (typically a conceptual rather than numerical model) to forecast possible coastal positions at a future time of interest. This time frame of interest should consider the possible management interventions and how long they need to be implemented given different degrees of land-use sensitivity to change in position of soft shores over time.

In most cases, management triggers based on erosion of soft shores require distinction between short-term erosion and long-term recession, as the capacity for recovery from short-term erosion may substantially offset the need for intervention in some locations for many years into the future, even as sea-level rise continues.

Although management triggers for erosion are commonly used to identify when engineering works are appropriate, they are also relevant to coastal planning and monitoring. In planning terms, a recession trigger may be used to identify if coastal erosion buffers have narrowed to the point that 'avoidance' of erosion is no longer practical over a planning time frame. Changes in coastal monitoring that may be indicated by triggers include the shift from monitoring for trend to monitoring for hazard (increased monitoring frequency) or where there is an increased likelihood of intervention, which will affect the distribution of sediment (increased spatial coverage of monitoring of the entire sediment budget).

6.6 Adaptation pathways on soft shores

Improved understanding of soft shore response to future conditions can be established through the identification of coastal geomorphology and recognition of spatial connectivity of coastal sediment transport (section 5) supported by an appropriate coastal monitoring program (section 0). However, despite these improvements, prediction of future coastal behaviour retains a high degree of uncertainty due to:

- difficulty identifying a coastal trend for recession or progradation with confidence
- the potential for historic trends to become unstable due to climate change
- uncertainty regarding how each section of coast will respond to sea-level rise
- spatially distributed effects of human interventions, including coastal adaptations.

In this context, the adaptation pathways approach to managing climate change impacts is considered to have high value for managing soft shores. The approach supports continued present-day use of high value shores, while acknowledging the potential for future recession.

The integration of monitoring and management, particularly when applied at a compartment scale, allows coastal managers to strengthen coastal resilience to climate change. This may be by locating the highest value assets in areas of greatest stability or by redistributing erosion pressure, with efficient use of natural sediment transport pathways.

Observations of coastal change, considered in a spatial context, potentially indicate an appropriate coastal management focus (Figure 6.6).

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7 Using available information

The dynamics of soft shores may occur as the result of a range of processes that are active at different time and space scales (Wright and Thom 1977). Information that is relevant to the management of soft shores therefore comprises observations of the coast itself, measurement of parameters that describe the forcing processes and increasingly model-based analyses. A wide range of information is available, varying from site-specific information to global coastal assessments. A detailed description of some of the data sources relevant to decision-making on soft shores is outlined in Information Manual 3: Available datasets.

This manual presents ways that available information, particularly information sources available at a national level, may support local and regional decision-making. However, it is crucial to recognise the importance of *locally collected data*, as the relevance and availability of coastal information vary inversely with scale (Figure 7.1).

Information that is relevant to soft shores varies with time scale (Figure 7.2), from observational data, which are most relevant to short time scales, through to information that is inferred or modelled, which may describe very long-term dynamics. Information may be collected or held by a range of agencies, including natural resource management groups, academic, state or local government agencies.

Much of the regional coastal information is held by state governments, which have developed significant repositories of information that is relevant to coastal management. State agencies with strong interests in coastal management include (accessed 4 May 2016):

New South Wales – Office of Environment & Heritage
http://www.environment.nsw.gov.au/coasts/

Queensland – Department of Environment and Heritage Protection
http://www.ehp.qld.gov.au/coastal/

South Australia – Department of Environment, Water and Natural Resources, including the South Australian Coastal Protection Board
http://www.environment.sa.gov.au/our-places/coasts

Tasmania – Department of Primary Industries, Parks, Water and Environment
http://dpipwe.tas.gov.au/conservation/coastal-management

Victoria – Victorian Coastal Council
http://www.vcc.vic.gov.au/page/about-us

Western Australia – Department of Planning
http://www.planning.wa.gov.au and

Department of Transport (Maritime Division)
http://www.transport.wa.gov.au/imarine/coastal-erosion-and-stability.asp

