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International Assessments of the Vulnerability of the Coastal Zone to Climate Change, Including an Australian Perspective

P. A. Abuodha
University of Wollongong, pabuodha@uow.edu.au

C. D. Woodroffe
University of Wollongong, colin@uow.edu.au

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Abstract

Australia, and considers global, and in some cases national, assessments of vulnerability to climate change to evaluate the implications for the Australian coast, or to assess the applicability of particular approaches and methods to Australia. Climate change vulnerability assessment aims at assisting policymakers in adequately responding to the challenge of climate change by investigating how projected changes in the Earth's climate may affect natural systems and human activities. Generally studies consider, exposure or susceptibility of natural coastal systems, the effect on socio-economic systems ("impact assessment"), and/or how human actions may reduce adverse effects of climate change on those systems or activities ("adaptation assessment", a measure of adaptive capacity). The framework for a climate change vulnerability assessment depends on the system under consideration, stressors, responses (effects), and actions (adaptation). It is important that each assessment is undertaken at the relevant spatial and temporal scales, and the results are often appropriate only at those scales.

Disciplines

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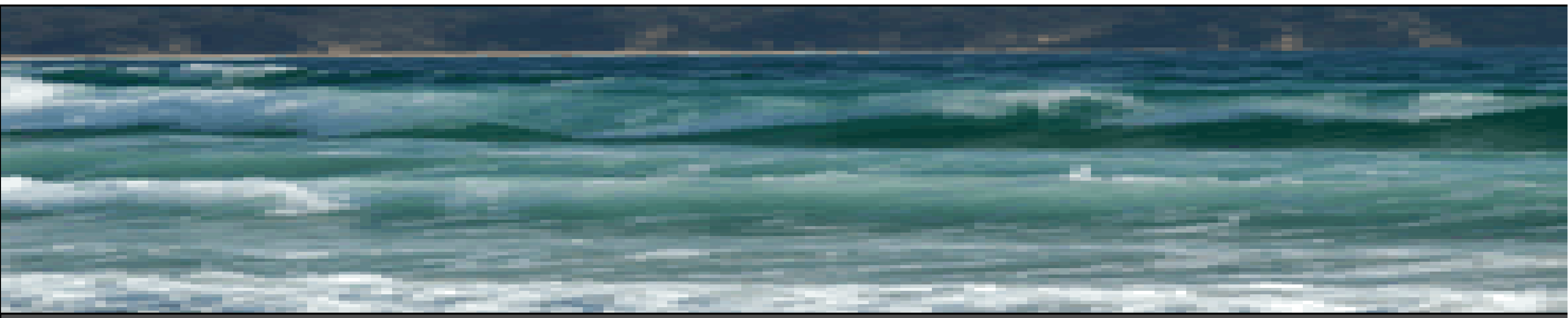
International assessments of the vulnerability of the coastal zone to climate change, including an Australian perspective



Prepared by
Pamela A. Abuodha and Colin D. Woodroffe
School of Earth and Environmental Sciences, University of Wollongong
for the
Australian Greenhouse Office, Department of the Environment and Heritage

2006

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Executive Summary

This review examines what global coastal vulnerability assessments say about Australia, and considers global, and in some cases national, assessments of vulnerability to climate change to evaluate the implications for the Australian coast, or to assess the applicability of particular approaches and methods to Australia.

Climate change vulnerability assessment aims at assisting policymakers in adequately responding to the challenge of climate change by investigating how projected changes in the Earth's climate may affect natural systems and human activities. Generally studies consider, exposure or susceptibility of natural coastal systems, the effect on socio-economic systems (“impact assessment”), and/or how human actions may reduce adverse effects of climate change on those systems or activities (“adaptation assessment”, a measure of adaptive capacity). The framework for a climate change vulnerability assessment depends on the system under consideration, stressors, responses (effects), and actions (adaptation). It is important that each assessment is undertaken at the relevant spatial and temporal scales, and the results are often appropriate only at those scales.

The reports and literature reviewed contain relatively little information directly on the Australian coast, but a range of techniques that have been adopted overseas is discussed. It is clear that there is no “off-the-shelf” methodology appropriate for the entire Australian coast, but several methods could be adapted for use in Australia. The unique nature of the Australian coast, however, and the innovative nature of several approaches adopted within Australia, suggests that it would be prudent to consider modifying techniques applied elsewhere or developing new tools to assess the vulnerability of the Australian coast to climate change.

Development and application of the IPCC Common Methodology (CM) in the 1990s represented a milestone in the development of international coastal vulnerability assessments. CM has been a foundation on which the majority of subsequent overseas methodologies have been based. In Australia, the National Coastal Vulnerability Assessment Case Studies Project (NCVACSP) was undertaken during 1994-95, comprising 9 case studies (one study in each state, with two in each of Victoria and the Northern Territory) and several deficiencies with the CM approach were identified. The 9 site-specific case studies have not been upgraded to a national level survey in Australia.

The following are the key points to arise from this review.

- The scale of data that international comparisons such as the Global Vulnerability Assessment (GVA) or Dynamic Interactive Vulnerability Assessment (DIVA) use concerning Australia is generally inadequate for assessment of vulnerability within Australia, or between different parts of the Australian coast.

- The majority of overseas assessments of the impact of climate change on coastal environments have concentrated on sea-level rise. There is an increasing recognition, but little assessment, of a series of other climate change drivers, such as changes in sea surface temperatures, precipitation and runoff, wave climate,

storm intensity and frequency, and ocean acidification, and the impacts they may have on coasts.

- Vulnerability is defined on the basis of a system's exposure and sensitivity to climate change, moderated by its adaptive capacity. Modelling these components is better developed in relation to natural systems than it is for socio-economic systems. Despite natural (autonomous) and planned adaptation, it is important to recognise that there will be residual impacts, particularly associated with extreme events. There has been relatively little consideration of the impact of storms and how this may change as a result of climate change.

- The Australian coast is unique; it contains a particularly diverse range of ecosystems and types of human use. Several factors mean that much of the Australian coast appears less vulnerable than highly developed coasts in Europe or North America. In particular, the Australian continent is stable, remote from former ice sheets, and hence subject to only gradual rates of sea-level rise. In addition, little of the coast requires protection today (much is uninhabited), and coastal settlements and infrastructure are generally not too close to the sea.

- Despite this, assessments by the Intergovernmental Panel on Climate Change (IPCC) identify that Australian coastal systems are threatened by climate change, and as a disproportionate percentage of the population lives along the coast, climate impacts on coasts will be amongst those environmental issues of most concern to Australia over the 21st century.

- Little detail about vulnerability of the Australian coast is contained in assessments by the Millennium Ecosystem Assessment, handbooks such as that prepared by UNEP, or databases such as that compiled for a global typology by LOICZ. These generally concentrate on assessment techniques that can be adopted by developing countries.

- Most methodologies for assessing relative global vulnerability of coasts to climate change, such as CM and DIVA, adopt metrics, such as the number of people at risk, the area of land lost, and protection costs or costs of adaptation. These monetary and non-monetary metrics are rarely the measures most suited to evaluating the Australian coast because, compared to coasts in Europe, the Australian coast is sparsely populated and little of the coast requires protection.

- In terms of a vulnerability assessment framework, review of international approaches has not identified a more appropriate methodology for characterising climate drivers than the matrix and template adopted by Engineers Australia (NCCOE, 2004, see Appendix 3).

- Low-lying areas of the Australian coast, particularly wetlands, estuaries and reefs (coral reefs have not been examined in detail in this review) appear the most vulnerable, and there is urgent need for a more systematic integration of high-resolution topographic/bathymetric datasets with tidal and storm surge extreme water levels.

- Indices of vulnerability, developed overseas, based on a few metrics (such as relief, rock types, landform, relative sea-level change, shoreline displacement, tidal range and maximum wave height), have not been applied in Australia. To develop an index for use in Australia, research is needed to identify the best set of parameters and to test their validity in an Australian context. This approach would be most appropriate at regional scale enabling prioritisation of those regions most at risk around Australia, but would need customising for Australian conditions (natural and socio-economic) and data availability.

- Most overseas modelling approaches have been based on the Bruun rule, which estimates sandy shoreline retreat in response to sea-level rise. The method has been criticised, overseas and within Australia, and Australian researchers are contributing to the international methodological debates concerning modifications to the techniques available. Both DIVA and CoastClim (a coastal module of Simulator of Climate Change Risks and Adaptation Initiatives [SimClim]) offer modelling capability that requires further testing, modification and validation in the Australian context. There appears to be considerable potential for integration of these open coast modelling techniques with developments that are already occurring, especially in south-eastern Australia.

- Climate change impacts on wetlands and estuaries are less clear. International approaches are primarily appropriate at global scales and cannot easily be adapted to address issues at the regional or local scale that is more relevant for Australian wetlands or estuaries.

- Few of the techniques available from global studies, since the CM, have been tested in the Australian context. Most would require further development and customisation, probably with new sets of data, but their adaptation (especially DIVA and CoastClim) should be considered in conjunction with further focus on methods developed within Australia.

1. Introduction

The coastal zone is a relatively small (<20%) but dynamic area of the Earth's surface. It is the location for more than 50% of the human population, providing wide societal benefits, containing a suite of natural ecosystems, and functions as a significant and complex region for biogeochemical transformation (Crossland, 2002). Its heterogeneity in physical, chemical, biological and human dimensions is a challenge to measure, model and manage. There is no single definition of the coastal zone; it varies according to the problem being addressed. For some purposes it is necessary to include the continental shelf and hinterland. The coast is rarely in a steady state, but changes over time in response to forcing – from daily (e.g. tides and precipitation-river flow), seasonal (e.g. climatic patterns), annual (e.g. fisheries yield), and decadal (e.g. ENSO) to millennial scales (e.g. sea level).

The shores of Australia include open coasts with rocky headlands, cliffs and sandy beaches, and sheltered coasts, bays and estuaries with muddy and sandy tidal flats (Australia State of Environment, 2001). The predominant substrates around the coastline are sand, mud and rock. Dunes and sandy beaches feature most commonly, with tidal mud flats more evident in the north. Rocky shorelines are limited but are common along the southern margins of the continent.

There is increasing recognition that human-induced climate change is a serious environmental problem. One of the most certain consequences of global warming is a rise in mean sea level, and as a consequence the coastal zone is regarded as one of the most vulnerable areas to climate change. In recent Intergovernmental Panel on Climate Change (IPCC) assessments it has been emphasised that climate change brings with it other implications for coasts, in addition to the threat of sea-level rise (Table 1). These climate change impacts include possible increases to sea-surface temperatures, greater variability in the patterns of rainfall and runoff, possible changes to wave climate, changes to the frequency, intensity and duration of storms, and changes to ocean chemistry associated with global warming, particularly ocean acidification. There is particular concern about extreme weather events (floods, droughts and cyclones) that pose additional threats to human infrastructure and settlements.

These changes will have widely differing effects depending on geographic location, and impacts on, and implications for, Australia are poorly understood at national, regional and local scales (Allan Consulting Group, 2005). Increasingly, Australians are moving to live, retire or make a living at the coast. Some 83% of Australians lived within 50 km of the coast in 1996 (Australia State of the Environment, 2001). The population of coastal areas is distributed unevenly; for example, in Victoria, where 85% of the population lives on the coast, habitation is concentrated in less than 10% of the coastline. Urban sprawl was identified as one of most important problems faced in the coastal zone by the Resource Assessment Commission (1993) and coastal strip development places increasing pressure on specific coastal habitats.

This review examines what global assessments say about Australia, and considers global, and in some cases national, assessments of vulnerability to climate change to evaluate the implications for the Australian coast, or to assess the applicability of particular approaches and methods to Australia.

Table 1. Principal climate change drivers and possible direct and indirect impacts on the coast of Australia, synthesised from IPCC and SURVAS summaries, with tentative indication of confidence level in their likelihood of occurrence (very high [VHC], high [HC], medium [MC], low [LC] or very low [VLC] confidence).

Climate change (Driver)	Principal direct physical and ecosystem effects	Potential secondary and indirect impacts
Sea-level change [VHC] (principally rise)	• increased coastal erosion [VHC] • increased inundation of coastal wetlands and lowlands [MC] • increased risk of flooding and storm damage [HC] • increased salinisation of surface and ground waters. [MC]	• infrastructure and economic activity impacted [MC] • displacement of vulnerable populations [LC]
Sea-surface temperature [HC] (principally rise)	• increased coral bleaching [HC] • pole ward species migration [LC] • increased algal blooms [LC]	• impact on tourism [LC] • possible health impacts [LC]
Altered precipitation and runoff [MC] (local increases/decreases)	• altered river sediment supply [MC] • altered lowland flood risk [MC] • water quality/nutrient impacts [LC]	• implications for erosion and flooding [LC]
Altered wave climate [LC] (uncertain)	• altered wave run-up [VLC] • altered erosion and accretion [LC]	• further erosion [LC]
Storm frequency and intensity changes [LC] (uncertain)	• increased waves and surges [LC] • altered cyclone zones [LC]	• further storm damage [LC]
Increases in CO_2 concentration in the atmosphere [VHC] and ocean [HC]	• increased ocean acidification [HC] • increased disruption to food chains (eg. Southern Ocean) [MC]	• less resilient reefs [LC] • impaired movement and function of high oxygen demand fauna (eg. squid, fish) [MC]

1.1 Background to climate change

Many pressures, impacts and predictions of change in the coastal zone have been identified in global assessments of the environment (OECD, 2001), of world resources (WRI, 2000), of oceans and coastal seas (IOC, 2002), and of global change (IGBP, 2001). Marine environmental degradation continues and in many places is intensifying (GESAMP, 2001). The Intergovernmental Panel on Climate Change (IPCC) in 2001, projected increased CO^2 concentrations and associated rises in global temperatures which will dramatically influence the coastal zone. These evaluations paint a picture of trends towards further degradation in the coastal zone, experienced differentially across regions, despite some local and regional successes in coastal management that have remediated processes such as pollution, eutrophication, and urban waste impacts on water quality.

The IPCC Third Assessment Report (TAR) provides the background for this review. Working Group II of the IPCC has summarised impacts, adaptation and vulnerability. The TAR indicated that many of the world's coasts are likely to experience increased levels of flooding, accelerated erosion, loss of wetlands and mangroves, and seawater intrusion. These issues were explored in detail in Chapter 6 on coastal zones and marine ecosystems, which recognised that low-lying islands and extensive coastal plains associated with estuaries and deltas appear particularly at risk. Chapter 12, which describes Australia (and New Zealand), recognises the vulnerability of coral reefs, such as the Great Barrier Reef with the probability of more frequent coral bleaching, and vulnerability of low-lying wetlands that are extensive along the north Australian coastline. The report also includes a section (12.6.4) considering the implications of the rapid economic and population expansion along Australia's coasts leading to greater community risk and insurance exposure to present and future hazards (Pittock, 2003).

Since the TAR in 2001, there has been an increasing body of evidence to suggest that global warming is already having an effect on reefs, with more frequent tropical sea-surface temperatures exceeding the tolerance of corals, leading to more widespread coral bleaching. It seems likely that the Fourth Assessment report, to be produced by IPCC in 2007, will further focus on these issues, emphasising the exposure of reefs in north-eastern Australia and wetlands in northern Australia. Low-lying coasts around Australia might be expected to experience increased levels of inundation, accelerated coastal erosion, and saline intrusion into coastal waterways and water tables. Evidence points to a severe impact potential, but presently knowledge of the vulnerability of coastal areas to sea-level rise and wider climate change remains incomplete. There is uncertainty about the rates of change and it is difficult to separate extreme events exacerbated by climate change from those that represent part of the current natural variability of climate.

1.2 Definition of terms

Vulnerability is commonly defined as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change' (IPCC, 2001a). Following the Allan Consulting Group report, vulnerability can be considered a function of 'exposure', the background climate conditions against which a system operates and any changes in those conditions, and 'sensitivity', the degree to which the system is affected by climate related stimuli; these together constitute the potential impact. This potential impact is further influenced by adaptive capacity, the ability of a system to adjust to climate change so as to moderate potential damage or to cope with its consequences (Allan Consulting Group, 2005).

In discussions of vulnerability of coasts it has generally been found useful to adopt the framework summarised in Figure 1, distinguishing between natural system vulnerability and socio-economic vulnerability to climate change, but emphasising their interrelatedness and interdependence (Klein and Nicholls, 1999). Assessment of vulnerability needs to start with an understanding of the natural system and its biophysical response to climate change (in particular sea-level rise); these comprise its susceptibility (exposure, or potential of the system to be affected by hazards), and its responsiveness or natural capacity to cope, measured by resistance or resilience (sensitivity). Coastal landforms and ecosystems may show resistance, which includes mechanical strength of materials, structural, ecological, and morphological resistance, and they may show natural resilience, the ability of the system to bounce back, or return to some quasi-stable state. Although these terms are most familiar in relation to natural or biophysical characteristics, similar concepts can also be applied to various other aspects of the coastal management process, such as social, cultural, or institutional resilience (Kay and Hay, 1993). The adaptive capacity describes how this ability to cope may be increased either through natural (autonomous) adaptation or through planned adaptation. Even with planned adaptation, residual risks remain, as tragically demonstrated when coastal defences around New Orleans failed under the impact of Hurricane Katrina in 2005. Appendix 1 provides a glossary of terms.

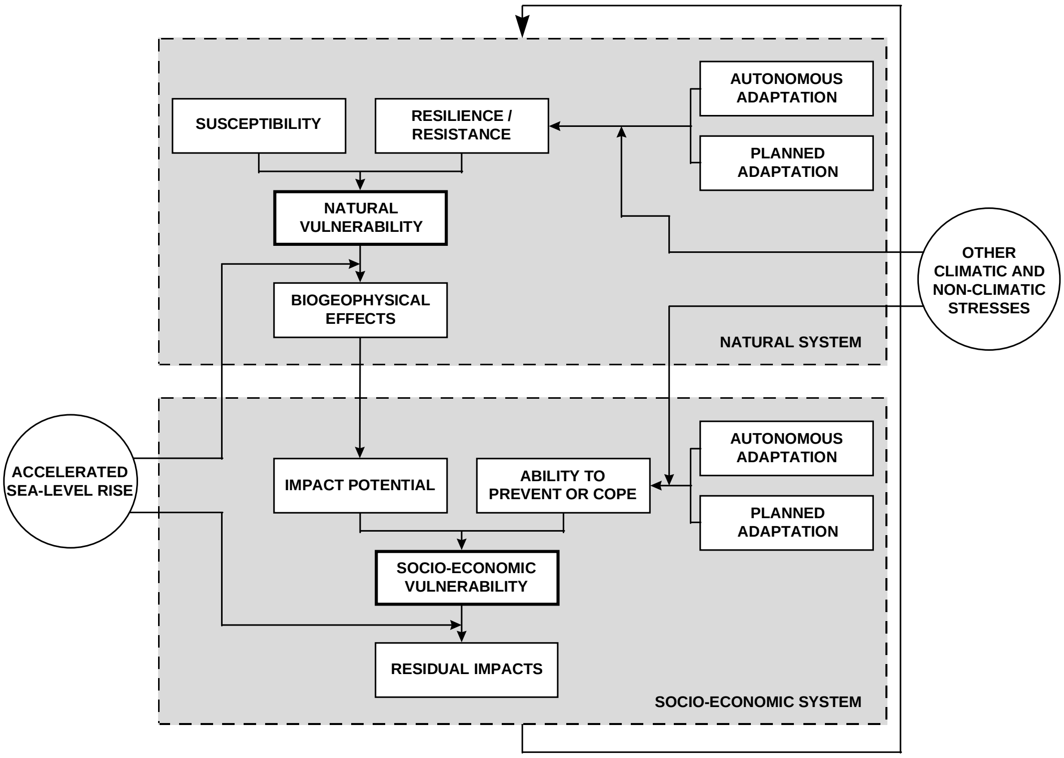


Figure 1. Definition of vulnerability of natural and socio-economic systems, following Klein and Nicholls (1999), used in UNEP and other international approaches to vulnerability assessment to sea-level rise. Further terms are defined in Appendix 1.