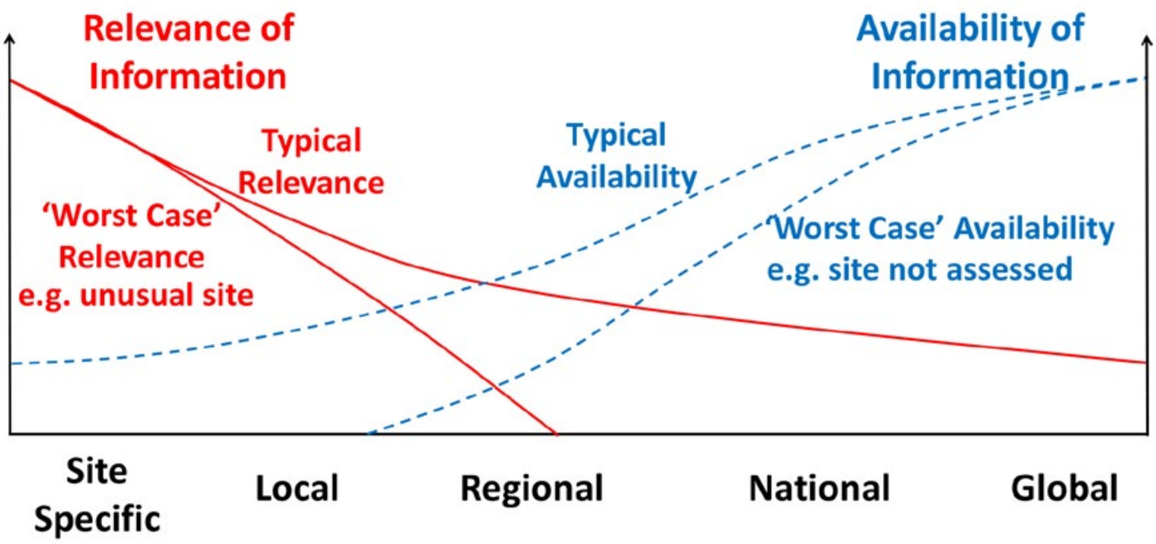

Figure 7.1 Relevance and availability of coastal information with scale. Source: Developed by the author.

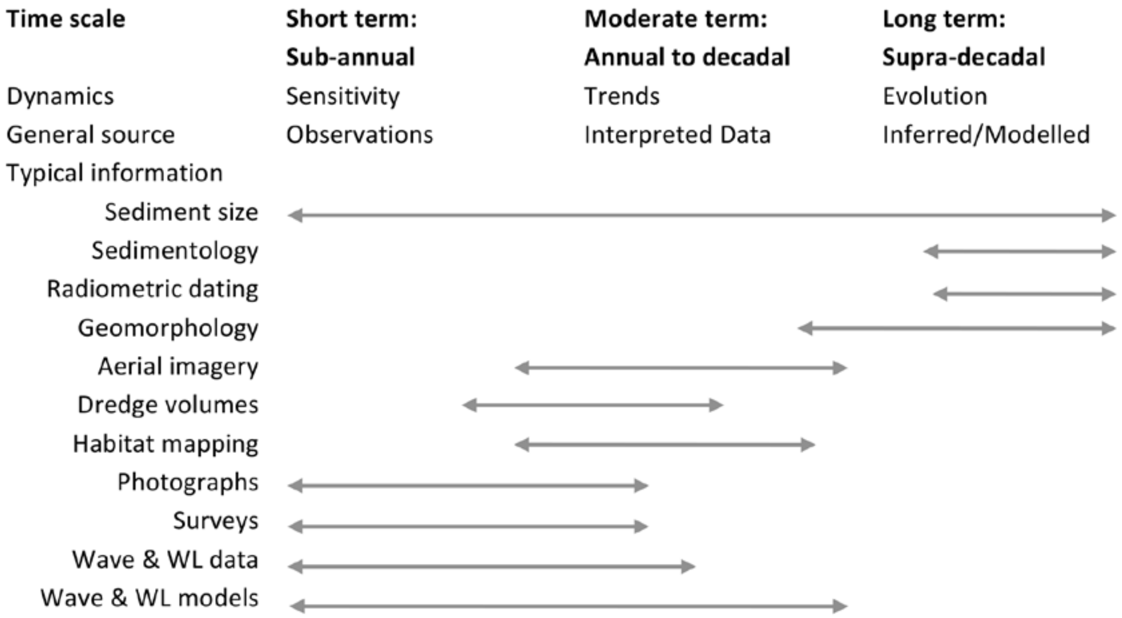

Figure 7.2 Typical information used to understand soft shores Note: The role of modelling (numerical and conceptual) becomes increasingly important for dealing with longer term coastal assessment. Source: Developed by the author.

In some instances, extensive local information is directly held by local government agencies or natural resource management groups. This has occurred either through decentralisation of coastal management, such as occurred in Victoria, or where a local government determined that a locally relevant form of management was required, with the Gold Coast being an early outlier, more recently followed by Sydney Coastal Councils.

State agencies have produced substantial policies and information relevant to coastal management, such as the *NSW coastline management manual* (NSW Government 1990), *WA coastal planning and management manual* (WAPC 2003), *South Australian Coastal action plans* (Caton et al 2009, Caton et al 2011).

In most cases, state government agencies also manage key data collection, such as waverider buoy deployments and tide gauge networks, some of which is also separately stored and analysed by the Bureau of Meteorology National Tidal Unit: http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml (accessed 4 May 2016).

Morphological data, including shore profiles, surveys and aerial photographs, are most commonly held by state agencies, although there is an increasing volume of data stored by local government agencies, particularly those facing existing erosion pressure.

7.1 Identifying information needs

The need to identify valid useful information occurs for all coastal decision-makers, whether their coast is locally information-rich or -poor. For information-rich sites, available information may need to be filtered, while on information-poor sites, the challenge is to identify information gaps and subsequently populate the gaps using alternate sources. Traditionally, much of the gap-filling was achieved through numerical modelling. Today, the prevalence of regional remote-sensed information provides a much stronger baseline for coastal managers to develop an understanding of their coast. This extends from highly accessible information with relatively limited spatial controls, such as Google Earth or NearMap, through to high resolution and accurate datasets such as LiDAR topography for extensive parts of the Australian coast.

Two alternative means of evaluating information requirements are in common practice (Figure 7.3). These may be equally valid, although the geomorphic approach is more commonly applied to assessments where long-term change is of interest, and the modelling approach is applied where short-term change is of greater interest. Some efforts to merge these approaches for longer term coastal change assessment is underway (van Maanen et al. 2016).

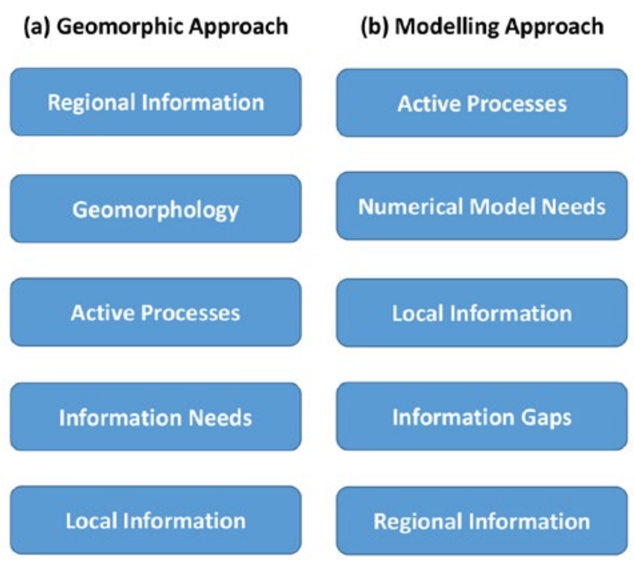

Figure 7.3 Frameworks to connect regional and local information. Source: Developed by the author.

The *geomorphic approach* uses regional information to determine a geomorphic classification for the site, based on landforms, sediment characteristics and the environmental conditions that shape the coast (van Rijn 1998). In turn, this indicates the key processes active at the site and indicates what information may be needed to be locally relevant. A comprehensive demonstration of this technique has been illustrated for Australian estuaries (Ryan et al. 2003), where the geomorphology plays a greater role in how the coast responds to stress.

In situations where a strong understanding of the coast, including its active processes, already exists, or the response of the coast is considered to fit a single conceptual model for change, *the modelling approach* is often efficient. The available set of local information is compared against the model requirements, with any data gaps identified, and populated either by regional information or supplementary modelling.

The relative efficacy of the two approaches has been demonstrated in studies of the whole Australian coast.

Study 1: The first-pass national coastal vulnerability assessment (DCC 2009) undertook an extensive evaluation of coastal datasets to assess locations that were most at risk due to projected sea-level rise. Common characteristics of identified sites were that they had little rock, experienced relatively low wave and tide conditions and their landforms had mainly developed over the late Holocene. This represents a relatively constrained geomorphic classification, highlighting the potential benefit of using a geomorphic approach to assess information needs.

Study 2: Generic design coastal erosion volumes and setbacks for Australia (Mariani et al. 2012) presented an analysis of coastal erosion modelling, considering different storm and beach types. Here the application of a unified model enabled a coarse resolution analysis around the Australian coast, thereby avoiding the complexity introduced by considering local geomorphology and different active processes. A key element of the approach was the assumption that using conservatively high estimates of erosion gives an allowance for local variation in how well the model fits reality. It is also noted that the component of progressive coastal change through alongshore sediment transport, which provides a major vector for coastal adaptation through engineering, requires evaluation on a local scale.

Study 3: East coast study project – national geomorphic framework for the management and prediction of coastal erosion (Mariani et al. 2013) undertook evaluation of several existing approaches to the analysis of potential coastal response to climate change for two selected embayments on the New South Wales coast: Avoca Beach and Cabarita Beach. These sites differed substantially, in that Avoca Beach is largely a closed compartment (for sediment transport), whereas Cabarita Beach is part of a wider littoral transport system (i.e. it is a leaky compartment).

Modelling of long-term behaviour was developed using a sediment budget–based approach using deterministic (best-estimate) and probabilistic (uncertainty) estimates of the factors influencing coastal change. The analysis highlighted the potential for results of the two methods to diverge significantly. The capacity of the probabilistic model to explore sensitivity of shoreline recession to variability of the sediment budget components was examined.

7.2 National Committee on Coastal and Ocean Engineering Framework

The National Committee on Coastal and Ocean Engineering (NCCOE) provides technical references that give professional guidance to practising coastal engineers. A series of documents relevant to coastal management and adaptation have been developed, including:

- At what price data? (NCCOE 1993)
- Guidelines for responding to the effects of climate change in coastal and ocean engineering (NCCOE 2012a)
- Guidelines for working with the Australian coast in an ecologically sustainable way (NCCOE 2012b)
- Climate change adaptation guidelines in coastal management and planning (NCCOE 2012c).

These documents and their application to coastal management are outlined in greater detail through Information Manual 7: Engineering solutions.

The NCCOE Guidelines include a systematic framework for the consideration of climate change impacts on coastal and offshore facilities. The guidelines outline available information regarding primary 'environmental' variables likely to be directly affected by climate change and secondary 'process' variables that may result from the interaction of the environmental variables with local conditions (Table 7.1).

This framework enables a step-by-step evaluation of the possible impacts of climate change upon a particular object or structure. When applied to either an observed section of coast or more widely to a geomorphic classification, the framework provides a means of identifying relevant coastal processes. NCCOE recommends the use of evidence-based behaviour where suitable information exists and application of sensitivity assessment where suitable information does not exist, to reduce the likelihood that poorly understood or modelled processes are neglected.