A clearly defined set of terminology is an important prerequisite for the Australian community to understand and cope with the potential future coastal impacts of climate change and sea-level rise. Over the past 15 years a specialist set of terminology has been developed to describe potential climate change impacts and impact management (Adger et al., 2004). This terminology is considerably different from that commonly adopted in emergency and risk management.

2. The Australian coast and its vulnerability to climate change

The unique physical setting of the Australian continent, its distinct and highly variable climate, and its unusual pattern of human use of the coastal zone mean that many of the approaches adopted in assessing coastal vulnerability overseas are either not directly applicable, or will require modification before adoption and application in Australia.

2.1 Characteristics of the Australian coast

The coast is a major icon of Australian life. The Australian coastline is one of the longest of any nation, but its length depends upon how the shoreline is defined and measured (Galloway et al., 1984). The coast of the mainland is more than 30,000 km, but total length exceeds 60,000 km (Australia State of Environment, 2001), and may be as much as 120,000 km if all estuaries, indentations, islands and island territories are included (Thom and Short, 2006). It ranges from the tropics to temperate latitudes (9-42^{o}S) and borders the South Pacific, Southern, and Indian Oceans. There are numerous small islands; the Great Barrier Reef, for example, extends for more than 2000 km along the coast of Queensland and contains around 2900 individual reefs on which there are many small islands. The Resource Assessment Commission (1993) adopted a definition of the coast as a strip 50 km wide, which accounted for a land area 17% of the total land area of Australia. However, such prescriptive definitions are generally not useful in the context of individual coastal management challenges (Kay and Alder, 2005). More than 10,000 beaches stretch for more than 50% of the shoreline, with the remainder being rocky or muddy. There are more than 700 coastal waterways, primarily estuaries (however, this also depends on definition with 970 estuaries recognised by NLWRA (Australia State of Environment, 2001), each with a series of associated low-lying shorelines and wetlands. Mangroves cover more than 12,000 km^2, being particularly extensive along estuaries in the Northern Territory and Queensland.

There is a disproportionately large percentage of the Australian population along the coast (typically more than 80%, depending on how the coast is defined). Not only are all the most major Australian cities coastal, but there is also a large, and particularly rapidly growing, non-metropolitan coastal population, characterised by the concept of 'sea-change' (National Seachange Taskforce, Gurran et al., 2006). People are moving particularly to the coasts of Victoria, New South Wales, Western Australia and Queensland. These states had higher rates of population growth (1991-1996) in the coastal zone (defined as 3 km) than in the rest of the state. In New South Wales and Queensland alone, an extra 179 000 people moved to the coast. In addition, the coast supports a wide range of agricultural, fisheries, commercial, industrial and recreational activities, transport and other services, and is the main focus of the nation's domestic and international tourism.

Coasts are generally dynamic environments, influenced by waves, tides and currents (Woodroffe, 2003). The nature of tidal variations differs around the coastline, with spring tidal ranges of more than 10 m experienced in north-western Australia. Wave climate is also variable, both in time and space (Short, 1999). Australia's coastal zone is continually changing due to a combination of natural factors and human activities. Change can be either gentle and barely perceptible over normal human timescales or dramatic as a result of extreme weather events. Severe storms, accompanied by surge, wave set-up and run-up, together with flooding, can cause massive shoreline relocation in terms of erosion or deposition, and irreversible damage to wetland and nearshore ecosystems through smothering by riverine silts. Widely differing rates of change, in relation to a combination of natural and human-induced factors, are experienced on the coast and long-term monitoring, as undertaken at Moruya in southern NSW, may be necessary to demonstrate patterns of cut and fill over decades or longer time scales (McLean and Shen, 2006).

2.2 Geomorphological history and sea-level change

Most coasts will experience some change whether or not there is a change in climate. Beaches and dunes are subject to natural changes of 'state' in response to wave energy and storm events (Short, 1999). Cliffs undergo gradual erosion and retreat. Mudflats and estuaries are subject to gradual sedimentation, and estuaries and deltas undergo hydrodynamic changes over time. Any impacts of climate change will be in addition to these natural patterns of adjustment. Many coasts are influenced either directly or indirectly by human activities, and it may be difficult for coastal managers to differentiate natural from human-induced changes (Woodroffe, 2003).

Present sea level was reached around most of the Australian coast about 6000 years ago (Nakada and Lambeck, 1989). In fact, around much of the coast, that 6000-year shoreline appears to have been slightly higher than the present shoreline, but its elevation varies from place to place. This results from subtle flexure of the continental margin, even on the largely stable Australian mainland, in this case primarily in response to the weight of the water that flooded broad shelves such as those that underlie the Great Barrier Reef and the Gulf of Carpentaria and which were emerged during the ice age. The overall trend of sea level relative to much of Australia over the past few thousand years has been a slight fall, although tide gauge records do suggest that sea level is now gradually rising relative to Australia, at rates close to or slightly below the global average of about 1.8 mm/year (e.g. Hunter et al., 2003).

2.3 Other climate drivers

There are unique aspects of Australian climate and geomorphology which give rise to a series of potential impacts under changed climate that differ from most of the rest of the world.

Whereas sea-level rise has been a prime focus of several of the global scale studies of coastal vulnerability, there is an increasing recognition, both internationally and within Australia, that there are likely to be additional impacts as a result of climate change. The ocean-atmosphere phenomenon termed El Niño, and the pressure difference termed the Southern Oscillation, in combination termed ENSO, is now recognised to have a profound effect on the climate and the sea levels across the Pacific. Their influence on Australia is still the subject of much research. Superimposed on the ENSO fluctuations are periodicities such as the Pacific Decadal Oscillation (PDO), partly expressed as the Interdecadal Pacific Oscillation (IPO), and the Indian Ocean Dipole (IOD). These variations in climate will make the assessment of the extent to which the climate is changing much harder.

Climate change is also likely to affect other climate parameters, with changes in the amount of precipitation that will have implications for river flow and the supply of sediments and nutrients to the coast (see Table 1). Around much of the world, the amount of sediment supplied by rivers to the coast has been completely changed from the sediment delivery that occurred before human modification. Clearing of catchments has resulted in great increases in sediment load, for example the Yellow River, which has become yellow because of the erosion of fine sediment from the Chinese hinterland. Conversely, the construction of dams has actually decreased the supply of sediment to the majority of rivers, and sediment starvation has contributed to a deficit of sediment that is linked with erosion of shorelines, particularly on deltas. By comparison, Australia is the driest inhabited continent, and therefore relatively small sediment loads are carried by its rivers, with many of these not reaching the coast. In addition to inland drainage, many rivers deposit sediment in estuaries or coastal lakes and the sediment does not actually add to coastal sediment compartments.

2.4 Vulnerability of the Australian coastal zone compared with overseas

Australia is relatively stable; it is well away from those areas of the planet rebounding from earlier ice loads, and there is almost no tectonic activity. Its remoteness from the polar icesheets means that Australia has experienced a sea-level history that closely reflects the overall ocean volume (which increases as ice volume decreases). This in turn means that it is more likely to experience a future pattern of sea-level change that is similar to the global average than are those places which are either tectonically active, or are close to existing or former ice sheets. This is a significant contrast to the coasts of northwest Europe and eastern North America where a trend of gradual, though decelerating, sea-level rise over the past few millennia is continuing and is clearly identifiable in the record of historic sea-level change derived from tide gauges.

In many parts of the world, the coast is undergoing rapid uplift (for example Scandinavia which is rebounding following the melting of kilometres of ice, or the north coast of New Guinea, which is uplifted episodically as the Pacific plate is subducted at the plate margin). In some places the coast is subsiding (for example the Mississippi delta, including New Orleans, as a result of crustal flexure beneath the weight of delta sediments). Sea level has changed in the past, having fluctuated over an amplitude of more than 100 m in response to the growth and melt of polar ice sheets over the past 2 million years. Global isostatic adjustment to the redistribution of water from polar icecaps to the sea means that several parts of the world that were adjacent to former ice sheets, notably much of north-western Europe and eastern North America, are experiencing a relative rise of sea level. Global sea-level rise, which appears to be occurring at a rate of about 1.8 mm/year is superimposed on the ongoing isostatic adjustment in these situations (Church et al., 2004).

Unlike the majority of the Australian coastline, many of the coasts overseas (in the northern hemisphere) are highly urbanised, and many are already protected by coastal defences. On these coasts, such as the holiday resorts of Britain or Europe, coastal management already involves protection of the coast and management of a vast array of local erosion problems. With only a few exceptions, coastal development on the Australian coastline has been undertaken behind natural foredunes or at sufficient setback that relatively little of the coast is presently in need of protection, relatively few beaches are sustained by sand nourishment, and there are, comparatively, relatively few hard engineering structures.

3. Global Syntheses: Evaluation and Assessment

A series of international projects have assessed the vulnerability of the world's coasts to climate change. This review examines what the international reports have concluded about Australia's vulnerability and to what extent the reports are consistent. It assesses whether any of these assessments provides a framework within which to assess the vulnerability of Australia's ecosystems and the well-being of coastal populations. The scope of this evaluation includes, but is not limited to storms, floods, cyclone damage, energy, buildings and settlements, salinity, wetlands, water, health, business and industry, desertification, biodiversity and bushfire. Various approaches have been adopted and involved establishing the current physical condition of the coast, considering variability of each condition in the face of ongoing natural environmental factors, and evaluating the likely response to climate change and associated sea-level rise.

3.1 Conceptual frameworks for coastal vulnerability assessments

Many criteria can be used for classifying vulnerability assessments. The evolution of vulnerability assessments is characterised by the improved consideration of the uncertainties involved in climate and impact projections, by the increased integration of climatic and non-climatic stressors, by a more realistic recognition of the potential for and the limitations to societal responses, by a greater importance of increased stakeholder involvement, and by a purposeful shift from science-driven vulnerability estimation to policy-driven vulnerability reduction (Fűssel, 2002).

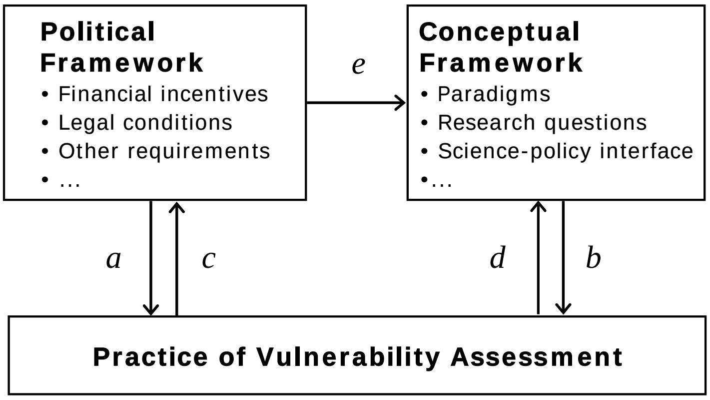


Figure 2. Interplay between the political framework, the conceptual framework, and the practice of climate change vulnerability assessment (based on Fűssel, 2002).

The past two decades have witnessed extensive research on potential and observed impacts of climate change on all kinds of natural and social systems (McCarthy et al., 2001). In the absence of a consensus definition of the term climate change vulnerability assessment, this report examines "any assessment of how projected changes in the Earth's climate could influence natural and human systems or activities, and/or how human actions could reduce adverse effects of climate change on those systems or activities, with the aim of assisting policy–makers to adequately respond to the challenge of climate change" (Fűssel, 2002).

Figure 3 illustrates the main links between the political framework, the conceptual framework and the practice of climate change vulnerability assessment. On the one hand, the political framework (e.g. the international legal framework and the financial provisions) and the conceptual framework (e.g. the formulation of the assessment goals) determine the practice of vulnerability assessments (***a, b***). On the other hand, the results of, and experiences with, actual vulnerability assessments are used to further develop the relevant political and conceptual frameworks (***c, d***). Furthermore, the political framework influences the development of the conceptual framework (e.g. by directing financial resources to specific types of vulnerability assessments; ***e***).

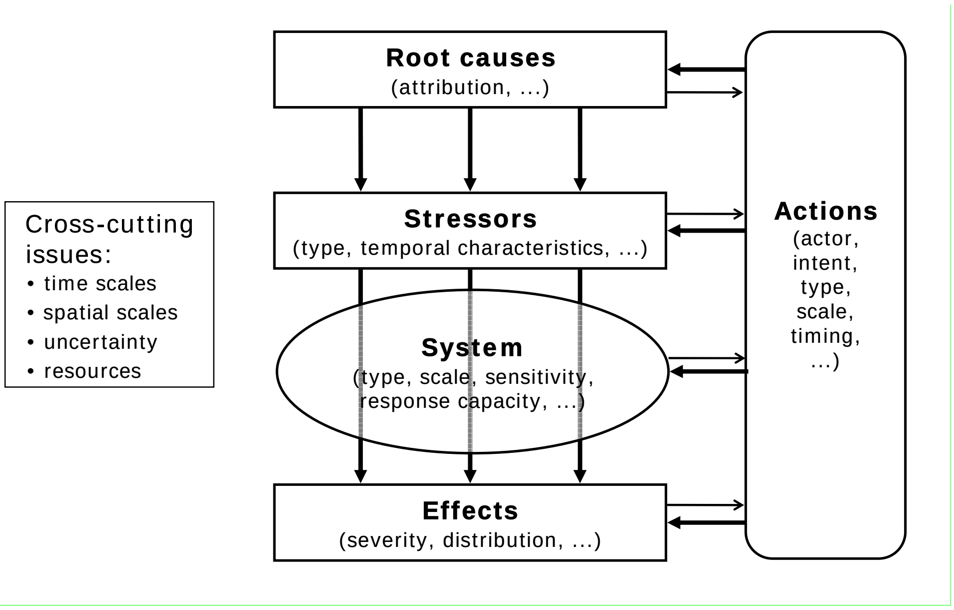


Figure 3. Generic framework for vulnerability and its assessment (based on Fűssel, 2002).

Figure 4 shows a more generic framework for vulnerability and its assessment, which is applicable beyond climate change alone. Its development has been motivated by the adaptation frameworks presented in Smithers and Smit (1997) and Smit et al. (2000). The framework presents a vulnerable system that is exposed to various stressors, which cause a variety of effects on that system (depicted by solid arrows with full heads). The stressors to the system can be associated with certain root causes, which are attributable

3.2 Intergovernmental Panel on Climate Change (IPCC)

3.2.1 Description

The IPCC Third Assessment Report (TAR) Working Group II has outlined impacts, adaptation, and vulnerability of coasts and low-lying areas. Whereas there has been a focus on the impact of anticipated sea-level rise, the TAR also considered the primary large-scale effect of other potential impacts, including increases in sea-surface temperature, changes in wave climate, circulation and acidity of the ocean, and potential changes in cyclone intensity, frequency and distribution.

The IPCC report indicated that rates of sea-level rise will be variable at the regional and local scales. The details of this variation are largely unknown; global climate models do enable some aspects of regional variation in sea-level to be modelled, but regional projections are not yet available and local projections are largely impossible. Evaluation of effects on several nations indicates that the likely impacts of sea-level rise can vary from country to country and from one geomorphic setting to another (Biljsma et al., 1996). Certain geomorphic settings are more vulnerable than others, for example, deltas, small islands and most particularly low-lying coral atolls are especially vulnerable. Coastal wetlands appear to be threatened with loss or significant change in most locations as their present location is intimately linked with present sea level, although their ability to respond dynamically to such changes by sedimentation and biomass production needs to be carefully considered (French et al., 1995). Urbanised sandy coasts may also be vulnerable if development is concentrated too close to the shoreline, primarily due to the large costs of maintaining a sandy beach for both recreation and protective purposes (Nicholls and Lowe, 2004). These costs are often highly uncertain.

The concept of vulnerability embraces: (1) the physical and socio-economic susceptibility to global climate change and (2) the ability to cope with these consequences (i.e. susceptible countries or areas may not be vulnerable). The IPCC developed a Common Methodology (CM) to provide a better understanding of societal vulnerability to climate changes, particularly sea-level rise (IPCC CZMS, 1992; IPCC, 1994). This CM procedure is examined in section 4.1.1.

3.2.2 What IPCC says about Australia

Although sea-level projections imply minor differences in the extreme estimates, the broad range of expected average sea-level rise by the year 2100 is in the range 0.1-0.9 m, with a mean of 0.5 m (IPCC, 2001b; NCCOE, 2004). For the majority of the Australian coast, it appears appropriate to adopt this projected sea-level rise. Several coupled atmosphere-ocean Global Climate Models (including the CSIRO model) suggest Australia will experience a slightly lower value than the global average. This increase in sea level is less than the current vertical range over which the tide varies around most of the Australian coast. It is also less than the height reached by the sea during the Holocene highstand around 6000 years ago around many parts of the Australian coast. These two comparisons serve to emphasise the challenges ahead in discriminating between the impact of sea-level change from the natural variability that already exists, and that which is likely to be experienced. For example, it has not been possible to establish the elevation of sea level 6000 years ago in many of those parts of Australia that have a large tidal range because many of the proxy indicators of sea level do not permit a clear discrimination of different tidal levels.

IPCC has also carried out several studies in individual developing countries, such as Mongolia, India, Kenya, China, Senegal, Brazil, Ukraine, Uganda, Mexico, Baltic States, the Caribbean Islands, Thailand, Sierra Leone and South Pacific (Tuvalu). No IPCC country study of this type has been undertaken in Australia; the greater availability of detailed population and economic data, and sophisticated topographic, remote sensing and other datasets, suggest that Australia has the capacity as a provider rather than a recipient of these types of assessments.

3.3 Millennium Ecosystem Assessment (MEA)

3.3.1 Description

The Millennium Ecosystem Assessment (MEA) is a framework report of ecosystems and human well-being designed to improve the management of Earth's ecosystems and ensure strategies to build capacity for analysis. The MEA is a global effort to analyse on a global, regional, and local scale the state of ecosystems, their capacity to provide goods and services, the multiple stresses that they are facing, and the potential for human actions to protect ecosystem goods and services by moderating these stresses (Ahmed and Reid, 2002; Gewin, 2002). Human well-being depends on a broad range of ecosystem services. The causal structure involving human well-being and ecosystem services is a closed loop that allows for feedbacks within the system. The relationships between different elements of the framework are amenable to human interventions that can alter the dynamics of the system (Millennium Ecosystem Assessment, 2005a; Fig. 2). The conceptual framework for the MA places human well-being as the central focus for assessment, while recognising that biodiversity and ecosystems also have intrinsic value and that people take decisions concerning ecosystems based on considerations of well-being as well as intrinsic value (see Fig. 2) The MA conceptual framework assumes that a dynamic interaction exists between people and ecosystems, with the changing human condition serving to both directly and indirectly drive change in ecosystems and with changes in ecosystems causing changes in human well-being. At the same time, many other factors independent of the environment change the human condition, and many natural forces are influencing ecosystems.