An example of the application of the NCCOE framework to identify relevant information is presented for Mandurah, Western Australia (Table 7.2). Using a combination of observations and conceptual and numerical modelling, the relative shoreline sensitivity to primary and secondary variables was examined for riverine, estuarine, tidal channel and coastal zones. A similar approach has been presented in the United Kingdom (Jay et al. 2003)

7.3 OzCoasts Portal

The OzCoasts Portal hosts a wide range of regional-scale information relevant to the identification of coastal geomorphology, including demonstration of the relationships between morphology and active coastal processes: http://www.ozcoasts.gov.au/index.jsp (accessed 4 May 2016).

Three sets of information available on the Portal that are relevant to identification of geomorphology and active processes are:

- estuarine typology (Oz Estuaries)
- beach typology and beach geomorphic models (Australian Beach Safety and Management Program)
- coastal landform and stability mapping tool (Smartline).

7.3.1 Oz Estuaries

The Oz Estuaries program included definition of an estuarine typology, based on identified relationships between forcing processes (waves, tides and run-off) and the landform units present within the estuary and adjacent coast (Heap et al. 2001, 2004). This geomorphic typology has been related to a series of conceptual models, including indication of the nature of sediment dynamics within each type of estuary (Ryan et al. 2003).

Table 7.1 Primary and secondary coastal variables. Source: NCCOE 2012a.

Primary variables	Secondary variables	
K1 – Mean sea level	S1 – Local sea level	S9 – Foreshore stability
K2 – Ocean currents / temperatures	S2 – Local currents	S10 – Sediment transport
	S3 – Local winds	S11 – Hydraulics of estuaries
K3 – Wind climate	S4 – Local waves	
K4 – Wave climate	S5 – Effects on structures	S12 – Quality of coastal waters
K5 – Rainfall/Run-off	S6 – Groundwater	
K6 – Air temperature	S7 – Coastal flooding	S13 – Ecology
	S8 – Beach response	

Table 7.2 Example application to sensitivity of shoreline stability. Example provided for application at Mandurah, Western Australia. Parameters K2, K6, S12, S13 not included on the basis of local knowledge or data limitations.

Zone Parameter	Riverine	Estuarine	Channel	Coastal
K1 – Mean sea level	Low	High	Moderate	Moderate
K3 – Wind climate	Negligible	High	Low	Low
K4 – Wave climate	Negligible	Moderate	Low	High
K5 – Rainfall/Run-off	High	Low	Moderate	Negligible
S1 – Local sea level	Low	High	Moderate	High
S2 – Local currents	High	Moderate	High	Moderate
S3 – Local winds	Negligible	High	Negligible	Low
S4 – Local waves	Negligible	Moderate	Negligible	High
S5 – Effects on structures	High	Low	High	High
S6 – Groundwater	Low	Low	Low	Low
S7 – Coastal flooding	Low	Moderate	Moderate	High
S8 – Beach response	Moderate	Moderate	Moderate	Moderate
S9 – Foreshore stability	High	High	High	High
S10 – Sediment transport	Moderate	Moderate	High	High
S11 – Estuary hydraulics	Low	Moderate	High	Negligible

7.3.2 Australian Beach Safety and Management Program

Collation of basic information and description of all of the beaches of Australia has been undertaken systematically on behalf of the Australian Beach Safety and Management Program. This information is available as a series of publications listed below. The description of each beach includes known information regarding the geomorphology, including classification as one of 12 types within the unified conceptual model for beach behaviour (Wright and Short 1984).

- Beaches of the Victorian Coast & Port Phillip Bay: A guide to their nature, characteristics, surf and safety (Short 1996).
- Beaches of the Queensland Coast: Cooktown to Coolangatta: A guide to their nature, characteristics, surf and safety (Short 2000).
- Beaches of the Southern Australian Coast and Kangaroo Island: A guide to their nature, characteristics, surf and safety (Short 2001).
- Beaches of the Western Australian Coast: Eucla to Roebuck Bay: A guide to their nature, characteristics, surf and safety (Short 2005).
- Beaches of Northern Australia: The Kimberley, Northern Territory and Cape York: A guide to their nature, characteristics, surf and safety (Short 2006a).
- Beaches of the Tasmanian Coast and Islands: A guide to their nature, characteristics, surf and safety (Short 2006b).
- Beaches of the New South Wales Coast: A guide to their nature, characteristics, surf and safety (Short 2007).

7.3.3 Smartline

A component of the First-pass national coastal vulnerability assessment (DCC 2009) was mapping of coastal landform information along the entire Australian coastline. A classification scheme was developed that described landform features in three separate zones, based on tidal conditions (Figure 7.4). This provides comparatively high resolution spatial information regarding areas that may resist erosion pressure or contribute to coastal sediment dynamics. Key interrogation of the Smartline database as part of the assessment included identification of the proportion of coast that was rocky, a mixture of sand and rock, or largely mobile sediments.

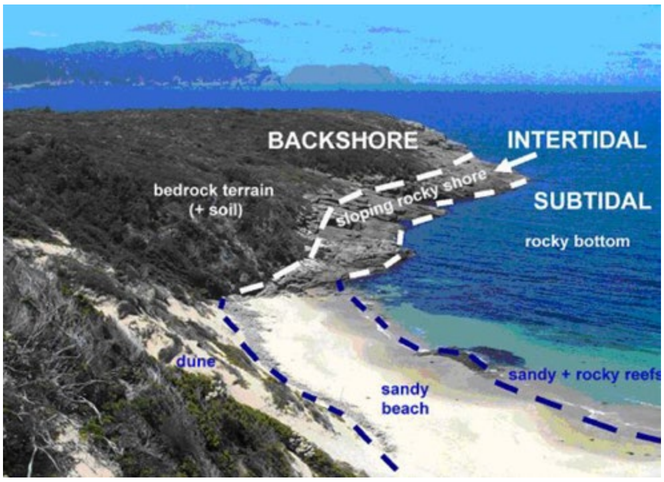

Figure 7.4 Tidal zones used to delineate landform descriptions in Smartline

Note: Landforms of the coastal zone are described in terms of three shore-parallel tide-defined zones indicated in this figure. Landforms within each of these zones are described using two descriptive attribute fields plus another field describing the overall zone profile or slope. Source: Sharples et al. 2009.

7.4 Geoscience Australia

Geoscience Australia, in its role as a repository for geosciences data, retains information related to both terrestrial and marine geology and sediments. This information has supported a number of investigations or interpretations that may be relevant to developing an understanding of coastal geomorphology.

The geomorphic frameworks supporting the estuarine typology on the OzCoasts Portal were developed through Geoscience Australia (Ryan et al. 2003). Some supplementary information is available from http://www.ga.gov.au/scientific-topics/marine/coasts-estuaries (accessed 4 May 2016).

Geoscience Australia has collated a range of hydrographic data sources and digitised existing hydrographic charts to produce a bathymetric and topographic grid across Australia and its coastal waters, at a spatial resolution of 250 m. This dataset is available from http://www.ga.gov.au/scientific-topics/marine/bathymetry (accessed 4 May 2016).

Marine sediment information collated by Geoscience Australia has been described and interpreted within a geomorphic context for several different parts of Australia. In general, this information is more relevant to the characteristics of shelf sediments and offshore from the shelf boundary than to the coastal margin. However, for much of Australia, this provides an important setting for inner shelf coastal sediment dynamics. A general description is available from http://www.ga.gov.au/scientific-topics/disciplines/sedimentology (accessed 4 May 2016).

The following documents provide relevant information about shelf sediments and regional geomorphology:

- Geomorphology and sedimentology of the northwest marine region of Australia (Baker et al. 2008)
- Geomorphic features of the continental margin of Australia (Harris et al. 2003)
- Sedimentology and geomorphology of the east marine region: A spatial analysis (Keene et al. 2008)
- Geomorphology and sedimentology of the South Western Planning Area of Australia: Review and synthesis of relevant literature in support of regional marine planning (Richardson et al. 2005)
- The geomorphology and sediments of Cockburn Sound (Skene et al. 2005)
- Seascapes of the Australia margin and adjacent sea floor: Methodology and results (Whiteway et al. 2007).

7.5 Coastal compartments

Coastal compartments are spatial units, identified along the coast, that have been presented as a means of better describing large-scale and long-term coastal behaviour. Similar approaches are widely used around the world, with a variety of scales and characteristics (McGlashan and Duck 2002; Hansom et al. 2004; Rosati 2005; van Rijn 2010; Nicholls et al. 2013). In Australia, application of compartments to coastal change assessment has historically been inconsistent and mainly applied to small areas. However, the value of the approach has been illustrated by the success of the Adelaide Beaches program (DEH 2005).

The Coastal Compartments Project has been coordinated by the Department of Environment, aiming to provide a consistent approach to compartment identification around Australia, based on the physical characteristics of the coastal environment. Such an approach will ensure that coastal erosion assessments can more readily be compared with adjoining areas, or upscaled to fit within larger regional assessments. As part of this project, Australia's coastline has been mapped as compartments based on landforms and patterns of sediment (sand and other beach material) movement: https://www.environment.gov.au/climate-change/adaptation/australias-coasts/coastal-compartments (accessed 4 May 2016).

A three-level approach towards definition of compartments has been proposed, each of which supports different types of decision-making (see Figure 5.10). A major benefit of using multiple levels is the improved ability to transfer information regarding coastal behaviour between scales, particularly information about alongshore sediment transfers, which are the dominant mechanism for change over time scales from decades to centuries (de Vriend et al. 1993, Cowell et al. 2003) and a crucial component in the expected coastal response to projected sea-level rise (DCC 2009, IPCC 2014).

Previous definitions of compartments in Australia have been applied at all three levels, although in many cases they have only been identified at one scale (Davies 1978, Searle and Semeniuk 1985, Roy 1994). The potential benefits of using more than one scale have been illustrated in the United Kingdom (Cooper and Pontee 2006), and a more complex example using multiple scales and multidisciplinary input was developed to provide connectivity between different planning scales for Western Australia, from site scale through to regional planning (Eliot et al. 2011). There are strong parallels in the field of river management (Gurnell et al. 2016). Most commonly, compartment concepts are considered only in a cursory fashion, at the scale of tertiary compartments or smaller, where the compartment is used as a boundary, from which there is limited or zero sediment transfer. This is a convenient setting for the use of numerical models.