Changes in factors that indirectly affect ecosystems, such as population, technology, and lifestyle (upper right corner of figure), can lead to changes in factors directly affecting ecosystems, such as the catch of fisheries or the application of fertilisers to increase food production (lower right corner). The resulting changes in the ecosystem (lower left corner) cause the ecosystem services to change and thereby affect human well-being. These interactions can take place at more than one scale and can cross scales. For example, a global market may lead to regional loss of forest cover, which increases flood magnitude along a local stretch of a river. Similarly, the interactions can take place across different time scales. Actions can be taken either to respond to negative changes or to enhance positive changes at almost all points in this framework (black cross bars; Millennium Ecosystem Assessment, 2005b)

The MEA has many things in common with the climate assessments compiled by the IPCC. The two assessments share several characteristics: i) their aim to provide policy-relevant information to policymakers; ii) the universal importance of their respective subjects of investigation (ecosystems and climate, respectively) for humankind; iii) the combination of knowledge from the natural and social sciences with other sources of knowledge; and iv) the consideration of issues at widely varying spatial levels. The main difference is that the IPCC focuses on a specific driver (i.e., climate change) whereas the MEA focuses on a specific system (i.e., ecosystems). As a result of this specific focus, the MEA framework cannot generally be applied to assessments of climate change impacts.

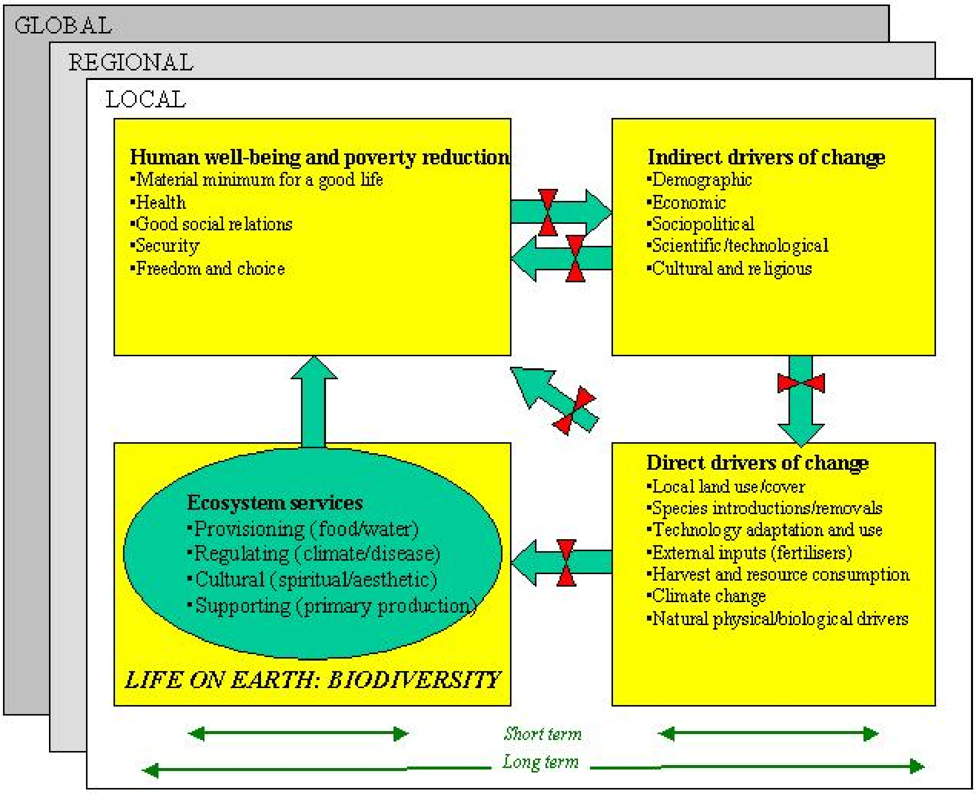


Figure 4. Millennium Ecosystem Assessment Conceptual Framework. Arrows show interconnections and red symbols indicate strategies and interventions. Note this approach can be adopted at global, regional or local scales.

3.3.2 What the Millennium Ecosystem Assessment says about Australia

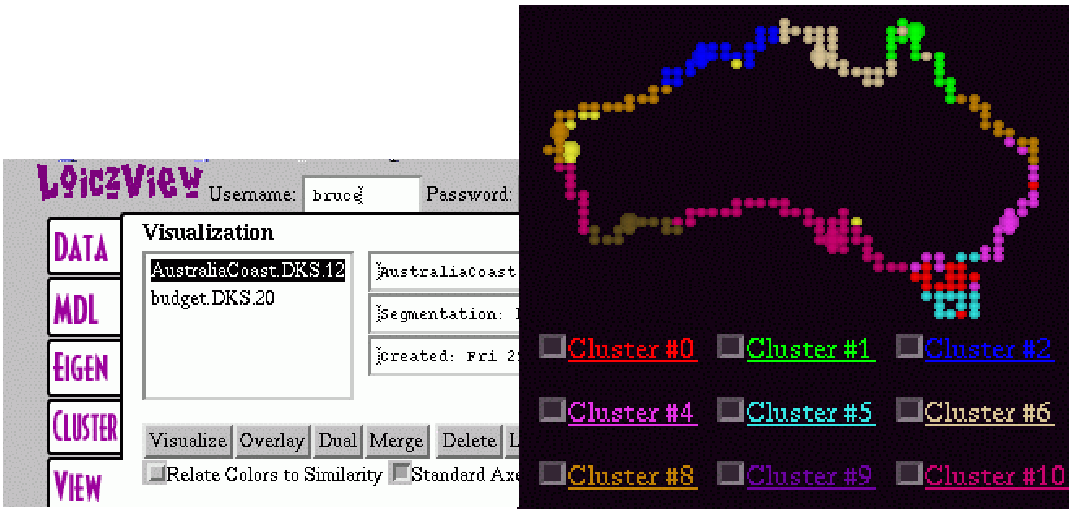
The global extent of wetlands is estimated to be in excess of 1,280 million ha (1.2 million km^2) but it is well established that this is an underestimate. MEA indicates that more than 50% of specific types of wetlands in parts of Australia were converted during the twentieth century (medium to high certainty). There is insufficient information available on the extent of all wetland types being considered in this report – such as inland wetlands that are seasonally or intermittently flooded, and some coastal wetlands – to document the extent of wetland loss globally. The classes are not always mutually exclusive, for example many of the coastal wetlands of Northern Australia are freshwater marshes.

Supporting and regulating services (such as nutrient cycling) are critical to sustaining vital ecosystem functions that deliver many benefits to people and to birds. Wetland ecosystems provide a diversity of services vital for human well-being and poverty alleviation (Millennium Ecosystem Assessment, 2005a) It is well established that provisioning services from wetlands, such as food (notably fish) and fibre are essential for human well-being. The delivery of fresh water is a particularly important service both directly and indirectly. In addition, wetlands have significant aesthetic, educational, cultural, and spiritual values and provide invaluable opportunities for recreation and tourism. Other important drivers of change in coastal wetlands include human impacts; for example, seagrass ecosystems are damaged by a wide range of human impacts, including dredging and anchoring in seagrass meadows, coastal development, eutrophication, hyper-salinisation resulting from reduction in freshwater inflows, siltation, habitat conversion for the purposes of algae farming, and climate change. Major losses of seagrass habitat have been reported in Australia, and current losses are expected to accelerate. The MEA refers to the issue of altered flows and their consequences for the rivers of the Murray-Darling Basin, including introducing an interim cap (an upper limit) on water diversions in the Basin in 1995. MEA contains global maps of coral reefs, estuaries, mangroves and seagrasses, based on UNEP atlases, but more detailed assessments of most of these resources are available from national datasets.

3.4 International Geosphere Biosphere Program (IGBP) and Land-Ocean Interactions in the Coastal Zone (LOICZ)

3.4.1 Description

The Land-Ocean Interactions in the Coastal Zone (LOICZ) project is a core project of the International Geosphere Biosphere Program (IGBP). This international science program has produced a number of overviews of the world's coasts and established a scientific agenda of research that needs to be undertaken (Holligan and de Boois, 1993; Kremer et al., 2005; Crossland et al., 2005).



Username: bruce

Figure 5. Example of LOICZView clustering procedure for the Australian coast, based on typology dataset.

LOICZ has developed a typology that can be used to determine appropriate weightings for preparing global syntheses, scenarios and models, particularly where there are limited data. The typology was intended to be both descriptive and dynamic, enabling grouping of the world's coastal zone into clusters of discrete, scientifically-valid units based on both natural and socio-economic features and processes. The LOICZ Typology and the LOICZView clustering tool focus on the world's coastline between 50 m elevation and 50 m depth, at 1 x 1 degree (some now increased to 0.5 x 0.5 degree) geographic raster projection (Buddemeier and Maxwell, 2000). Web-LOICZView is a web-based graphical user interface using a set of data analysis tools that enables clustering and visualisation of datasets (Figure 5). LOICZ also provides a metadata guide to these data. The typology divides the world coastal zone into land, coast and sea cells a degree on each side, and populates those cells with data on dozens of variables ranging from air temperature to population density and from bathymetry to soil texture. This might be useful where it is not possible to conduct empirical studies to develop global scenarios and models since large areas of the coastal zone have similar properties. Since not all areas can be sampled, a rational approach to LOICZ studies must involve identifying the major categories of coastal units and ensuring that each grouping is adequately represented in the data sets used for preparing global syntheses. In addition the typology is used as the basis for encouraging new research projects in coastal types that are under-represented in current research activities and for analysing and reporting results on a regional and global basis.

3.4.2 What LOICZ says about Australia

Typology development has been tested using Australia/and New Zealand. These areas were chosen because of the existence of expert typologies for the regions (Smith and Crossland, 1999). This prototype typology for Australia was developed using a subset of the original LOICZ data set corresponding to the Australia/New Zealand coastline. Although a number of key findings emerged, for example, strong similarities among the expert typologies and the various clustering approaches indicating robust, distinguishable 'structure' in the nature of coastal environments, the existence of the expert classifications already developed for Australia makes the clustering approach largely redundant for further use. There have been several attempts to divide the Australian coast into regions. including the Interim Marine and Coastal Regionalisation for Australia (IMCRA) developed though broad consultation (IMCRA technical group, 1998), and contained in the Coastal and Marine Resources Information System (CAMRIS) data holdings. IMCRA has been replaced in the marine realm by the recent Marine Bioregionalisation (by National Oceans Office, DEH, 2005) that provides a more focused assessment than is possible at the scale of the LOICZ typology. The typology may be useful for those parts of the world where few data exist, but national datasets are generally available limiting the utility of LOICZ typology for studies within Australia. Regionalisations of this type are generally designed with broad objectives in mind; there is not a single accepted regionalisation for the Australian coast, but it is debatable whether a single approach could be developed that would capture coastal regions relevant for vulnerability assessment to climate change (see Kay et al., 2005a, 2005b).

3.5 United Nations Environment Program (UNEP)

3.5.1 Description

The UNEP Handbook on Methods for Impact Assessment and Adaptation Strategies was designed to assist developing countries conduct climate change impact and adaptation assessments, as inputs to the National Communications as required by the United Nations Framework Convention on Climate Change (UNFCCC) (Carter et al., 1994). UNEP continues to develop and/or support the development of global, regional and national harmonised environmental data and databases, especially geo-referenced indicators for environmental assessments and early warning activities. Its Chapter 7 on coastal zones contains several sections outlined in Table 2.

Table 2. Methods for climate change impact assessment and adaptation strategies as outlined in Chapter 7 of the UNEP Handbook on Methods for Impact Assessment and Adaptation Strategies (1998).

7.1 Nature and scope of the problem Delineation of the study area; Absolute and relative sea-level change; Biogeophysical effects and socio-economic impacts
7.2 An array of methods 7.2.1 Acquisition and management of data • Global sea-level changes; Coastal topography and land use; Socio-economic data; • Management of data 7.2.2 Index-based approaches 7.2.3 Methods for addressing biogeophysical effects • Increasing flood-frequency probabilities; Erosion and inundation; Rising water tables; Saltwater intrusion; • Summary 7.2.4 Methods for assessing potential socio-economic impacts • Population; Marketed goods and services; Non-marketed goods and services
7.3 Scenarios • Relative sea-level rise; Other scenarios
7.4 Autonomous adaptation
7.5 Planned adaptation • Identification of adaptation options • Evaluation of adaptation options
7.6 Summary and implications

The UNEP methodology establishes a generic framework for thinking about and responding to problems of sea-level rise and climate change. It consists of seven steps:

1. Define the problem
2. Select the method
3. Test the method
4. Select scenarios
5. Assess the biogeophysical and socioeconomic impacts
6. Assess the autonomous adjustments and
7. Evaluate adaptation strategies.

The last step is itself split into seven sub-steps. At each step, methods are suggested but the choice is left to the user. This approach is useful in a range of situations, including sub-national or national level studies. The UNEP approach might constitute a pilot study, or follow earlier studies such as those completed using the IPCC Common Methodology, or be a quick screening assessment prior to more detailed vulnerability assessment (Klein and Nicholls, 1998, 1999). Information gathered with this methodology can then be used as input for future modelling. Qualitative or quantitative physical and socioeconomic characteristics of the national coastal zone are the key inputs resulting in evaluation of a range of user-selected impacts of sea-level rise and potential adaptation strategies according to both socioeconomic and physical characteristics.

The UNEP Handbook elaborates on the IPCC guidelines (see Section 3.2 and Section 4.1) by presenting and discussing a broad range of approaches that might be used for addressing the question "What does climate change mean to us?" and, to a lesser extent, "What might be done about it?". It consists of two parts: A generic part deals with the framing of the assessment, the development of socioeconomic and climate change scenarios, integrated assessment, and adaptation. A sectoral part discusses methods for impact and adaptation assessment. The Handbook discusses important theoretical aspects of adaptation and presents specific methods for the assessment of adaptation measures (Burton et al., 1998; O'Brien, 2000; Kovats et al., 2003).

3.5.2 What UNEP says about Australia

The UNEP handbook is designed to assist developing countries conduct climate change impact assessments. Data held by UNEP for Australia is derived from Australian State of the Environment reports (1996, 2001).

4. International approaches for assessing coastal vulnerability

Several international approaches have been developed as assessment tools or models for use in the coastal zone. Coastal areas have been a particular focus for consideration of adaptation to sea-level rise, as well as the relationship of adaptation to wider coastal management. The United Nations Framework Convention on Climate Change (UNFCCC, 2004) has compiled a useful compendium on methods and tools to evaluate impacts of vulnerability and adaptation to climate change, adopting a summary table format to assess the techniques. That approach is adopted here and extended in Appendix 2.

A number of key approaches can be identified, and the links between them are outlined below. First the IPCC Common Methodology (CM) is outlined and its contribution to Global Vulnerability Assessment (GVA) is described. Second, the use of vulnerability indices is examined and their utility for the Australian coast considered. Third, the Bruun rule is summarised as it underlies many of the more automated tools available to assess coastal vulnerability. Finally, several international techniques and approaches are outlined that can assist a user, such as a coastal planner or engineer, in evaluating different coastal management strategies. More complete assessments of tools are given in Appendix 2 including:

- The Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment (SURVAS)
- Land and wetland loss assessment following Klein/Nicholls
- Dynamic Interactive Vulnerability Assessment (DIVA)
- Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM)
- Community Vulnerability Assessment Tool (CVAT)
- The Climate Framework for Uncertainty, Negotiation and Distribution (FUND)
- Coastal Zone Simulation Model (COSMO)
- South Pacific Island Methodology (SPIM), and
- Shoreline Management Planning (SMP).

4.1 IPCC Common Methodology and Global Vulnerability Assessment

The IPCC Common Methodology was first proposed in 1991 to assist in estimating a broad spectrum of impacts resulting from sea-level rise, including the value of lost land and wetlands. This method is useful for coastal studies at the sub-national up to the global scale and has been tested in several trials in Australia. It has led to several other global vulnerability assessment approaches (eg. Hoozemans et al., 1993; DIVA), but has not been adopted to the same extent in Australia.

4.1.1 IPCC Common Methodology

Even modest increases in sea level will result in a series of direct or primary impacts on coasts, such as erosion, inundation of low-lying areas, flooding and storm damage and salinisation of groundwater and waterways. These are also likely to result in secondary impacts on infrastructure, livelihoods, and health. Preliminary assessments of probable impacts of accelerated sea-level rise were undertaken at national level for the Netherlands and the US. The CM specified three scenario variables: global climate change including sea-level rise; socio-economic development; and response options. It involved 7 steps (Table 3 and Appendix 2.1).

Table 3. Comparison of the IPCC Common Methodology vulnerability assessment procedures and their refinement in an Australian context by Kay and Waterman (1993), Harvey et al. (1999a), and the wetland risk assessment procedure of van Dam et al. (1999), based on Ramsar (2002).

	IPCC CM	**Kay & Waterman**	**Harvey et al**	**van Dam et al**
Definition of study area	Step 1	Step 1	Steps 1 & 2	Step 1
Data collection	Steps 2 & 3	Steps 2 & 3	Steps 3-6	Steps 2 & 3
Assessment	Steps 4 & 6	-	Step 7	Steps 2 & 3
Responses	Steps 5 & 7	Step 4	Step 8	Step 4

Testing of the CM in an Australian context was undertaken initially at Geographe Bay in Western Australia (Kay et al., 1992), and subsequent studies were completed on the Cocos (Keeling) islands, a coral atoll territory in the Indian Ocean (Woodroffe and McLean, 1993) with further application to Kiribati (Woodroffe and McLean, 1992; McLean and Woodroffe, 1993). The CM was found deficient because the biophysical framework is not adequate to support the engineering and cost-benefit stages. The CM uses monetary valuations as an estimate of a coastal nation’s vulnerability to future sea-level rise, employing a cost-benefit test to assess the preferred response option to mitigate future coastal impacts. Although applied across 46 case studies in 25 countries by the time of the World Coasts conference in 1993 (IPCC, 1994), a number of concerns were raised particularly by Australian researchers at an Eastern Hemisphere workshop held in Tsukuba, Japan 3-6 August 1993 (McLean and Mimura, 1993). Misgivings ranged from minor operational shortcomings to more fundamental methodological concerns, especially: the applicability of economic-based assessment in the case of primarily subsistence economies in the Asia-Pacific region; inadequacy as a tool for coastal managers to formulate sea-level rise impact assessment policies; lack of time dependency; and the narrow geographic conception of the coastal zone (Kay and Hay, 1993; Kay and Waterman, 1993; Kay et al., 1996). Further criticisms of the CM have been described by Klein and Nicholls (1999). Nevertheless, the CM approach has underpinned several subsequent vulnerability assessment procedures, including the study by Harvey et al. (1999a) and the wetland risk assessment procedure of van Dam et al. (1999).

4.1.2 Global vulnerability assessment

Data initially compiled in conjunction with CM assessments fed into the first major global vulnerability assessment (GVA) undertaken by Hoozemans et al. (1993). This global summary of vulnerability is an important milestone in assessing the impact of accelerated sea-level rise. Stimulated by the IPCC CZMS and its CM, it outlined the socioeconomic and ecological implications of accelerated sea-level rise in terms of population at risk, wetlands loss, rice production changes and protection costs. The report, and the datasets that were generated in its support, have had great significance because they have underpinned a series of the subsequent developments, particularly SURVAS and DIVA, and, as is discussed in section 5, it set the standard for the types of metrics that would be used for comparative purposes in assessing vulnerability.

The approach taken in the GVA involved assessment at national level, thus parameters needed to be determined on a country basis. The GVA was the first compilation of quantitative information on coastal vulnerability to sea-level rise. The results of this work have been widely used as the basis for international policy analysis and in integrated assessments, including IPCC. However, constraints include obsolete data, a static one-scenario approach to sea-level change as the only driving variable, and arbitrary assumptions on socio-economic development and adaptation. Hydraulic regime, for example, a measure of wave energy, is classified as high for the whole of Australia (Figure 3.2 in Hoozemans et al., 1993), as is protection status (Figure 3.6 in Hoozemans et al., 1993). Coastal topography was determined on the basis of ETOPO-5, a rasterised grid of global elevation with approximately 9 km horizontal and 1 m vertical resolution (with some input from Bureau of Mineral Resources in Australia, now Geoscience Australia). In many of the analyses Australia and New Guinea are treated as a region (Pacific large islands). The principal concerns in this region are recognised to be concerning coastal ecosystems. The Cocos (Keeling) Islands are listed separately from the rest of Australia, and these are ranked 17th out of the 50 most vulnerable countries on the basis of people at risk from sea-level rise (Table 6.11, Hoozemans et al., 1993). Australia contains some of the most extensive and diverse tropical-temperate coastal environments in the world (in terms of temperature, wave energy and geomorphological zones). A continental-scale approach such as GVA is therefore unrepresentative of the diversity within country.

In Australia, the National Coastal Vulnerability Assessment Case Studies Project (NCVACSP) was undertaken during 1994-95, comprising 9 case studies, one study in each state, with two in each of Victoria and the Northern Territory. The CM and GVA led to upscaling elsewhere around the world (this is studies at local scale were combined to give regional assessments of vulnerability), particularly through the EU-funded SURVAS project. However, in Australia there was, by contrast, a downscaling in the effort devoted to vulnerability assessment in Australia (McLean, 2000). The approaches to determining regional variability in vulnerability adopted elsewhere have not been applied to the same extent in Australia.

4.2 Vulnerability indices

A number of indices have been developed as rapid and consistent methods for characterising the relative vulnerability of different coasts. The simplest of these are assessments of the physical vulnerability of the coast, while the more complex also examine aspects of economic and social vulnerability.

An early attempt to develop a coastal vulnerability index to climate change, particularly sea-level rise, was developed for the United States by Gornitz and Kanciruk (1989), considering inundation and flooding and susceptibility to erosion. It has been suggested that this index could be applied in a global context by Gornitz (1991), although its application was only demonstrated for the US in that study. It was recognised that the index could be improved if it had a term related to storm frequency, and if it included a term related to population at risk (Gornitz et al., 1991).

A coastal vulnerability index, as proposed by Gornitz, has also been incorporated into an analysis of many of the shorelines of the US by Thieler of the United States Geological Survey (USGS). This coastal vulnerability index (CVI) is derived to show relative vulnerability; it combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a relative measure of the system's natural vulnerability to the effects of sea-level rise. This approach uses relative contributions of six variables: tidal range contributing to inundation hazards, wave height linked to inundation hazard, coastal slope (susceptibility to inundation and rate of shoreline retreat), historic shoreline erosion rates, geomorphology (relative erodibility) and historic relative rates of sea-level rise (eustatic and hydroisostatic). Modelling is in raster, re-sampled to a 3-minute grid cell, but with visualisation in vector. For example, barrier islands with small tidal ranges, low coastal slope and high historical rates of sea-level rise have a high vulnerability, whereas rocky cliffed coasts with lower rates of retreat or sea-level rise are the least vulnerable (Thieler 2000). These maps form a basis for developing a more complete inventory of variables influencing vulnerability to future sea-level rise, and for more detailed at-a-site assessment (Hammar-Klose and Thieler, 2001; Thieler et al., 2002; Hammar-Klose et al., 2003; Pendleton et al., 2004a-f, 2005a-d).

The Gornitz and Kanciruk approach has also given rise to similar, but modified indices that have been used elsewhere. For example, in Canada a sensitivity index (SI) has been developed to assess coastal sensitivity to sea-level rise. In this case it is developed for the entire Canadian coastline using 2899 1:50,000 map sheets and the index is scaled using a 1-5 scaling developed for Canadian coastal types, with final ranking as low, moderate or high. A shortcoming at this scale is that numerous areas of high sensitivity are overlooked because of the scale and the method of scoring. Attributes concerning the Canadian coast are contained in a Coastal Information System (CIS), and this can be used to calculate the sensitivity index (SI) (Shaw et al., 1998), or further variables can be added, as has been adopted locally to derive an erosion hazard index (EHI) (Forbes et al., 2003). Such an approach has been extended more generally to the Arctic coastal dynamics project (Rachold et al., 2000).

A further modification was undertaken by Hughes and Brundrit (1992) for application to the South African coast. In this case the index needed modification because of the shortage of data on shore displacement (ongoing shoreline change) and vertical land movements. Added, however, was an element that assessed economic value in terms of infrastructure, so that an index comprised location, infrastructure at risk and hazard. A similar approach has also been used at local site level in South Africa (Hughes and Brundit, 1991; Hughes et al., 1992, 1993). The outcome of this is a physical vulnerability index. When population is added as a variable, the outcome is a coastal social vulnerability index as discussed later in this section.

Table 4. Summary of coastal vulnerability indices, their geographical application and the variables needed to implement them.

Index	Geographical application	Variables considered	Reference
Coastal vulnerability index (CVI)	USA	Relief, vertical land movement, lithology, coastal landform, shoreline displacement, wave energy, tidal range	Gornitz and Kanciruk (1989), Gornitz (1991), Gornitz et al. (1991)
Coastal vulnerability index (CVI)	USA	Historic shoreline erosion rates, geomorphology, relative rates of sea-level rise, coastal slope, wave height , tidal range	Thieler (2000) and numerous other USGS reports
Social vulnerability index (SoVI)	USA	Principal components analysis of Census-derived social data	Boruff et al. (2005)
Coastal social vulnerability score (CSoVI)	USA	Combination of CVI and SoVI	Boruff et al. (2005)
Sensitivity index (SI)	Canada	Relief, sea-level trend, geology, coastal landform, shoreline displacement, wave energy, tidal range	Shaw et al. (1998)
Erosion hazard index	Canada	As SI, plus exposure, storm surge water level, slope	Forbes et al. (2003)
Risk matrix	South Africa	Location, infrastructure (economic value), hazard	Hughes and Brundrit (1992)
Sustainable capacity index (SCI)	South Pacific	Vulnerability and resilience of natural, cultural, institutional, infrastructural, economic and human factors	Yamada et al. (1995)
Sensitivity index	Ireland	Shoreface slope, coastal features, coastal structures, access, land use	Carter (1990)
Vulnerability index	UK	Disturbance event frequency, relaxation (recovery) time	Pethick and Crooks (2000)

The above approaches are largely derived from the initial work of Gornitz, with an index widely applied in the US and in modified form to Canada and parts of South Africa. Several researchers have seen a need to incorporate data on storm and storm-surge occurrence and frequency. It has also been viewed as important to incorporate social data on people at risk, the most detailed social vulnerability analysis being the synthesis by Boruff et al. (2005). The social vulnerability index (SoVI) uses socio-economic variables on a coastal county basis in a principal components analysis (PCA) to produce the overall coastal social vulnerability score (CSoVI).

The CVI was obtained by manipulating scores of 1 to 5 attributed to each of the 7 variables (Table 5). Based on the assumption that the intensity of impact is related to these quantifiable variables;

$$CVI = \sqrt{((a1 \times a2 \times a3 \times a4 \times a5 \times a6 \times a7)/7)}$$

A dimensionless index is determined, and on the basis of this index coasts can be grouped into three categories; low, moderate and high sensitivity. A coast with a high sensitivity index for example, would be in a region of low relief, unconsolidated sediments, with barrier islands, high tidal range, high wave energy levels and rapid relative sea level rise. A low sensitivity index coast would have high relief, a rocky shore with resistant non-eroding bedrock, falling sea-level, low tidal range and low wave energy. The sensitivity index method of classifying coasts accommodates not just sea-level but also the potential of other factors that render the coast more or less sensitive to change.

Table 5. Matrix for determination of coastal vulnerability index (CVI), adapted from the coastal risk classes of Gornitz (1991). A similar approach could be used in Australia.

Category	Very low	Low	Moderate	High	Very High
VARIABLE	**1**	**2**	**3**	**4**	**5**
a1. Relief (m)	≥ 30.1	20.1 - 30.0	10.1 - 20.0	5.1 - 10.0	0 - 5.0
a2. Rock type	High-medium grade metamorphic	Low-grade metamor. Sandstone	Most sedimentary rocks	Coarse unconsolidated sediments	Fine unconsolidated sediments
a3. Landform	Rocky, Cliffed coasts	Medium cliffs, Indented coasts	Low cliffs, salt marsh, coral reefs, mangrove	Beaches (pebbles), Estuary, Lagoon	Barrier and bay beaches, mudflats, Deltas
a4. RSL change (mm/yr)	≤ -1.1 Land rising	- 1.0 - 0.99	1.0 - 2.0 Eustatic rise	2.1 - 4.0	≥ 4.1 Land sinking
a5. Shoreline displacement (m/yr)	≥ + 2.1 accretion	1.0 - 2.0 stable	-1.0 - + 1.0 erosion	-1.1 - -2.0 erosion	≤-2.1 Erosion
a6. Tidal range (m)	≤ 0.99 Microtidal	1.0 - 1.9 Microtidal	2.0 - 4.0 Mesotidal	4.1 - 6.0 Mesotidal	≥ 6.1 Macrotidal
a7. Annual max wave height (m)	0 - 2.9	3.0 - 4.9	5.0 - 5.9	6.0 - 6.9	≥ 7.0

The purpose of CVI calculation is to assess the impacts of a rise in relative sea-level (such as might be caused by climate warming) on the Australian coast. This involves an examination of the nature and extent of coastal features that would be sensitive to such change. Sensitivity means the degree to which a rise in sea level or storm surge would initiate or accelerate geomorphological changes such as coastal retreat and beach erosion. A modified version of the coastal vulnerability index CVI of Gornitz (1991) could be used to assess the sensitivity of Australian coastline. It would be better to customise the variables rather than to adopt the seven variables listed in Table 5 uncritically.

Figure 6 shows how a different CVI index might be obtained for local assessment of the Australian coast. Local assessment on a section of embayed coast in eastern Australia is shown schematically, with the relative susceptibility of the variables in Table 5 shaded to show their ordinal ranking. Lower sensitivity is indicated for rocky headlands than sandy beaches; a still higher susceptibility is indicated for the estuary, although this is problematic as described below.

Table 5 could be adapted for a national assessment of vulnerability, in a similar way to the susceptibility mapping undertaken on the Canadian coast (Shaw et al. 1998). However, it would be critical to select more appropriate variables and scale them for the Australian environment (as the Canadians did for their SI and EHI). For example, the rate of observed sea-level rise varies little around the Australian coast, meaning that variable a4 shows little if any differentiation. Similarly there is generally insufficient data on observed patterns of historical shoreline change (as in the case of South Africa), in contrast to those parts of the Arctic coast where melt of permafrost has resulted in erosion rates of 10s of metres a year, with clear implications for future vulnerability. Incorporation of classifications developed in Australia, such as sand barrier types (Roy et al., 1994), or beach morphodynamic states (Short, 1999), might be appropriate, but would need validation and testing before widescale application.

Whereas this index approach could be applied to sections of open coast (for example, the 10s of kilometres of Sydney's beaches), it is less clear whether such an approach can be extended to the often extensive shorelines of the many estuaries and embayments (for example, the 100s of kilometres of estuarine foreshores associated with Sydney Harbour, Botany Bay, broken Bay and Port Hacking). Determination of an index for the estuary in Figure 6 is especially problematic, and would necessitate much further development of datasets such as OzEstuaries. Furthermore, the CVI method yields numerical data which cannot be directly equated with particular physical effects; it does not measure rate of retreat, or volume of erosion. The index does not capture storm surge or sediment transport.

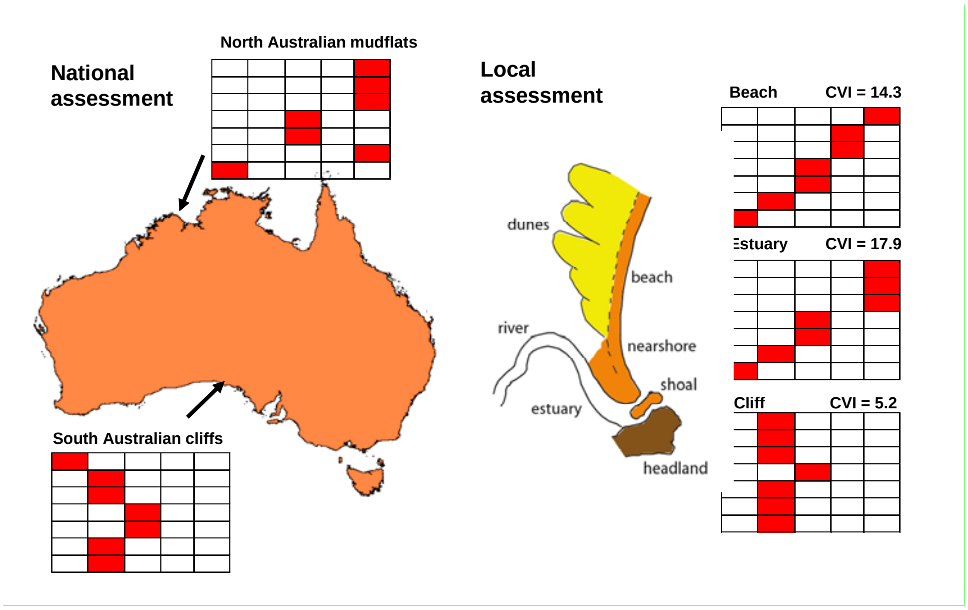


Figure 6. Possible CVI approach and template for vulnerability assessment at local or national scale shown with schematic representation of the rankings in Table 5.

In the Pacific, vulnerability has been assessed using an approach developed from the CM advocated by Kay and Hay (1993), that assesses both vulnerability and resilience. Vulnerability is scaled –3 – 0, and resilience is scaled 0-3; this is undertaken across a series of sectors including natural (physical, biological), cultural (communal, national), institutional (village, national), infrastructural (individual, communal, national), economic (subsistence, cash) and human (populations). These values are then summed into a Sustainable Capacity Index (SCI). An SCI is calculated for existing conditions and estimated under response strategies in order to assess the effectiveness of adaptation (Yamada et al., 1995). This approach is incorporated into the South Pacific Island Methodology (SPIM, see Appendix 2.10). SPIM is particularly useful in coastal settings with limited quantitative data but considerable experience and qualitative knowledge, such as developing island nations. As such it could be used to carry out initial studies in parts of Australia with limited data but it would also depend on being able to rank resilience and vulnerability.

A further development has been a rather more general environmental vulnerability index (EVI) developed by the South Pacific Applied Geosciences Commision (SOPAC) (Kaly et al., 1999), but extended jointly by SOPAC and UNEP (SOPAC, 2004). This assigns rankings to 50 factors, at the scale of entire countries. The EVI simultaneously examines levels of risk and conditions now, predicting how the environment is likely to cope with future events. A scale of 1 (resilient) to 7 (vulnerable) is shown graphically for each of 50 indicators (32 indicators of hazards, 8 of resistance and 10 that measure damage). The values are summed to give a simple average, and portrayed as a report card. Hazards range beyond climate change, but a climate change sub-index can be calculated. Australia attains an EVI score of 238 which places it in the ‘at risk’ class (fourth class out of five), indicating less risk than most countries. It is noticeable that coastal hazards are included in the index, so that land-locked nations tend to score a lower EVI. The factor gaining the greatest score for Australia is Biotechnology. This appears to be because Australia mostly uses biological processes in industrial production of certain drugs, synthetic hormones, and bulk foodstuffs as well as the bioconversion of organic waste and the use of genetically altered bacteria in the cleanup of oil spills; and the nation gets a climate change sub-index of 2.77, again not high on a global scale.

4.3 Bruun rule

Introduced in 1962, the Bruun Rule is the best known model relating shoreline retreat to an increase in local sea level. It estimates the response of the shoreline profile to sea-level rise and is best applied at small scales such as local sites along coasts. It has been applied extensively along coasts in NSW and Tasmania (as described in section 5). On the basis of cross-shore profiles in Denmark and California, Per Bruun indicated an equilibrium profile beach shape expressed by the formula:

$$\underline{h=Ay^{2/3}}$$

where h is water depth (Figure 7), y is the distance offshore and A is a scaling parameter based on sediment characteristics. Bruun considered that this simple generic geometric model of nearshore profile could be used to determine evolution of a sandy shoreline in response to sea-level rise. This conceptual model implied that sand was moved from the upper part of the beach profile to accumulate on the lower part of the profile to the depth at which sediment movement ceases, termed the closure depth, beyond which only small amounts of sand are lost in a seaward direction. Many of the quantitative and computational models are based on prediction of the retreat of local shorelines using this mathematical model known as the Bruun rule.

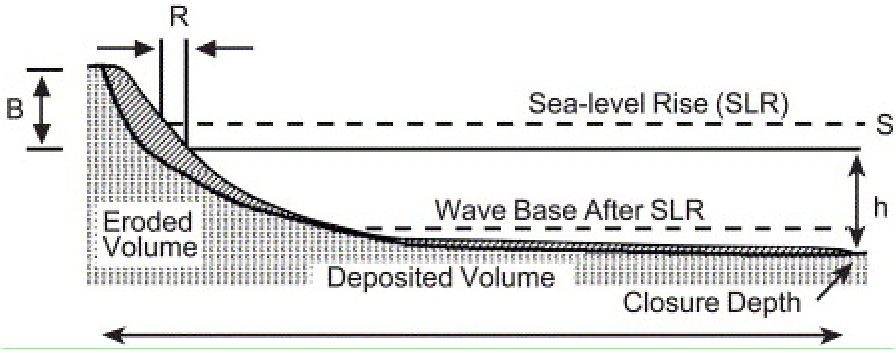


Figure 7. The Bruun Rule of shoreline erosion.