Coastal compartments are areas in which there is strong connectivity between marine and terrestrial landforms. Hence, they are natural management units, presented in a simple spatial format. Applications of compartments include identification of spatial context for coastal evaluations, a common framework for dialogue about the coast, support to coastal management decision-making and a range of technical uses largely relating to coastal stability assessment. Some applications of compartments are listed in Table 7.3 and given brief descriptions below:

Table 7.3 Some applications of Coastal Compartments.

Context	• Identification of area to be evaluated • May be used for problem scaling
Communication	• Cross-jurisdictional cooperation • Spatial basis readily comprehended by non-technical audience • Common framework for discussion between disciplines
Decision-making	• Cross-jurisdictional cooperation • Better appreciation of coastal management precedents • Recognition of stabilisation trade-offs
Technical use	• Improved coastal erosion assessment • Sediment budget development • Upscaling and downscaling of coastal information • Identification of key coastal processes

Context: Coastal compartments provide an indication of a spatial area within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange. This implies that either natural or imposed changes at any point in the compartment may affect any other part, recognising that such relationships are strongly bound by proximity. The use of compartments is therefore one of context, to identify an area that should be considered in a coastal study. Specifically, questions that should be considered are:

- How may an imposed action, such as installation of a groyne, affect the wider coast through changes to the sediment budget?
- Have changes to the wider area influenced locally observed response?

Note that this does not mean that compartments must be used to define a study area or a model area. These are typically smaller due to data or budget limitations.

A qualitative assessment within the compartment context is often valuable for problem scaling when dealing with coastal instability. Considering whether an observed issue is prevalent within a compartment or adjacent compartments may provide guidance on the type of management solutions available and therefore suggest the form of technical advice most likely to be useful (Figure 6.6). For example:

- If there is a balance of erosion and accretion within a tertiary compartment, then there is potential opportunity to manage the problem through coastal stabilisation works, which transfer stresses along the coast
- For a coastal stability issue that is affecting the majority of a tertiary compartment, then it is appropriate to improve coastal resilience, including techniques that improve the transfer of sand from the nearshore to the beach and dune system
- If erosion and accretion occur differently between tertiary compartments, then it is possible that the stress can be more evenly distributed, including artificial interventions such as bypassing. However, limited natural sediment transfer at compartment boundaries determine that balancing erosion and accretion requires long-term management
- If erosion or accretion is prevalent across multiple compartments, then the issue is likely to be dominant in the long term. This typically requires a decision about where to focus the problem, such as through identification of sacrificial coastal nodes.

Communication: A key feature of the compartment framework is that it is developed from physical attributes rather than a jurisdictional basis. This highlights situations where communication between coastal managers may be necessary and supports formation of strategic planning groups, such as the Victorian Coastal Council, Sydney Coastal Councils, Peron Naturaliste Partnership or Cockburn Sound Coastal Alliance. The Tweed Bypass sand transfer system from northern New South Wales onto Gold Coast beaches is a good example of planning, construction and communicating the application of sediment movements between compartments.

The relatively simple spatial representation of compartments may be a valuable tool for communication between technical agencies and the general public. Recent application of CESM (French and Burningham 2009; French et al. 2016a, 2016b) has highlighted the value of participatory spatial tools to discuss the basis for coastal management decisions with a non-technical audience and engage with their knowledge, as well as gain their acceptance.

Communicating through a common spatial framework may also create value by enhancing dialogue between technical staff involved in different disciplines (Eliot et al. 2011). However, the existing strong relationship between habitats and morphology (Lyne et al. 2006) includes links between catchments areas and coastal compartments; this more broadly suggests that compartments may have value as natural management units when considering natural resource management or coastal ecosystem services.

Decision-making: Recognition of the interconnected nature of marine and terrestrial landforms within a compartment may support simplified decision-making by coastal managers, including local and state government agencies.

For agencies managing large areas, compartments can be used for low-cost geographic screening, particularly when this information is combined with knowledge of the direction of net alongshore sediment transport. As the compartments, particularly at tertiary level, provide preliminary guidance regarding the possible extent of development impacts, the compartments framework may be used to guide the distribution of infrastructure. For example, destabilising infrastructure may be preferentially excluded from a compartment containing sensitive or high amenity coastal areas. Alternately, a largely isolated single compartment may be identified as a strategic coastal node, with focused coastal protection works and interventions creating a minimised coastal footprint.

An understanding of how coastal dynamics vary within or between compartments is an important offset for decision-making that is strongly affected by precedents:

1. Sediment redistribution within compartments is commonly stronger than transfer between compartments. Consequently, there may be substantial differences in erosion-recovery patterns or long-term coastal evolution depending on whether a compartment is 'leaky' or has an external source of sediment. This has been demonstrated through numerical modelling as part of the Coastal Compartments Project (Mariani et al. 2013). Where significant differences occur between compartments in the same government jurisdiction, the application of a single set of coastal management principles can be strained.
2. The perceived efficacy of coastal protection works at one location is often deemed to be an indication that a similar method can be applied to adjacent locations or those which are structurally similar (e.g. using groynes at the downdrift end of a compartment). These parallels should be carefully assessed in the context of overall sediment transfers within the compartment system, as they are ultimately related to the reliability of sediment supply and the relative length of coast over which fluctuations in sediment supply can be distributed.
3. A compartment-scale perspective of coastal sediment dynamics is required to determine the regional effect of coastal protection works, due to their potential effects on alongshore sediment transport, particularly if considering the long-term consequence of sea-level rise.