The Bruun approach is often used, assuming that the rate of retreat equates to 50-100 times the rate of sea-level rise. Although applied with some success in the US (Zhang et al., 2004), there has been criticism of several aspects of the Bruun rule as a "one model fits all" solution (Cooper and Pilkey, 2004). For example, closure is a difficult concept to resolve in the field; estimates of the closure depth used for coastal erosion hazard assessment in New South Wales on exposed ocean beaches have varied between 20 m and 50 m. Applicability of the rule must be questioned where there are bedrock outcrops or variable lithology, or where longshore transport is significant or there is significant loss in a landward direction to dunes or wash over. The rule takes no account of complexities introduced by currents or other subtle interactions between morphology and process. The effect of individual storms, well-documented on the NSW coast, is ignored, and the time scale of sediment movement is not defined.

4.4 Evaluation of semi-quantitative and computational approaches

There has been a series of international approaches for assessing vulnerability of a coast to climate change, many of which have developed from the IPCC Common Methodology for vulnerability assessment. The effectiveness with which approaches adapted elsewhere in the world, and those adapted within Australia, can be applied to assess vulnerability to coastal change are evaluated below.

4.4.1 SURVAS

The SURVAS (Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies) project developed a global assessment of vulnerability of the coastal zone. It uses a common assessment methodology (in many cases the CM), identifying key indicators for the assessment of coastal natural susceptibility and socioeconomic vulnerability and resilience to the impact of climate change, particularly accelerated sea-level rise (Nicholls and de la Vega-Leinert, 2000). The approach involved a network of international experts on vulnerability and adaptation studies, identifying key indicators for the assessment of susceptibility and resilience to the impact of accelerated sea-level rise. A questionnaire and matrix of indicators of vulnerability and adaptation was developed. The SURVAS database http://www.survas.mdx.ac.uk has no data on Australia and the approach has not yet been applied in Australia (see Appendix 2.3). The SURVAS approach was an independent outcome of the IPCC CM vulnerability assessment initiatives; it has not been embraced in Australia, which has undertaken a series of similar assessments with alternative methodologies (see Table 9, and Kay et al., 2005a, 2005b). SURVAS has now been superceded by DIVA.

4.4.2 Land and wetland loss assessment following Klein and Nicholls

This modelling approach was developed from the Hoozemans et al. (1993) GVA, and considers changes to flooding by storm surges (a human-system impact) expressed in terms of the number of people at risk of flooding on average per year, and loss of coastal wetlands. The effect of flooding was modelled by using sea-level rise scenarios generated by the HadCM3 coupled atmosphere-ocean climate model, and the Special Report on Emission Scenarios (SRES) world story-lines (Arnell et al., 2004), which defines a range of socio-economic factors in terms of globalisation versus regionalisation and economic versus environmental drivers (Nicholls et al., 1999; Nicholls, 2004). In initial modelling the world's coast was segmented into 192 polygons representing coastal nations, for which average population density for coastal areas was derived. From this the number of people in the hazard zone and the average annual number of people flooded were calculated. In the absence of a global database on flood protection, this was modelled based on national GDP assuming a lagged evolving response. In both cases, whether there is sea-level rise or not, the A2 world experiences (see Table 6) the greatest level of flooding, indicating that it is growth in the world's population, and movement of people into the coastal zone, which lead to the greatest increase in number of people subject to flooding. This approach has been considerably refined with the DINAS-Coast project and the development of DIVA.

Table 6. IPCC SRES story lines based on emissions scenarios.

The A1 family describes a world with rapid economic growth during the 21st century and a substantial reduction in the regional variations of income per head. Global population rises during the first half of the century, peaks mid-century, then declines. New and efficient technology is rapidly introduced. The A1FI scenario sees the continuation of fossil fuels as the main energy source.
The B1 family describes a world with the same population growth as the A1 family. There are rapid changes in economic activity away from production towards a service economy rather than being entirely economically driven. Clean and efficient technologies are introduced. Like A1, this storyline describes a convergent world involving global co-operation.
The A2 family describes a world that remains heterogeneous with regional identity being preserved and lower income growth per head. Global population rises continuously throughout the century. The introduction of new and efficient technology is less rapid than the other scenarios with a gap between richer and poorer nations.
The B2 family describes a world with population increasing throughout the 21st century, but at a lower rate than A2. Levels of economic growth and technological development are less than those of A1 and B1, with increasing regionalisation.

4.4.3 DINAS-Coast and DIVA

A European project, involving British, German and Dutch scientists, DINAS-Coast (Dynamic and Interactive Assessment of national, regional and global vulnerability of Coastal Zones to Climate Change and Sea-level Rise) has developed tools to help policy makers interpret and evaluate coastal vulnerability. The tool called DIVA (Dynamic Interactive Vulnerability Assessment) enables analysis of a range of mitigation and adaptation scenarios. The project has attempted to predict the global impact of climate change on the coastal zone for the next 100 years, involving a range of mitigation and adaptation scenarios. The DIVA method uses the project DINAS-COAST database, which builds on methods and expertise developed in a range of scientific-technological disciplines (including the GVA and SURVAS projects).

DIVA is specifically designed to explore the vulnerability of coastal areas to sea-level rise. It comprises a global database of natural system and socioeconomic factors, relevant scenarios, a set of impact-adaptation algorithms and a customised graphical-user interface. Factors that are considered include erosion, flooding, salinisation and wetland loss. DIVA enables user-selected climatic and socioeconomic scenarios and adaptation policies, on national, regional and global scales, covering all more than 180 coastal nations (McFadden et al., 2004).

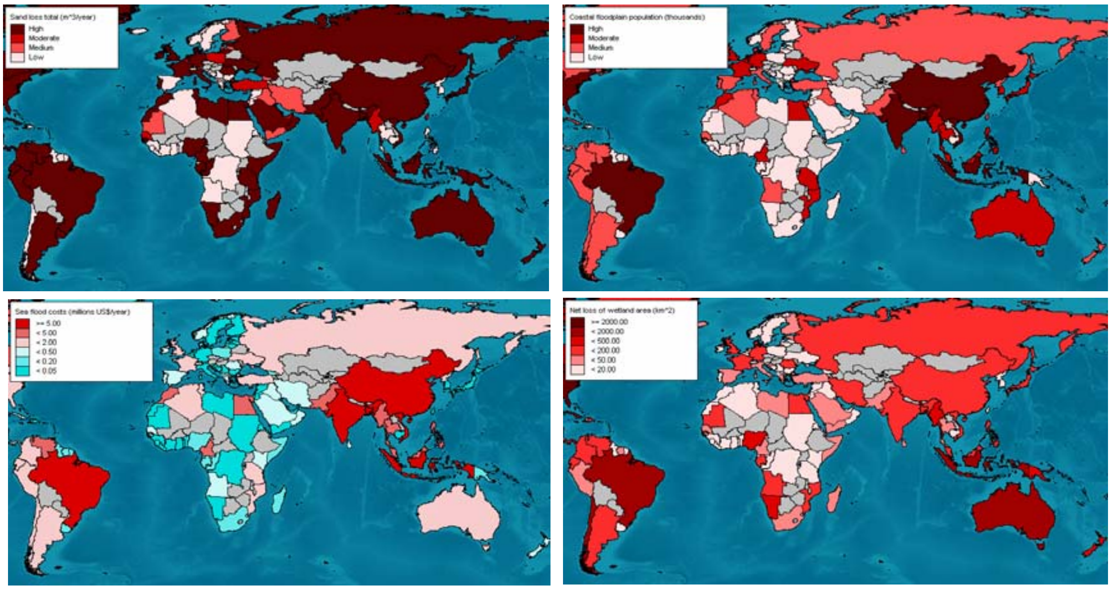


Figure 8. Selection of type of map outputs possible from DIVA at a global scale, indicating total sand loss, coastal floodplain population, sea flood costs, and net wetland loss under particular SRES and sea-level scenarios, and for user-defined time slices.

The model is driven by sea-level rise scenarios produced with the climate model of intermediate complexity, CLIMBER, of the Potsdam Institute for Climate Impact Research, and by socio-economic scenarios produced by Hamburg University. The first modules assess erosion, subsequent modules assess socio-economic impacts, and the final module is the adaptation module, which implements adaptation measures based on preset or user-defined decision rules, and analyses the results using maps, charts and tables. The modules are invoked sequentially in the order of their cause-and-effect relationship.

DIVA can be applied both globally (Figure 8) and at a national scale as is shown in Figure 9. A recent development in the linear representation of the coastline uses a technique called dynamic segmentation which measures distances from the beginning to the end of a coastal reference string and spatially references coastal features based on these measurements (Sherin and Edwardson, 1996; Sherin, 1999). The segmentation of the world's coastline was performed on the basis of a series of physical, administrative and socio-economic criteria, producing 12,148 coastline segments in total. It contains data on about 180 coastal segments for Australia (Figure

10), but model outputs are generally at regional and administrative unit level (in the Australian case at state or territory scale). For site-specific applications the model would have to be modified to incorporate local variables. At this stage, application at a national scale does not give particularly insightful perspectives on vulnerability of the Australian coast to climate change, but with a clearer understanding of the premises behind the modelling, either this suite of software, or a similar approach adopting a more customised segmentation, might offer a tool that could be developed for more effective use in Australia.

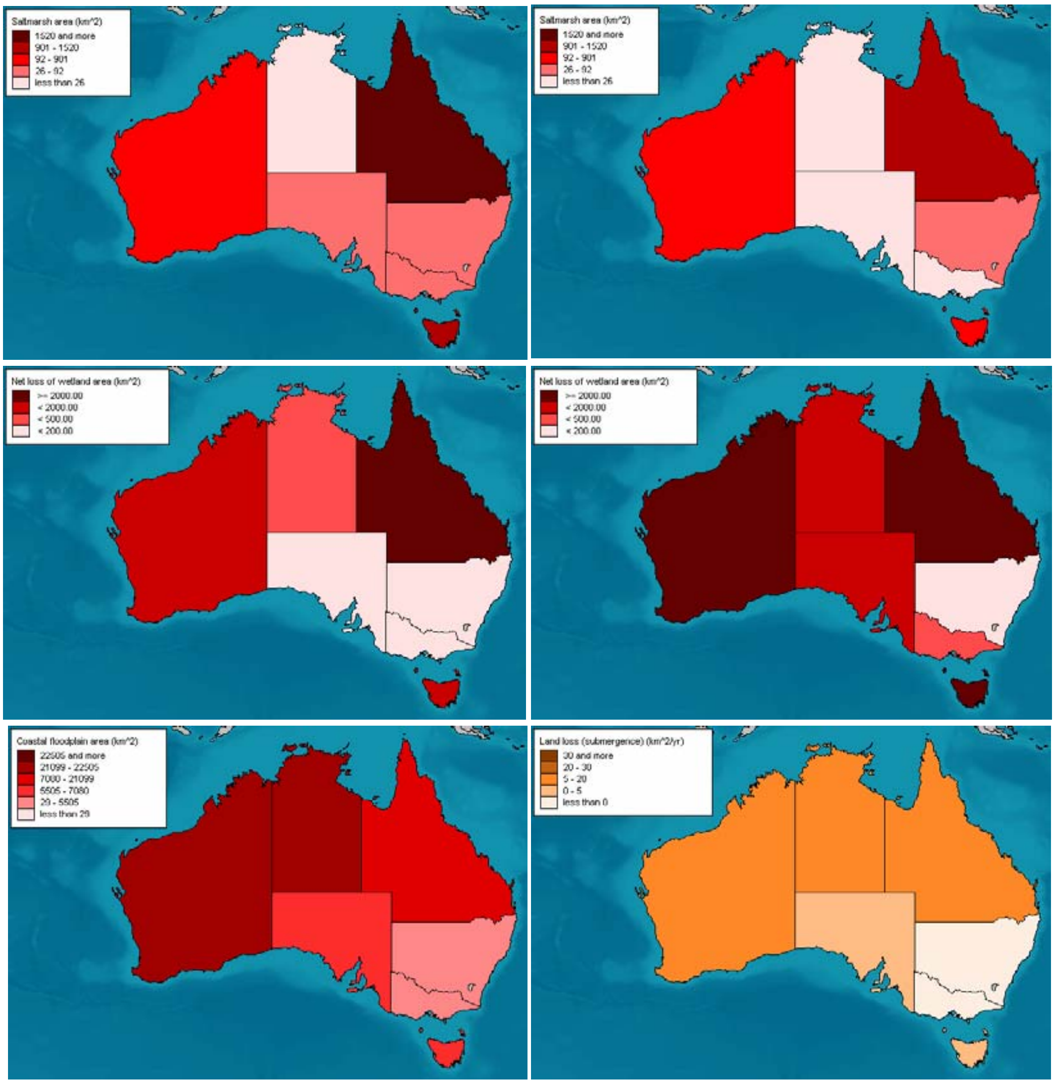


Figure 9. Selection of the type of output possible from DIVA at administrative unit scale (state and territory in case of Australia), in this case area of salt marsh in 2050 and in 2100, wetland loss in 2010 and 2050, coastal floodplain area and land loss. Such products are produced under particular SRES and sea-level scenarios, and for user-defined timeslices.

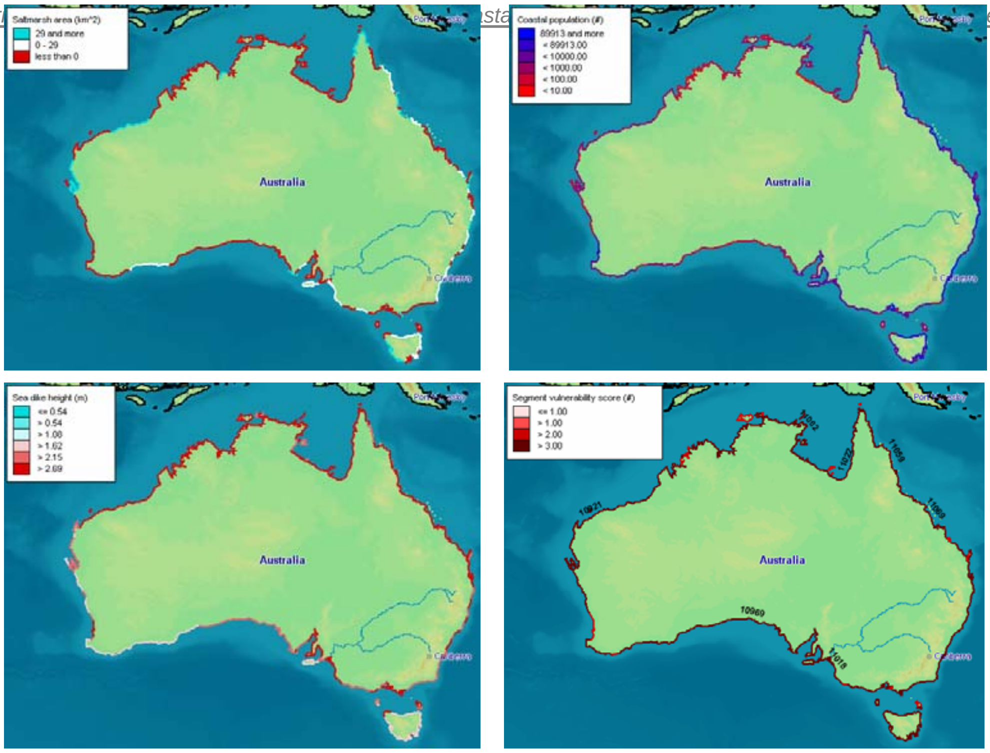
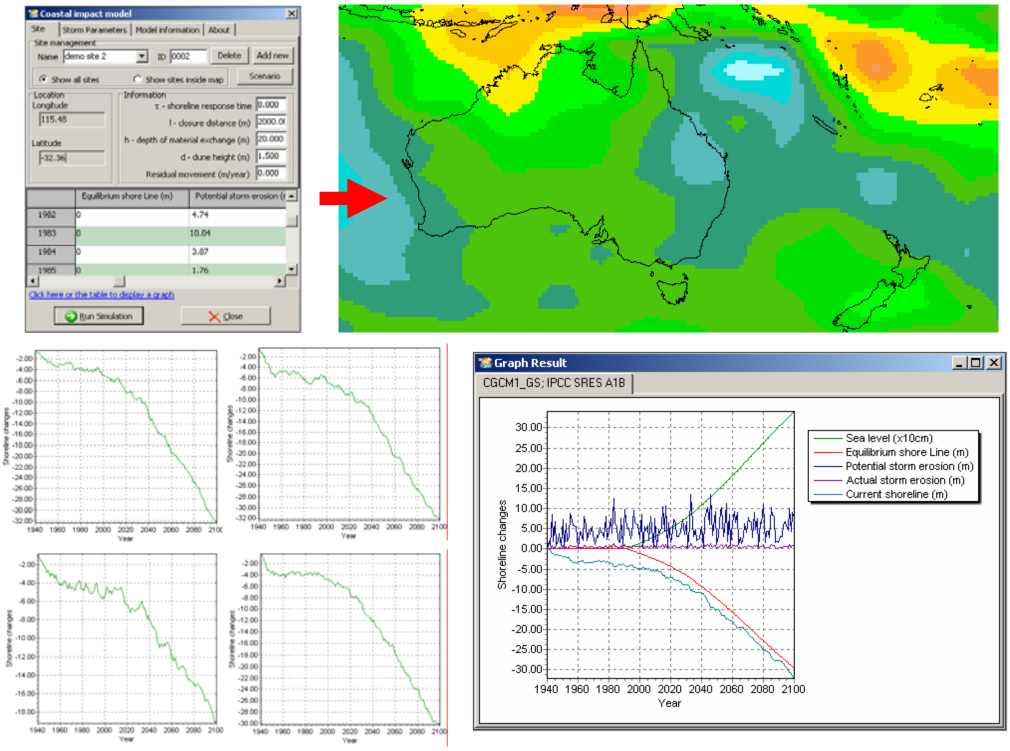


Figure 10. Selection of output from DIVA showing segmentation of the coast; examples include saltmarsh area, coastal population, sea dike height (although it is difficult to see how such a dataset can have been derived for Australia!), and vulnerability of segments. These depend on particular SRES and sea-level scenarios, and user-defined timeslices.

4.4.4 SimCLIM

The Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM) Open Framework Software System is part of an ongoing effort to design tools to aid decision-making under changed climate conditions (Warrick et al. 2005). It was developed from a “hard-wired” system originally built for New Zealand (Warrick et al., 1996, 2001; Kenny et al., 1999, 2000). The purpose of SimCLIM is to link and integrate complex arrays of data and models (particularly based on CO_2 concentration as produced by the MAGICC model for IPCC, Wigley, 2000), in order to simulate, temporally and spatially, biophysical impacts and socioeconomic effects of climatic variations, including extreme climatic events. In this way, it provides the foundation for assessing options for adapting to the changes and reducing the risks. SimCLIM enables examination of potential erosion and flooding in response to future climate scenarios including sea-level rise due to climate change, global warming as well as changes resulting from local land movements. Its coastal subroutine involves an erosion model that is a modified version of the Bruun Rule.



Name demo site 2
ID 0002
● Show all sites
○ Show sites inside map
Longitude 115.48
Latitude -32.36
τ - shoreline response time 0.000
l - closure distance (m) 2000.0
h - depth of material exchange (m) 20.000
d - dune height (m) 1.500
Residual movement (m/year) 0.000

	Equilibrium shore Line (m)	Potential storm erosion (
1982	0	4.74
1983	0	10.04
1984	0	3.87
1985	0	1.76

Figure 11. Application of CoastClim in Western Australia. Regional values for climate drivers can be derived from global outputs of GCMs. Characteristics of a particular coast are input into the dialogue box, and the model can be trained using historical patterns of shoreline change. Subsequent simulations show the effect of changing the response time of the shoreline, the closure depth and the height of the dune. A composite of all output variables from CoastClim shows the nature of results, including storm simulations.

SimCLIM is designed to support decision-making and climate proofing in a wide range of situations where climate and climate change pose risk and uncertainty. The probabilities and return periods for such extreme events can also be queried for the future using an array of future scenarios of climate change, as released by the IPCC. The software enables a wide range of potential users to examine future climate scenarios in the context of their particular sectoral interests. The method features a separate sea-level generator to calculate sea-level change due to climate change and global warming in association with that resulting from local land movements.

One of the distinct advantages of using the generator is that it allows rapid generation of place-based sea level scenarios, which accounts for some uncertainties associated with emissions scenario. Values for isostatic adjustment and other local factors need to be input by the user. SimCLIM also includes a set of developed impact models. For the coastal zone, the focus is on erosion and flooding, taking into account storm effects, local sea-level trends and lag effects in order to provide time-dependent responses of the shoreline to sea-level rise at selected sites. The coastal flood model is spatial and allows the user to examine changes in the areas of potential inundation from the combined effects of sea-level rise and extreme storm events.

Figure 11 shows sample of the type of output for demo site 2, in Western Australia generated from CoastClim version 0.1, an integrated assessment model for climate change impact on shoreline position that forms a component of SimCLIM. CoastClim is a simulation model of shoreline changes for beach and dune systems based on a variant of the Bruun Rule, enabling “what if” scenarios on coarse temporal and spatial scales. Initial data inputs into the model are shoreline response time (to effects of storms, sea-level rise) in years, closure distance from the shoreline (m), depth of material exchange or closure depth (m), dune height (m) and residual shoreline movement (m/year). Using ‘what if’ scenarios for the inputs and varying the input values, different types of graphs can be obtained as shown in Figure 11 on the right. The current shoreline after varying different inputs is shown in Figure 11 on the left. Patterns of regional sea-level variation can be derived from Global circulation models (GCM) outputs; these can then be used in conjunction with the coastal simulator. Shoreline position extends historical reconstructions, as shown in Figure 11.

CoastClim would seem to have considerable potential for application in Australia. The demonstration from the WA coast indicates the ability of the model to generate trends that are similar to historical patterns, but further validation on other parts of the Australian coast, particularly those that do not show a consistent trend of shoreline displacement, are needed. It would also be very useful if this approach incorporated shoreline models other than just the simple Bruun rule (for example those described by Cowell et al., 2006), and could be integrated with mapping such as that undertaken by Sharples (2004) in Tasmania.

4.4.5. Community Vulnerability Assessment Tool (CVAT)

The Coastal Services Center of National Oceanographic and Atmospheric Administration (NOAA), based in Charleston, has developed a Community Vulnerability Assessment Tool (CVAT), which supports the linking of environmental, social and economic data in the coastal zone. CVAT is a static GIS map overlay procedure that enables a relative risk or vulnerability analysis of coastal communities to a series of existing threats. Such a tool would require customising to the Australian environment where there is a different suite of hazards and access to appropriate data is not as centralised in Australia. The CVAT procedure comprises 7 steps;

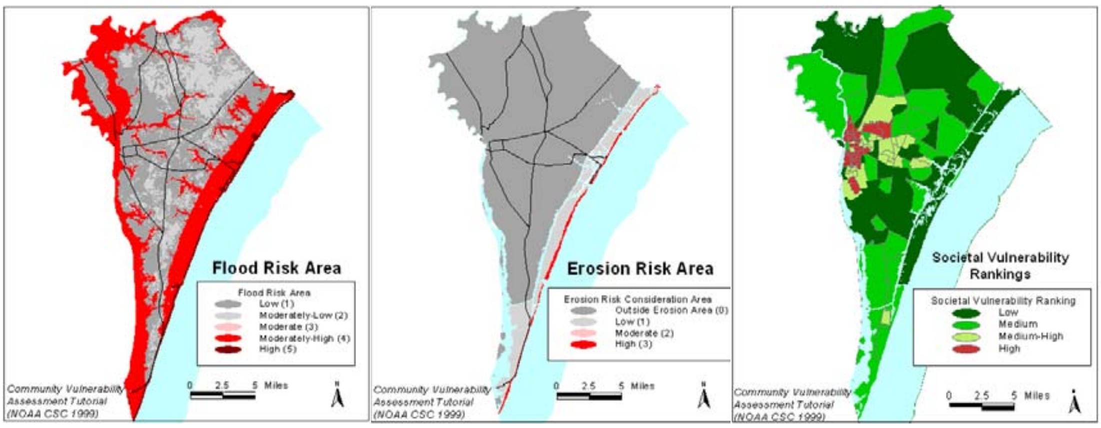


Figure 12. Sample of CVAT mapping procedure adopted by NOAA.

1. Hazard identification and prioritisation
2. Hazard analysis
3. Critical Facilities analysis
4. Societal analysis
5. Economic analysis
6. Environmental analysis and
7. Mitigation opportunities

A sample of the sort of maps prepared by the NOAA Coastal Services Center group is shown in Figure 12. Although not designed to address climate change, this GIS-based approach could be used to map vulnerability of the Australian coast to a series of hazards including those related to climate change.

4.4.6. FUND and FARM

The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is an integrated assessment model for climate change impacts and adaptation analyses with a number of linked modules. The FUND model is specified with different geographic resolutions for socioeconomic and physical aspects, aggregated into major world-regions, including Australia. The coastal module of FUND examines the potential dryland and wetland losses as a result of sea-level rise, and then applies an economically optimum assessment of the benefits of coastal defence. Even under extreme scenarios a benefit-cost evaluation suggests that while certain areas will be abandoned, widespread protection of developed coasts will continue. FUND projections are for 16 world regions, and the population change and per capita growth are assumed to be uniform for all countries within the region and are extended post-2100. Results are better seen as ‘what if’ analyses rather than conventional analysis. While integrated assessment models such as FUND are powerful tools for thinking about the future, the resulting metrics need to be interpreted with great caution.

Future Agricultural Resources Model (FARM) works in a similar way to FUND but is mainly for agricultural resources. It calculates direct cost of land and wetland loss (Darwin and Tol, 2001). FARM contains a regional geographical information system (GIS) that estimates the type of land lost to sea-level rise and a regional computable general equilibrium (CGE) economic model that estimates direct cost (DC) and equivalent variation (EV), a welfare measure that also accounts for second order economic effects. FARM-based DC is lower than FUND-based DC where FARM based protection levels are higher than FUND-based protection levels. FARM’s wetland values are average values of all wetlands in the land classes at risk to sea-level rise with no value assigned to any environmental services that wetlands might provide. Hence they capture only a small portion (less than 1 percent) of the wetland values considered by FUND, which include recreation and nature values. Dry land values are average values of all land not wetland in the land classes at risk. Global scale analyses involve a series of generalisations about Australia (for example that the total shoreline length of Australia and New Zealand is only 18,000 km). FUND or FARM might be of use in those few instances where coastal protection is considered in Australia, but their scale is generally global.

4.4.7 Other tools

Other tools include;

- Coastal Zone Simulation Model (COSMO) developed in the Netherlands, a decision-support model for coastal zone managers to evaluate management strategies under different scenarios, including long-term climate change;
- Shoreline Management Planning (SMP), a generic approach to the strategic management of the combined hazards of erosion and flooding hazards in coastal areas adopted in the UK and
- South Pacific Island Methodology (SPIM) developed for South Pacific islands.

Details of these tools are given in Appendix 2.

There are a number of other beach models that are used by engineers to address beach behaviour in planning and design time scales. These include Storm-induced beach change model (SBEACH) and Global Environment and Ecological Simulation of Interactive Systems (GENESIS) that involve parameterisation of wave climate and modelling of longshore drift. More complicated models include MIKE 21 and COAST3D. These are essentially process models and cannot yet be effectively used to forecast morphological change over longer timescales or to develop scenarios in response to climate change.

4.5 Application of international approaches to the Australian coast

The international approaches, their application and validity in Australia, and limitations on use are summarised in Table 7, and discussed in detail in section 5.

Table 7. Summary of international approaches for assessing coastal vulnerability to the Australian coast, their validity and limitations.

Tool	Validity in the Australian context	Principal limitations
IPCC Common Methodology	several sub- national case studies have been carried out in Australia	Generally not applicable to extensive areas of remote coast
Vulnerablilty index	CVI widely used in US, and adapted for use in other countries	Would require Australian customisation of variables
Bruun Rule	Bruun rule has been applied in NSW and Tasmania, underlies many studies	Controversy over equilibrium profile, alternatives suggested
SURVAS	Not applied in Australia	Superceded elsewhere
Land and wetland loss assessment	Has been applied using coarse data for Australia	Details of wetland response more varied than model simulates
DIVA	Australian data within DINAS-coast and can be applied at global scale	Segmentation approach could be used at more appropriate scale
CoastClim and SimClim	Demo case uses Western Australia	Offers potential but requires further testing and validation
CVAT	US GIS tool for local government	Datasets limited in Australia
FUND	Gives estimates of the economic effects of sea-level rise values of dryland, wetlands and protection costs	Global model based on benefit-cost and directed towards coastal defence
COSMO	Could perhaps be applied in Australia	Developed for Dutch coast
SPIM	Could be applied in Australian island states with limited data sets	Requires ranking of vulnerability and resilience, not quantifiable
SMP	Coastal management plans	No uniformity between plans

5. Synthesis/Conclusions

Each of the various assessments that have been reviewed here concentrate on sea-level rise as the most significant consequence of climate change. Many international assessments considered here are focused on developing countries, for example UNEP guidelines, US country studies (USCS), as well as the data book on sea-level rise (Mimura and Harasawa, 2000). Most studies identify coastal erosion as a prominent impact, although in many cases this is an *a priori* premise through adoption of the Bruun rule that assumes that if the sea rises the shore retreats, without necessarily considering field setting. The next most common impact foreshadowed is increased flooding, both from river inundation of low-lying coastal plains, and increased storm surge levels. Few other climate impacts are examined for coastal areas. Several studies address wetland loss, but most base this simply on inundation of low-lying areas. DIVA models vertical sedimentation and its propensity to offset the retreat of wetlands, however field research indicates that sedimentation rate is highly variable between coastal wetlands in Australia (Rogers et al., 2006), and these models do not simulate the complexities of wetland evolution. If cyclone intensity or frequency changes then further cyclone damage seems inevitable, but few studies address this.

In terms of human impacts, population at risk is modelled. Rarely at global, or even regional scale, can buildings and settlements, or business and industry, be modelled. Impacts on salinity and water resources in coastal areas are generally not considered. There is considerable literature on health and how this may be affected by climate change, but little of it appears focused specifically on the coast. Ecological impacts such as desertification, biodiversity and bushfires have been considered generally in an Australian context, but are not particularly coastal in focus.

Vulnerability assessment needs to be designed for the scale of enquiry that is required by the user. If the objective is a global comparison of the vulnerability to sea-level rise, then it is necessary to design studies that are predicated on consistent and comparable estimates of the impacts of climate change in both monetary and non-monetary terms. For example, the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project in Europe assessed vulnerability to global change of human sectors that rely on ecosystem services. It used internally consistent socio-economic and climate (primarily SRES), land use and nitrogen deposition scenarios to assess sensitivity and the capacity of the sector to adapt. ATEAM (2004) assessed agriculture, forestry, carbon storage, nature conservation, and mountain tourism through the 21st century. However, this comprehensive project was based on terrestrial ecosystems and did not specifically address the coast. Several of these tools are aimed at global comparison, and these generally provide little information that can be used at regional or local scales within Australia.

An early attempt to adopt such a consistent methodology for coasts led to the development of the IPCC Common Methodology (CM) and to the global vulnerability assessment (GVA) synthesis. It also underlies the philosophy of SURVAS and the development of the DIVA tool and the forthcoming consideration of long-term sea-level commitment by the OECD (Nicholls et al., 2006). The majority of these initiatives have come out of Europe and have involved successive updates of global databases and datasets. In relation to coasts, relatively few studies have adopted the SRES scenarios (Nicholls, 2004; Nicholls and Lowe, 2004). Impacts on coral reefs have generally not been considered in this report, but it is noteworthy that Hoegh-Guildberg and Hoegh-Guildberg (2004) do undertake a study using the SRES scenarios in relation to impacts on the Great Barrier Reef.

The IPCC CM has also been a stimulus for development of methods for vulnerability assessment in the Asian region (McLean and Mimura, 1993) and throughout the Pacific region, including the SPIM approach (Yamada et al. 1995; Kaly et al 1999; Mimura and 2000; Hay et al 2003). However, in the Australian context the CM was seen as being deficient, and less prescriptive approaches have been suggested for testing on a jurisdictional basis (Kay et al., 1996; Harvey et al., 1999).

Although Australia is treated in global assessments, it is important to recognise that these are often based on data-poor or deficient coastal descriptors that do not adequately capture the variability of the Australian coast in time or space. In the most recent modelling developments, the DIVA dataset has been considerably extended from the earlier segmentation of world coasts primarily on a national basis. However, despite the fact that DIVA undertakes calculations based on at least 188 coastal segments around the Australian coast, it does not produce output at finer spatial resolution than state level. Within Europe the jurisdictional boundaries are at much smaller scale, and the relative vulnerabilities that are generated are of greater use in terms of coastal management initiatives.

5.1 Metrics for analysis

One of the issues that needs to be considered is the metrics that are used to measure vulnerability. A range of metrics assessing associated physical, biological and socio-economic impacts is reviewed in a forthcoming OECD report that considers sea-level rise over the next 500 years (Nicholls et al., 2006). This report explores the issues, develops methods to estimate the long-term dangers of climate change, and considers the benefits of actions to mitigate the risks for coastal areas (Nicholls et al., 2006). It summarises the issue of metrics based on discussions at a workshop and through a questionnaire survey. Metrics are required, first to assess the exposure to climate change, and secondly to consider the impact. This approach has utility also in studies of erosion, independently of whether that is caused by climate change; for example the EUROSION study in Europe adopted a series of indicators of pressure (equivalent to exposure) and impact (Doody et al., 2004). Global sea-level rise scenarios (and preferably ‘local’ sea-level rise scenarios) and elevation data are a prerequisite for most metrics (Table 8). Some metrics measure exposure, others measure impacts, costs of adaptations and residual risks.

The metrics outlined in Table 8 and used in the majority of global assessments of vulnerability are not parameters that can be easily generalised for the considerable length of the Australian coastline. There might be scope to develop approaches such as the segmentation of the coast and calculation of vulnerability at segment level within Australia if it is considered that the metrics generated could be meaningful in the Australian context. However, it would be necessary to examine coasts at a considerably finer scale than can presently be handled by models designed to establish the relative vulnerability between different nations.

The more complex issue of metrics that adequately assess impact and that can appropriately incorporate adaptation poses still further challenges. The most widely adopted approach has been to calculate the costs of coastal protection. Coastal defences are already widespread in Europe and the assets at risk justify hard engineering solutions (and increasingly soft engineering like beach nourishment). By contrast, little of the Australian coast presently needs coastal protection, and engineering-based cost-benefit analysis is less appropriate, except locally.

Table 8. Exposure metrics and the data required to calculate them at regional to global scale, sources in Europe, and possible sources in Australia.

Metrics for coasts, based on Nicholls et al (2006)	Data sources at global scale or in European context	Possible sources at Australian regional scale
'Local' sea-level rise scenario	Global/regional sea-level rise scenarios, uplift/subsidence and global isostatic models such as Peltier (2001)	Global sea-level rise estimates downscaled to develop regional trends (e.g. SIMClim), a local factors and regional isostatic model such as Nakada and Lambeck (1989)
Land area at risk	Elevation, SRTM (Isciences, 2003); USGS GTOPO30 elevation data; SPOTIMAGE (high resolution) elevation data Tidal range, extreme water levels, LOICZ typology; DIVA database	Elevation, Geosciences Australia databases for Australia, including SRTM Tidal range, extreme water levels, National tidal centre (BOM)
Land use at risk	Land Use, IMAGE Team (2002); CORINE Land Use data; USGS EROS Data Center; IFPRI FAO; NASA DMSP Eurosion database	Land Use, AGO land use imagery for Australia
People at risk	Population, GPW3 (CIESIN and CIAT, 2004); Landscan (2003)	Population – similar global dataset, plus Australia 2006 Census and MESH blocks
Ecosystems at risk	Ecosystem Distribution, UNEP-WCMC Atlases (e.g., mangroves, coral reefs, sea grasses)	Various datasets of Australian ecosystems
Economic value at risk	Economic Assets, IMAGE Team (2002); Gridded economic output database (Nordhaus, 2006)	Economic Assets
Human infrastructure at risk	Transport networks, harbours, airports, power stations (esp. nuclear), land fills	Datasets as available
Cultural/heritage at risk	Cultural and heritage sites, elevation, DIVA database	
Changes in event frequency	DIVA database	
Rates of change (e.g., erosion)	DIVA database	

Metrics that have been adopted to describe impact include, land area lost, people displaced, ecosystem losses or change, economic value lost, human infrastructure lost, cultural or heritage losses, adaptation costs, changes in extreme event frequency, and rates of accelerated erosion (Nicholls et al., 2006). The data to establish these parameters is even more difficult to obtain and often presupposes a biophysical response that is itself uncertain. Approaches adopted overseas have used administrative boundaries, for example, the social vulnerability study of the US coast ranks coastal counties based on CVI and CSoVI (Boruff et al., 2005). In the case of Australia it is imperative that the factors that require assessment be clearly defined before such vulnerability studies are undertaken. It is uncertain with what effectiveness the metrics described above could be determined for any part of the Australian coastline because of the low density of habitation and sparse data.

5.2 Vulnerability indices

One widely adopted approach to assessing the exposure of coasts to climate change drivers, particularly sea-level rise, has been to use a vulnerability index. Vulnerability indices have been used in studies in many countries. These produce relative rankings in terms of vulnerability but do not provide quantitative measures (land lost, etc).

There may be merit in attempting to determine exposure for the Australian coast, and in ranking relative impact (i.e. incorporating socioeconomic variables), but the distinctiveness of Australian coasts means that it will be necessary to derive an approach that adequately characterises those factors that are important in the Australian context, rather than adopting an ‘off-the-shelf’ procedure from overseas.