An objective of coastal compartments definition is to focus coastal managers' attention on the connected nature of marine and terrestrial landforms. This is intended to disrupt expectation that the whole coast under management can be made stable. For every effort towards stabilisation, the consequent trade-off should be clearly identified and understood. This way of thinking reduces the likelihood of tail-chasing through successive coastal stabilisation works.

Technical use: The major technical use for compartments is to improve erosion hazard assessments by better integrating regional and local coastal change. Regional changes may include the effects of climate or sea-level fluctuations and the consequent variations in sand supply (Eliot 2013). Local changes include storm responses and coastal interactions with natural and artificial structures. Improved knowledge of how local changes may have broader impact is essential to good coastal planning. Equally, refined understanding of how regional change influences local response can improve setback assessment and structural design (Thomson et al. 2005).

Compartments that are used to provide a setting for regional coastal processes should be identified based on the relative magnitude of local coastal change and the proximity to compartment boundaries. Large-scale engineering works, such as ports and harbours, should be considered over all compartment levels to ensure adequate identification of possible effects. However, most planning and engineering investigations require consideration at a secondary compartment scale, as this incorporates broad sediment transport processes over inter-decadal timescales, including consideration of potential climate change impacts on soft shores. If proposed works are unlikely to restrict sediment transport on an inter-annual scale, assessment may occur at tertiary compartment scale. In all cases, proximity to a compartment boundary may suggest the need to consider adjacent compartments.

Landform information used to develop the compartments, including indications of sediment transport pathways and sinks, is equally important to the development of quantitative sediment budgets. Consequently, the compartments framework provides a useful spatial basis for the development of sediment budgets (Rosati 2005). Detailed application of a sediment budget–based coastal assessment has recently been conducted in the Geraldton area (Tecchiato et al. 2015). The effect of timescale on sediment budget variability can be important, with ocean–estuary exchange and pulses of sand supply contributing to these fluctuations.

The importance of understanding the connectivity of coastal compartments through sedimentary pathways has been suggested by the different outcomes for Avoca and Cabarita beaches in the application of long-term recession modelling (Mariani et al. 2013). The largely enclosed nature of Avoca Beach, as demonstrated by the surface sedimentology (Figure 7.5), highlights the limited sand volume available for sediment redistribution in response to sea-level rise. Whether a compartment is likely to be isolated, to leak sediment or to be supplied by external sediment is the most important factor affecting long-term coastal recession. The relative capacity for offshore sediment supply to offset the recession due to sea-level rise has been determined for relatively few locations around Australia. Landform analysis (e.g. Figure 5.11) may provide a preliminary indication, which may be further supported by stratigraphic or radiometric dating techniques (Roy et al. 1997).

Definition of compartments over multiple spatial scales supports the processes of upscaling and downscaling, where information collected or applicable at one particular scale is made meaningful at another larger or smaller spatial scale (Eliot 2013). Upscaling involves the aggregation of information from a finer scale, often sparse across the wider area. Downscaling involves interpretation of coarse-scale information at a finer scale, usually through the use of additional information. The concepts of upscaling and downscaling are important tools for combining regional and local coastal change assessments, often using a sediment budget approach.

Connectivity of marine and terrestrial landforms is used as a basis for compartment definition. The identified landforms and pathways for transport may also suggest the key active coastal process and therefore indicate appropriate conceptual models for coastal dynamics, including models that embrace different scenarios of climate change forces (Eliot et al. 2013). This may lead to their application in landform-based coastal vulnerability assessment (Eliot et al. 2012).