The index most widely used has been based on Gornitz; this approach has been subsequently modified in each of the US, Canada, and South Africa. It is important to recognise that both the Canadian and the eastern US coasts are experiencing erosion and shoreline retreat because there is relative sea-level rise that is accentuated as the coast is gradually subsiding in isostatic response to melting of ice sheets that covered much of North America. Isostatic subsidence characterises much of north-western Europe, except Scotland and Scandinavia which are uplifting, in response to melting of ice. Australia is remote from former ice sheets; it is tectonically stable, and around much of its southern shorelines it is exposed to high-energy wave action that can result in erosion of large volumes of sediment (and their gradual return over decades, see McLean and Shen, 2006). Although a coastal vulnerability index has not been rigorously tested around the Australian coastline, there are many similarities between parts of the Australian coast and much of the coast of South Africa, and it is not unreasonable to anticipate that the CVI developed in other parts of the world where rates of sea-level rise, and shoreline displacement are high, will require modification (as it did in South Africa) because the variables cannot be adequately determined or are not sufficiently discriminatory in Australia.

5.3 Socioeconomic evaluation

Sea level is rising gradually, and will respond only slowly to mitigation of climate change because of the slow turnover of the oceans, such that sea-level rise will occur regardless of mitigation that may slow the longer-term rate. Direct-Cost (DC) estimates are commonly used to measure the economic damages of this sea-level rise commitment (Darwin and Tol, 2001). These global economic assessments have been based on highly generalised datasets that inadequately capture the factors that would be necessary for national or more localised assessment within Australia. The modelling approaches themselves may have merit, but it would be necessary to totally customise the data before applying, or adopting, any of these tools within Australia.

FUND and FARM are economic models at a global scale, dividing the world into 16 regions. Australia and New Zealand are categorised together. Darwin and Tol (2001) have reported on dryland loss, wetland loss and protection costs using FARM and FUND for Australia. Such estimates suffer from three limitations:

1. Values of threatened endowments are not well-known
2. Loss of endowments does not affect consumer prices, and
3. International trade is largely overlooked

Because of these limitations, DC estimates may significantly misrepresent the economic losses that might be generated by sea-level rise, globally and even more so regionally. For many parts of the world there is considerable uncertainty about the value of land and capital endowments threatened by sea-level rise. Although the authors of this study indicate that the way to reduce this uncertainty is to obtain more accurate data on the value of land and capital in general, including market and non-market components, it is not clear that present or future management in Australia will be primarily driven by such monetary considerations, or that coastal protection is the only, or best, option. In the case of Australia, it is necessary to clearly define the problem before vulnerability indices are used, as there is considerable uncertainty with what effectiveness the metrics described in Table 8 could be determined for any part of the coastline. Alternative approaches can be developed within Australia; for example, Hennecke et al. (2004) describe a low-cost and time-efficient method for rapidly conducting an initial assessment of the potential monetary and land loss caused by sea-level rise and a major storm event on coastal urban areas in Australia.

5.4. Australian approaches to vulnerability assessment

In considering the extent to which assessment strategies similar to those used overseas should be adopted in assessing the vulnerability of the Australian coastal zone to climate change, it is important to recognise that several assessment methodologies have already been developed specifically for the Australian coast by Australian researchers. Although not primarily the scope of this study, Table 9 summarises the main approaches that have been adopted since the Australian Coastal Vulnerability Assessment Project (ACVAP). In addition, a framework for analysis of response to climate change drivers has been outlined by Engineers Australia in Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering (The National Committee on Coastal and Ocean Engineering (NCCOE), 2004). NCCOE guidelines provide a template at a series of spatial scales enabling prioritisation of climate drivers in national or regional assessment, and suitable for local scale assessments (see Appendix 3). The climatic drivers interact with coastal environments in often-complex ways to drive coastal evolution. The key and secondary climatic stress factors are given in Appendix 3, and shown schematically in Figure 13.

Table 9. Principal methods adopted to assess vulnerability of the Australian coast to climate change (based on Kay et al., 2005a, 2005b; Australian Greenhouse Office, 2006).

Approach	Geographical application	Principal methods	References
Wetland mapping	Northern and north-western coasts	Wetland mapping in Kakadu and elsewhere in the NT, in line with Ramsar wetland assessments	Finlayson et al. (2002) Eliot et al. (2005)
Landform mapping	South Australia	Holocene landform mapping as a guide to vulnerability	Bryan et al. (2001) Harvey et al. (1999b)
Storm surge zones	Queensland	Queensland Climate Change and Community Vulnerability to Tropical Cyclones project	Queensland Government (2004)
Beach vulnerability	New South Wales	Fuzzy and probabilistic modelling	Cowell et al. (2006) Cowell and Zeng (2003)
Beach vulnerability	Tasmania	Mapping beaches for Bruun rule and assessing inundation risk	Sharples (2004)

The NCCOE has created a comprehensive set of tables that map the relationships between these two sets of environmental variables with consideration of a further series of variables within each of the 78 cells (Appendix 3). This comprehensive approach could provide a suitable template for broader adoption across vulnerability assessment of much of the Australian coastline; consideration of overseas approaches has unearthed no more appropriate framework for the Australian coast.

6. Challenges and recommendations for further assessment

A review of international assessments of the vulnerability of coasts to climate change shows that global assessments generally indicate that the Australian coast is not amongst the most vulnerable coasts around the world. Reefs and wetlands are the most vulnerable natural ecosystems, but at the global level the Australian nation is not as vulnerable as those that are more heavily dependent on their reefs or wetland environments. Little information directly on the Australian coast has come from the analysis, but the several techniques that have been adopted overseas offer some prospect for testing in Australia. However, the unique nature of the Australian coast, and the innovative nature of several approaches adopted within Australia, makes it prudent to consider modifying techniques applied elsewhere or developing new techniques to assess the vulnerability of the Australian coast to climate change.

As the world's largest island, Australia has a wide range of coastal and marine environments, which extend from the tropical northern regions to temperate (and even polar) southern latitudes. The Australian coastline is heterogenous; for example, Western Australia has an extensive coastline ranging from the tropical north to the temperate south, with a wide range of habitats and biological communities including rocky shores, sandy beaches, algal reefs and kelp forests, which dominate the temperate south, and coral reefs, estuaries, bays, seagrasses beds, mangrove forests and coastal salt -marshes, which dominate the tropical north. As well as latitudinal variation, there are also the less understood mid-water, outer-shelf and deepwater habitats. Australia's marine environments also include external territories in the Indian Ocean, South Pacific Ocean, Southern Ocean and Antarctica (IMCRA, 1998).

In a global context, the various pressures and proxies for impacts show Australia to be in generally ‘good’ condition. Arid and semi-arid landscapes, low population density, limited industrial development and, in recent years, a comparatively strong ethic and actions for coastal management and remediation approaches contribute to this global standing. At local scales, the Australian coastal zone contains examples of most pressures and impacts seen elsewhere, although usually not to the same spatial extent or intensity of impact. Hot-spots of estuarine impacts are associated with urban centres and riverine conditions, under pressure from land-use patterns and practices, and range from relatively pristine to impacted (Heap et al., 2001). Many of these have a historical context. A feature of Australia is the commitment of the community and its institutional structures to resolve problems by taking action, involving regulation and legal instruments, policy and planning initiatives, education and community participation mechanisms. There is relatively close engagement of science with the management and policy arena and the wider community in addressing coastal problems, comparable with some of the globally successful approaches to coastal zone management being undertaken nationally and regionally in other parts of the world (for example, in the Baltic Sea). Land use practices, erosion and sedimentation, elevated nutrient loads in rivers, and water storage and extraction appear to be major issues in Australia requiring resolution through further actions and additional information from science. The further application of an ecosystem approach and an enhanced appreciation of the catchment-to-coast water continuum as a unit for management and assessment offer some major challenges for targeted scientific research that can fill gaps in understanding and knowledge.

Several methodologies have been reviewed which it would be useful to test further in terms of their suitability for use on the Australian coast. These include SimClim (particularly CoastClim), DIVA, CVI and CVAT. Research is needed, both applying them in case-study local scale studies and examining whether they could be used to indicate the relative vulnerability of different parts of the nation’s coast. There appears to be merit in developing similar approaches for the Australian coast in more detail, particularly to prioritise decisions. It will be most expedient to modify these overseas approaches in conjunction with methods already developed and adopted for parts of the Australian coast (Table 9). Several different techniques may need to be adopted for different types of coast and may be more appropriate than one national approach. Sharples (2004) provides a framework that includes first-pass indicative mapping at large scale, and more detailed local and site-specific scale methods. Coastal erosion has been studied outside the context of sea-level rise and climate change. For example, EUROSION is the European initiative for sustainable coastal erosion management that assessed metrics for vulnerability to erosion. It defined a RICE (radius of influence of coastal erosion) and then considered indices to score (i) pressure (which corresponds to exposure) and (ii) impact (EUROSION, 2004).

Identifying coastal regions is important. However, neither IMCRA (1998), which gives a meso-scale regional description of Australia with data attributes such as climate, oceanography, geology and geomorphology, and biota, nor coastal mapping undertaken by CSIRO (Galloway et al., 1984) provide the regionalisation (or segmentation) of the coast that will be needed if relative vulnerability is to be mapped. A regionalisation is usually very specific to the purpose for which it is undertaken. Of greater utility than a project to regionalise the coast in terms of vulnerability where that is only broadly defined, would be development of a coastal information system in which data on a wide range of attributes could be analysed to produce mapping, regionalisation and prioritisation based on a series of different needs (not just vulnerability to climate change). There have been a series of attempts to compile a coastal information system; for example, an Australian Coastal Atlas (ACA) was commenced in 1995 to help increase knowledge about Australia's coastal zone, and thus provide an accessible information base to support decision-making for coastal zone management (Blake, 1996; Australia State of the Environment, 2001). The Atlas was a partnership arrangement between States, the Northern Territory and the Commonwealth (see http://www.environment.gov.au/marine/coastal_atlas) and has now been integrated with the Australian Natural Resources Atlas.

Table 10. Priority data sets needed for incorporation into a coastal information system (see also Kay et al., 2005a, 2005b, Australian Greenhouse Office, 2006).

Fundamental coastal dataset	Comments
Seamless coastal topography	Need to blend onshore topography and offshore bathymetry
Shoreline	No uniform national definition of shoreline
Jurisdictional boundaries	Cadastre, Australia's Marine Boundaries (AMSIS), Marine Cadastre
Protected areas	National Parks, Marine Protected Areas, Aquatic Reserves
Imagery	Aerial photography, Remote Sensing
Geology	Sedimentary environments, Quaternary mapping
Geomorphology	Substrate type, Landforms, Soils
Habitats	Ecosystems, Vegetation
Topography	Hinterland topography
Bathymetry	Bathymetric image, isobaths
Population	Census
Anthropogenic Features	Assets, ocean disposal sites, recreational resources,
Transport	Rail, shipping lanes, roads, ferry routes.
Infrastructure	Petroleum wells, ports, pipelines, submarine cables, navigational aids.
Environmental Management	Bioregions. Marine planning regions.

Table 10 summarises the type of data sets that should be included in a coastal information system and that could then be accessible for consideration of vulnerability as needed.

Below, a series of recommendations is made in terms of different ways to progress vulnerability analysis of the Australian coast, with particular emphasis on where international methodologies or approaches could be integrated with data, methodologies or projects already commenced within Australia.

1. **Vulnerability assessment framework**. The NCCOE template, Appendix 3, provides a framework that could be more widely used around Australia. This approach, adopted by Engineers Australia, enables the identification of the principal climate change drivers at a site, and could be undertaken by coastal specialists or through group consultations. A schematic example of how this might be undertaken at national and at local level is shown in Figure 13.

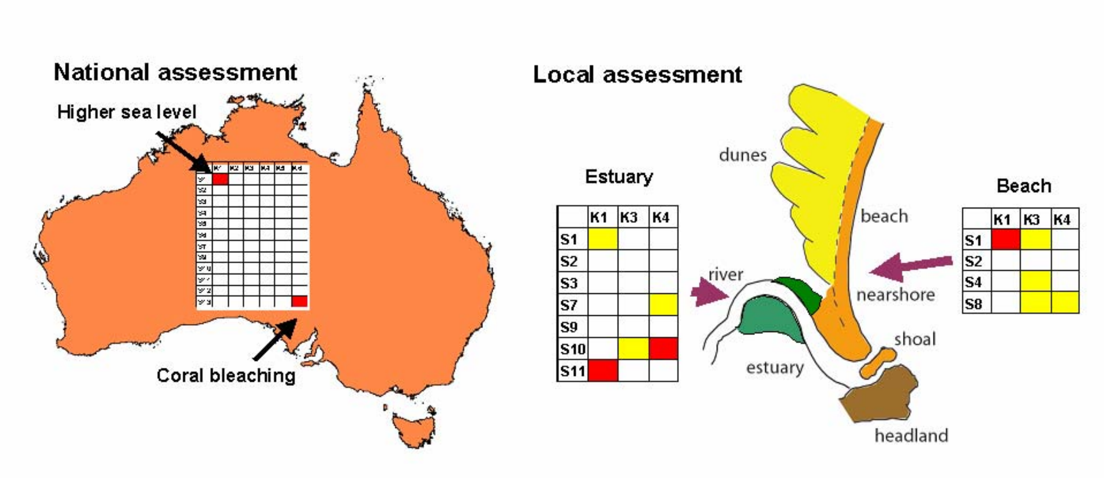


Figure 13. NCCOE interaction matrix template (Appendix 3), showing schematically the way that it might be used as a framework to identify principal climate change drivers.

2. **Coastal topography at risk**. There is little doubt that the areas most at risk are low-lying areas. These are generally not mapped adequately at scales that are relevant for projected sea-level rise or flood inundation as may occur as a result of greater flows or impoundment. Sharples (2004) outlined techniques for indicative mapping at state level, combining nationally available digital elevation models (DEM) with information on tidal and extreme water levels. This approach could be most effectively improved by use of better resolution DEMs as developed by Geoscience Australia (eg. SRTM), and as new techniques such as LIDAR become more widely available for more local scale studies. A seamless coastal topography, as described for the US by National Research Council (2004) would considerably improve how those areas most prone to inundation can be identified.
3. **Vulnerability index**. Vulnerability indices developed overseas have generally been based on the CVI developed and used by the USGS to characterise coasts on the basis of 6 or 7 variables. Such mapping at national or state level may be useful, in combination with the approach above, to map those parts of the coast that are most vulnerable. Any index adopted from overseas will need customising for the Australian coast, and the effectiveness with which the coast can be divided into segments of comparable characteristics will limit the scale of application. Such indices are static comparisons with limited predictive capability, but have use in prioritorising decisions.
4. **Storm surge inundation modelling**. The resolution of the topographic modelling described above (2), is generally not sufficient to detect areas potentially inundated by storm surges. In this respect the assessments undertaken by the Queensland Government (2004) provide the detailed analysis of storm surge behaviour needed. Extension of this approach through integration with high-resolution topography (such as LIDAR) could enable much more detailed risk assessment, including socio-economic analyses. Whereas preliminary analysis of this sort has begun (McInnes et al., 2003), more systematic adoption of an approach such as CVAT would enable a more consistent approach and better integration of socio-economic variables into vulnerability assessments.

5. **Open coast vulnerability**. Both DIVA and CoastClim (SimClim) offer modelling capability that requires further testing and validation in the Australian context. DIVA would appear to provide a framework that might be useful for open coasts, if a suitable scale of segmentation could be incorporated and outputs generated at a different scale of inquiry. This would require major changes to the existing tool, but this might be more expedient than trying to design a new approach from the beginning. It seems likely that the Bruun rule will need modification in application to Australian coasts. Cowell et al. (2006) provide a series of alternative suggestions for characterising coastal behaviour for the Australian envioronment; the mapping approach used by Sharples (2004) provides a method to extend modelling around extensive areas of the Australian coast. CoastClim appears to be a valuable way to combine these into a modelling software. CoastClim focuses on erosion and flooding in the coastal zone, taking into account storm effects, local sea-level trends and lag effects in order to provide time-dependent responses of the shoreline to sea-level rise at selected sites. The coastal flood model is spatial and allows the user to examine changes in the areas of potential inundation from the combined effects of sea-level rise and extreme storm events. However, many sections of the Australian coast undergo periodic erosion and recovery, and it will be very necessary to test these models to see if they hold any predictive value for the Australian coast.
6. **Estuary and wetland vulnerability**. The DIVA approach to wetland modelling (based on the Klein and Nicholls (1999) update of the GVA approach), attempts to model wetland loss as a function of shoreline segment, using an estimate of sedimentation rate. Australian wetlands are generally associated with estuaries and wetland ecology and geomorphology are complex and rarely directly related to the open shore characteristics. The OzEstuaries database (acquired under NLWRA, held by GA, www.ozestuaries.org) provides 2D mapping of many estuaries, although not always with all wetland delimited. It might be possible to adapt some of the estuary mapping (for example taking an approach based on Holocene geomorphological units as done by Bryan et al., 2001, in South Australia) to develop a more powerful tool for determining likely response of estuaries and associated wetlands to climate change, but it is clear that any such approach will need to be based on a range of assumptions which have not been rigorously tested, and that will need much more research. Alternatively, it may be more appropriate to undertake focused research on particular wetlands, such as those of Kakadu, because it seems highly unlikely that simple heuristic models developed overseas will adequately simulate the behaviour of these unique wetlands.
7. **Economic analyses**. It is not clear that international approaches, often highly focused on economic outcomes such as the cost of land protection with coastal defences, are entirely appropriate for the Australian context. Socioeconomic analyses for the coast are presently less developed than natural system analyses. It needs to be considered whether monetary valuations should drive Australian coastal strategies. Rapid population increase in Australian coastal metropolitan and seachange communities necessitate increasing awareness of climate change impacts on the coast. The impact of storms and the episodic nature of extreme events, generally poorly handled in overseas models, will be of particular significance to communities on the Australian coast.

8. **Coastal information systems**. Geographic information systems (GIS) are the best way to handle, and make available, the fundamental data. Well-managed and accessible information systems with the necessary fundamental datasets can be used for multiple purposes. In the case of Coastal Information systems, it will require clear exposition of priorities in order to ensure that the most needed datasets are addressed first. It will also be necessary to consider the best data format for information, and this will be partly scale dependent. Inter-agency and intergovernmental collaboration will be essential if the necessary data sets are to be integrated and widely available.
9. **Coastal regions**. Segmentation of coast, as adopted in CVI and DIVA, would enable data capture along open coasts, and would provide a mapping visualisation of relative vulnerability. It is less clear whether such approaches will be as useful for wetlands and estuaries around Australia. It may be necessary to adopt alternative approaches in the case of extensive areas inland of the coast, such as estuaries. One example of mapping shoreline using dynamic segmentation is the approach to intertidal rocky shores in Queensland (Banks and Skilleter, 2002), but it is unclear that this segmentation can be used for anything other than the purpose for which it was collected. In the case of vulnerability to climate change, it remains unclear (in that there is unlikely to be consensus) what the major climate threats are, and what data are required to fill the gaps.
10. **Collaborative and consultative approach**. As demonstrated by the high level of participation in a coastal vulnerability workshop hosted by the Australian Greenhouse Office in December 2005 (AGO, 2006), there is considerable interest in, a range of views concerning, and a collective will for further assessment of the vulnerability of the Australian coast to climate change. Vulnerability to climate change needs to be integrated with risk assessment and emergency management, because the most dangerous aspects of climate change are likely to become manifest through the occurrence of extreme events, as demonstrated when Hurricane Katrina struck New Orleans in 2005. The geography of Australia means that many of the impacts of climate change will inevitably affect the coast; it will be important to undertake a range of assessments, to continually review and re-assess those assessments, and to experiment with a range of overseas, and Australian-developed, tools and methodologies.