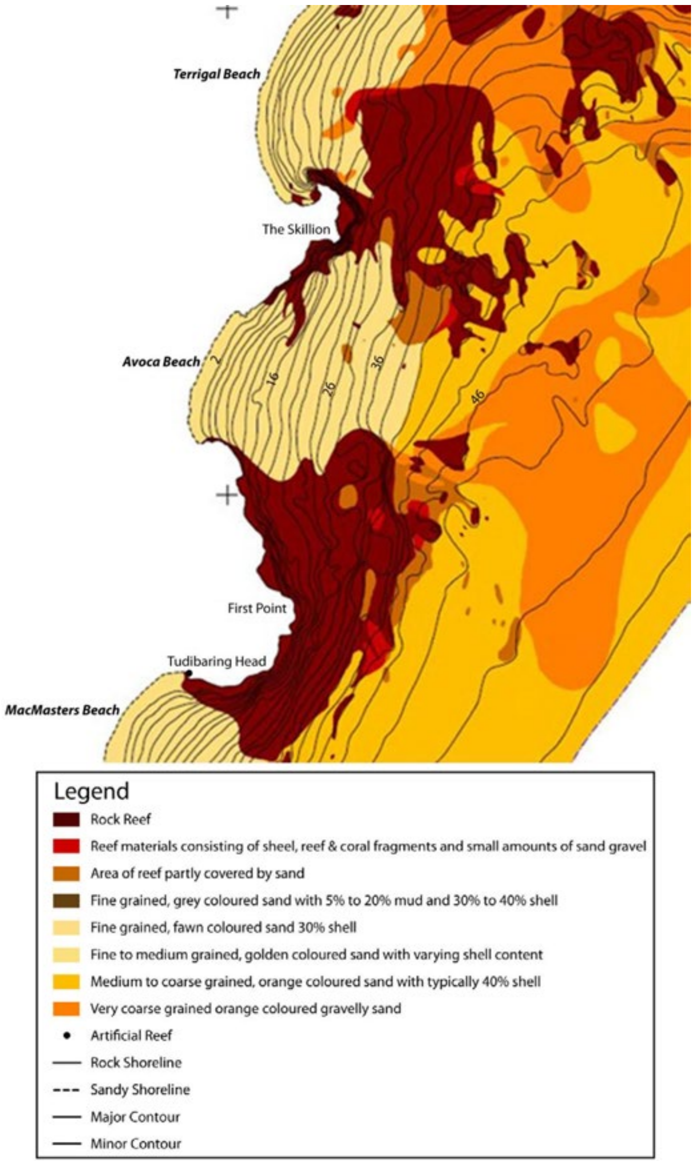

Figure 7.5 Avoca Beach sedimentology.

Note: The Avoca coastal compartment is characterised by large headlands and extensive offshore reefs isolating it from adjacent coastal compartments. Source: Mariani et al. 2013.

7.6 References and further reading

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8 Glossary

Adaptation pathway	The sequence of management actions (over time) directed to achieving long-term adaptation objectives
Aeolian	Relating to or arising from the action of wind
Average recurrence interval (ARI)	The average time interval between occurrences of an event of a particular magnitude. Events of a given recurrence interval may occur in more rapid succession when influenced by extrinsic (background) environmental conditions.
Bank	The edge of a landform adjacent to a waterbody, which has been primarily formed by the action of water currents (rather than waves). Typically, banks occur on rivers, streams and estuaries, although they may also occur on ocean coasts subject to strong tidal action.
Bathymetry	The vertical level of the sea floor in ocean, seas and lakes; by common convention described as water depth below a nominated vertical datum, which typically corresponds to lowest astronomic tide.
Beach	The portion of the coastal zone which is, at some time, subject to wave action. The seaward limit of a beach is typically defined as the spring low tide line, and the landward limit is often defined as the vegetation line.
Coastal adaptation	Future modification of behaviour through construction of infrastructure or change in land-use practices that prevents or reduces adverse impacts associated with coastal hazards.
Coastal compartment	An area of coast, bounded alongshore by large geologic structures, where changes in geology or geomorphic features exert structural control on the plan form of the coast.
Coastal hazard	The interaction of coastal processes with human use, property or infrastructure, the action of which adversely affects or may adversely affect human life, property or assets.
Coastal inundation	When ocean water levels and waves are high enough to cause flooding of normally dry land.
Coastal recession	A continuing landward movement of the shoreline OR a net landward movement of the shoreline within a specified time.
Coastal sediment cell	A length of coast and adjacent areas within which the movement of sediment is apparent through identification of land features that function as sediment sources, transport pathways and sediment sinks. Typically, sediment exchange to adjacent cells is restricted, although cells are rarely isolated completely.

Coastal terrace	A coastal landform comprising a wide, near-horizontal surface, with steeper gradients above and below. Terraces typically occur as subtidal or intertidal features and are common on low-energy estuary beaches.
Coastal vulnerability (to climate change)	The threat to coastal landforms, associated infrastructure or land use that may be caused by a sustained shift in environmental conditions.
Depth of closure	The water depth beyond which repetitive profile or topographic surveys (collected over several years) do not detect vertical seabed changes, generally considered the seaward limit of littoral transport. Note that this does not imply the lack of sediment motion beyond this depth.
Downdrift	The predominant direction of movement (towards) for sediment transported along the coast by the actions of waves and currents.
Holocene	An epoch of the Quaternary Period, from the end of the Pleistocene, about 8,000 years ago, to the present time.
Landform	A naturally shaped 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.
LiDAR (Light Detection and Ranging)	A type of aircraft-based remote sensing, using laser-driven pulses of light and multispectral cameras to scan and process digital information about a landscape. A commonly used application of LiDAR is to provide high resolution topography.
Mean sea level (MSL)	The average level of the surface of the sea, over a nominated period of time. A range of different periods are commonly used for averaging, including monthly, annual or over a 19-year tidal cycle.
Resilience	The ability of a coastline to recover its original configuration following the effects of erosive episodes (e.g. cyclones, strong storms or coastal flooding).
Shoreline	A discrete line representing the landward limit of the sea at some point in time. Methods to define shoreline vary and may be based upon a fixed vertical level, or by the apparent interface of water and land using a particular means of detection, such as aerial photography.
Storm surge	A rise in water levels that may be attributed to atmospheric influences including pressure, wind and waves during a storm or tropical cyclone.
Tides	The periodic rising and falling of the water surface resulting from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth.

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