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Appendix 1. Definition of terms (following SURVAS, 2001)

Ability to Prevent or Cope*:* The technical, institutional, economic and cultural ability to prevent or cope with climate change (generally sea-level rise) impacts. This is the equivalent of the natural system's resilience and resistance, and is also largely influenced by both autonomous and planned adaptations (see below for definitions).

Accommodation: All natural system effects are allowed to occur and human impacts are minimised by adjusting human use of the coastal zone. Examples of accommodation policies include flood-proofing or raising buildings, changing agriculture towards more flood-tolerant crops, etc.

Adaptation: Adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli, or their effects, that moderate, harm or exploit beneficial opportunities.

Adaptive capacity: The ability to plan, prepare for, facilitate and implement adaptation measures. Factors that determine adaptive capacity of human systems include economic wealth, technology, information and skills, infrastructure, institutions and equity. This, like the notion of vulnerability, is a multi-dimensional concept.

Autonomous Adaptation: The coastal system's spontaneous adaptive response to climate change impact (generally sea-level rise). This is determined by the natural system's resilience and resistance, and the socio-economic system's ability to prevent or cope. Examples include increased wetland accretion, or changes in the price of coastal property.

Do nothing: This may also be a response to the problem of climate change impact (generally sea-level rise), and may result from an active analysis that there is no problem, and hence nothing to do, or ignorance/lack of understanding about the need to adapt. Therefore, it is important to define why nothing is being done.

Flooding*:* Temporary submergence of the land from which either partial or total recovery may occur.

Impact potential: This is the socio-economic equivalent of the natural system's susceptibility, but is inevitably dependent on human influences.

Inundation*:* Permanent loss of land or flooding that is so frequent that no recovery is likely. A flood frequency of ≥ once per year is often a good threshold value, to distinguish frequent flooding from inundation, but site-specific judgements based on the likely response may be necessary.

Planned adaptation: The planned responses to climate change impact (generally sea-level rise), which usually would involve an informed policy maker and some agreed collective action. Several technical options for planned adaptation have been recognised.

Protection: Natural system effects are controlled by soft or hard engineering, reducing human impacts in the zone that would be impacted without protection. The form of adaptation that most readily springs to mind – sea walls, dikes, beach nourishment, etc.

Resilience*:* The speed with which a system returns to its original state after being perturbed, the ability of the system to bounce back, or return to some quasi-stable state. Resilience concepts can also be applied to various other aspects of the coastal management process, such as social, cultural, or institutional resilience.

Resistance: The ability of the system to avoid perturbation in the first place, its strength, such as mechanical strength of materials, structural and morphological resistance.

Retreat: All natural system effects are allowed to occur and human impacts are minimised by pulling back from the coast. Examples of retreat policies include landward realignment of flood defences, building setbacks on eroding coasts, refusing permission to rebuild properties damaged during storms, etc.

Susceptibility: The natural system's potential to be affected by climate change impact (generally sea-level rise). This is largely independent of human influences.

Vulnerability: The degree to which a system is susceptible to, and unable to cope with injury, damage or harm. (IPCC, 2001a, 2001b, Allan Consulting Group, 2005).

Vulnerability Assessment (VA)*:* An analysis of the scope and severity of the potential effects of climate change impact (generally sea-level rise).

VA Framework: This is the conceptual framework of the analysis, encompassing the fundamental questions and issues relating to vulnerability to climate change impact (generally sea-level rise).

VA Tools: These encompass the range of qualitative and quantitative analyses carried out in order to answer the questions posed by the VA framework. These range from for example, quantitative erosion calculations using the Bruun rule, or increases in flood risk, to expert judgment about the consequences of climate change impact (generally sea-level rise).

Appendix 2 International approaches for assessing vulnerability of a coast to climate change and assessment of validity in the Australian context

Appendix 2.1 Inter-governmental Panel on Climate Change (IPCC) Common Methodology (CM)

Description	Widely used framework for vulnerability assessment first proposed in 1991. CM incorporates expert judgment and data analysis of socioeconomic and physical characteristics to assist the user in estimating a broad spectrum of impacts from sea-level rise, including the value of land and wetlands lost. It presents a list of analyses that should be done, but does not explicitly instruct the user on how to perform the analyses. Information from this methodology is generally used as a basis for further physical and economic modelling. The user follows seven steps: (1) delineate the case study area; (2) inventory study area characteristics; (3) identify the relevant socioeconomic development factors; (4) assess the physical changes; (5) formulate response strategies; (6) assess the Vulnerability Profile; (7) identify future needs. Adaptation focuses around three generic options: retreat, accommodate or protect.
Appropriate Use	This approach is most useful as an initial, baseline analysis for country level studies where little is known about coastal vulnerability.
Scale	CM can be used in sub-national, national, regional and global analysis.
Key Output	Vulnerability profile and the list of future policy needs to adapt both physically and economically. A range of impacts of sea-level rise, including land loss and associated value and uses, wetland loss, etc.
Key Input	Physical and socioeconomic characteristics of the study area.
Ease of Use	Requires considerable knowledge on a range of techniques for estimating biophysical and socioeconomic impacts of sea level rise and adaptation. It has been criticised and redesigned by several groups of researchers.
Training Required	Significant training required to complete the seven steps (weeks or months); often performed by external consultants rather than in-country experts.
Training Available	No formal training currently offered.
Computer Requirements	Methodology does not explicitly state how to perform analyses; analytical method chosen by the user will determine the computer needs.
Documentation	Original documentation from 1991 is unavailable. Update provided in IPCC CZMS (1992)
International studies	IPCC CZMS (1992), Nicholls (1995, 1998a, 1998b) Bijlsma et al. (1996) Nicholls and Mimura (1998) Klein and Nicholls. (1999)
Contacts for Tools, Documentation, Tech. Assistance	Coastal Zone Management Centre, P.O. Box 20907, NL-2500 EX, The Hague, The Netherlands; Tel: 1.70.311.4364, Fax: 31.70.311.4380.
Cost	No cost to obtain documentation.
Validity in the Australian context	Used in many coastal countries, including along the Australian coast in an adapted form. Sub- national nine case studies have been carried out in Australia using the IPCC Common Methodology in northern Spencer Gulf, South Australia, Geographe Bay, Western Australia and Cocos Island among others. Examples of studies: Harvey et al.(1999a), Harvey et al (1999b), Kay et al. (1996), Kay et al. (1992), McLean and Mimura (1993), Morvell (1993a, 1993b), Waterman **(**1996), Woodroffe and McLean (1993)

Appendix 2.2 Bruun Rule

Description	The first and best known model relating shoreline retreat to an increase in local sea level is that proposed by Per Bruun (1962). The IPCC reports that 1 cm rise in sea level erodes beaches about 1 m horizontally. This becomes a large issue for developed beaches that are less than 5 m from the ocean (IPCC, 1998). The Bruun rule states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth. The Bruun rule can be applied to correlate sea-level rise with eroding beaches. The Bruun rule estimates the response of the shoreline profile to sea-level rise. This simple model states that the beach profile is a parabolic function whose parameters are entirely determined by the mean water level and the sand grain size. The analysis by Bruun assumes that with a rise in sea level, the equilibrium profile of the beach and shallow offshore moves upward and landward. The analysis is two-dimensional and assumes that (1) the upper beach is eroded due to the landward translation of the profile and (2) The material eroded from the upper beach is transported immediately into the offshore and deposited, such that the volume eroded is equal to the volume deposited; and (3) The rise in the nearshore bottom as a result of deposition is equal to the rise in sea level, thus maintaining a constant water depth in the offshore (SCOR, 1991).
Appropriate Use	The Bruun rule is only applicable for small scale local sites.
Scale	Over long stretches of coast, the Bruun rule and associated cross-shore transport models become complex. There has been a number of critiques e.g. Cooper and Pilkey (2004)
Key Output	Shoreline recession (in metres relative to sea-level rise).
Key Input	An increase in sea level, (S), cross shore distance (L) to the water depth (h) taken by Bruun as the depth to which nearshore sediments exist (depth of closure), and B is the height of the dune.
Ease of Use	Easy to use with numerous assumptions
Training Required	Familiarity with the coastal zone being investigated
Training Available	None
Computer Requirements	None, unless it is incorporated into a model.
Documentation	Originally proposed by Per Bruun in 1962
International studies	Bruun (1962, 1988)
Contacts for Tools, Documentation, Technical Assistance	See applications above
Cost	No cost to use the Bruun rule
Validity in the Australian context	Bruun rule has been applied in NSW, Australia and in Tasmania but caution needs to be exercised where other factors influence sediment budget or control profile. Examples of studies: Cowell et al. (1992, 1995, 1996, 2006) Cowell and Zeng **(**2003) Hennecke et al**.** (2004) Sharples (2004)

Appendix 2.3 SURVAS

Description	The SURVAS (Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies) project developed a global assessment of vulnerability of the coastal zone using a common assessment methodology, identifying key indicators for the assessment of coastal natural susceptibility and socio-economic vulnerability and resilience to the impact of climate change, particularly accelerated sea-level rise.
Appropriate Use	For the assessment of coastal natural susceptibility and socio-economic vulnerability and resilience to the impact of climate change, particularly accelerated sea-level rise.
Scale	SURVAS can be applied in sub-national, national, regional and global analysis.
Key Output	Workshop reports (see international references).
Key Input	Expert knowledge in workshop context
Ease of Use	Depends upon consensus between experts
Training Required	Expert judgement required.
Training Available	None
Computer Requirements	Is required when modelling
Documentation	The SURVAS database http://www.survas.mdx.ac.uk/sitemap.htm
International studies	Workshops held in Egypt, Germany and UK. Examples of studies: SURVAS (2000a, 2000b, 2001) Nicholls (2000)
Contacts for Tools, Documentation, Technical Assistance	See documentation above
Cost	No cost to use the approach
Validity in the Australian context	Approach may be valid to the Australian context but is yet to be applied. During a SURVAS overview workshop in UK in 2001 it was reported for Australia that geological, historical and current sea-level data exists. Other data include those from UNFCCC and NC as well as data on present coastal erosion and storminess climate variability.

Appendix 2.4 Land and wetland loss assessment following Klein and Nicholls

Description	The effect of flooding was modelled by Nicholls (Nicholls et al., 1999; Nicholls, 2004), using sea-level rise scenarios generated by the HadCM3 coupled atmosphere-ocean climate model, and the Special Report on Emission Scenarios (SRES) world story-lines, which defines a range of socio-economic factors in terms of globalisation versus regionalisation and economic versus environmental drivers (Arnell et al., 2004). The Nicholls modelling considered changes to flooding by storm surges (a human-system impact) expressed in terms of the number of people at risk of flooding on average per year, and loss of coastal wetlands. From this the number of people in the hazard zone and the average annual people flooded were calculated. In the absence of a global database on flood protection, this was modelled based on national GDP assuming a lagged evolving response. In both cases, whether there is sea-level rise or not, the A2 world experiences the greatest level of flooding, indicating that it is growth in the world's population, and movement of people into the coastal zone which lead to the greatest increase in number of people subject to flooding. The developing world, particularly that in South Asia has the highest exposure to flooding due to the large population increase, and the smallest adaptive capacity, in this modelling linked to the small increases in the GDP per capita.
Appropriate Use	Wetlands all over the world
Scale	The segmentation of the global shoreline involved 192 polygons representing coastal nations, for which average population density for coastal areas was derived.
Key Output	Effects of flooding of coastal wetlands.
Key Input	Sea-level rise scenarios generated by the HadCM3 coupled atmosphere-ocean climate model, and the Special Report on Emission Scenarios (SRES) world story-lines. Estimates of length of wetland shorelines.
Ease of Use	Requires considerable knowledge on a range of techniques for estimating biophysical and socioeconomic impacts of sea-level rise and adaptation.
Training Required	Training required to understand sea-level rise scenarios
Training Available	None
Computer Requirements	Is required when modelling
Documentation	See contacts below.
International studies	Klein and Nicholls (1999) Nicholls (2004)
Contacts for Tools, Documentation, Technical Assistance	Richard Klein, Potsdam Institute for Climate Impact Research, Germany; e-mail: Richard.Klein@pik-potsdam.de. Robert Nicholls, University of Southampton, UK; e-mail: rjn@soton.ac.uk.
Cost	No cost to use the approach
Validity in the Australian context	Has been applied at global scale with only general data for Australia.

Appendix 2.5 DIVA and DINAS-COAST

Description	Dynamic Interactive Vulnerability Assessment (DIVA) is a tool for integrated assessment of coastal zones produced by the EU-funded DINAS-Coast consortium in 2004. It is specifically designed to explore the vulnerability of coastal areas to sea-level rise. It comprises a global database of natural system and socioeconomic factors, relevant scenarios, a set of impact-adaptation algorithms and a customized graphical-user interface. Factors that are considered include erosion, flooding salinisation and wetland loss. DIVA is inspired by the paper-based Global Vulnerability Assessment (Hoozemans et al., 1993), but it represents a fundamental improvement in terms of data, factors considered (which include adaptation) and use of PC technology.
Appropriate Use	DIVA is designed for national, regional and global scale analysis of coastal vulnerability, including consideration of broad adaptation issues.
Scale	DIVA covers all 180+ coastal nations in 12,148 coastal segments at national, regional, and global scales.
Key Output	The impacts of sea-level rise under a range of different user-defined scenarios, including some adaptation options. For each SRES the program produces a table, a map and chart.
Key Input	The user's chosen scenarios
Ease of Use	The software is explicitly intended to be easy to use, and draws on extensive experience in graphical user interfaces
Training Required	Designed to be used without significant training — an interested user should be able to explore this tool without any training
Training Available	If required, contact DINAS-COAST consortium — see contacts below.
Computer Requirements	Windows 2000/XP, 2 GHz Pentium, 512 MB memory, 5 GB free hard drive.
Documentation	Included with the DIVA tool
International studies	DIVA has been used to develop assessments of wetland loss and the effects of mitigation. Examples of studies are; Hoozemans et al. 1993 Nicholls (2002) Hinkel and Klein. (2003) Vafeidis et al. (2003, 2004a, 2004b)
Contacts for Tools, Documentation, Technical Assistance	http://www.pik-potsdam.de/DINAS-Coast/ or http://www.DINAS-Coast.net. Richard Klein, Potsdam Institute for Climate Impact Research, Germany; e-mail: Richard.Klein@pik-potsdam.de. Robert Nicholls, University of Southampton, UK; e-mail: rjn@soton.ac.uk. Richard Tol, University of Hamburg, Germany; e-mail: tol@dkrz.de. Onno Kuik, Vrije Universiteit, The Netherlands; e-mail: onno.kuik@ivm.vu.nl. WL Delft Hydraulics, the Netherlands; e-mail: info@wldelft.nl
Cost	Free download from http://www.DINAS-Coast.net
Validity in the Australian context	DINAS-Coast database contains 135 segments for the Australian coast.

Appendix 2.6 CoastClim of Simulator of Climate Change Risks and Adaptation Initiatives (SimClim)

Description	The Simulator of Climate Change Risks and Adaptation Initiatives (SimClim) software enables examination of future climate scenarios in several contexts. The method features a separate consideration for sea-level rise (sea-level generator) due to climate change and global warming and that resulting from local land movements. One of the distinct advantages of using the generator is that it allows rapid generation of place-based sea-level scenarios, which account for some uncertainties associated with emissions scenario, but may not account for isostatic change. SimClim also includes a set of developed impact models. For the coastal zone, the focus is on erosion and flooding. The simple erosion model is a modified version of the Bruun Rule, which takes into account storm effects, local sea-level trends and lag effects in order to provide time-dependent response of the shoreline to sea-level rise at selected sites. The coastal flood model is spatial and allows the user to examine changes in the areas of potential inundation from the combined effects of sea-level rise and extreme storm events. The purpose of SimClim is to link and integrate complex arrays of data and models in order to simulate, temporally and spatially, bio-physical impacts and socio-economic effects of climatic variations, including extreme climatic events. In this way, it provides the foundation for assessing options for adapting to the changes and reducing the risks. SimClim is designed to support decision-making and climate proofing in a wide range of situations where climate and climate change pose risk and uncertainty.
Appropriate Use	A tool to aid decision-making under changed climate conditions.
Scale	SimClim can be applied in sub-national, national, regional and global analysis.
Key Output	Current shoreline (m).
Key Input	For the coastal erosion model part of SimClim, one requires; shoreline response time, closure distance (m), depth of material exchange (m), dune height (m) and residual movement (m/year) and well as storm parameters.
Ease of Use	The distinctive advantage of the SimClim open system, as opposed to the hard-wired system, is the flexibility afforded to users for importing their own data and models in order to customise the system for their own purposes – much like a GIS.
Training Required	Training is useful
Training Available	Training can be arranged by contacting Peter Urich at management@climsystems.com or www.climsystems.com/site/home
Computer Requirements	Knowledge of computer is required.
Documentation	Included with the SimClim software.
International studies	Kenny et al (1999, 2000) Warrick et al (1996, 2005)
Contacts for Tools, Documentation, Technical Assistance	Climsystems Ltd, P. O. Box 638, Hamilton, New Zealand. Climsystems Home. http://www.climsystems.com/site/home/
Cost	There is a cost to the use of the software. Contact Peter Ulrich (see documentation)
Validity in the Australian context	The coastal impact model of SimClim is a possible tool to use in Australian coastal zones.

Appendix 2.7 Community Vulnerability Assessment Tool (CVAT)

Description	Community Vulnerability Assessment Tool (CVAT) supports the linking of environmental, social and economic data in the coastal zone. It is a static GIS map overlay procedure that enables a relative risk or vulnerability analysis of coastal communities to a series of existing threats. The CVAT procedure comprises 7 steps; (1) Hazard identification and prioritisation, (2) Hazard analysis, (3) Critical Facilities analysis, (4) Social analysis, (5) Economic analysis, (6) Environmental analysis and (7) Mitigation opportunities analysis. A CD-ROM provides a step-by-step guide for conducting community-wide risk and vulnerability assessments. It also provides an illustrative case study demonstrating the process for analysing physical, social, economic and environmental vulnerability to hazards at the local level. It contains a detailed case study on New Hanover county, North Carolina, which illustrates the use of the Community Vulnerability Methodology Assessment methodology in a specific community.
Appropriate Use	Used to conduct a community vulnerability assessment to a range of hazards (not specifically addressing climate change).
Scale	The assessment focuses on the community level
Key Output	Relative risk or vulnerability analysis of coastal communities to a series of existing threats.
Key Input	Environmental, social and economic data for the coastal zone in GIS format.
Ease of Use	The CD-ROM is relatively easy to use.
Training Required	It provides a framework for vulnerability and risk assessment, which allows communities to carry out the assessment. CVAT is most useful for people who wish to gain an understanding of how to conceptualise community vulnerability.
Training Available	The NOAA coastal services offers training on how to do a risk and vulnerability assessment. More information on this training is available at www.csc.noaa.gov/training/cvat-tool.html
Computer Requirements	The following options are available for using the information on the CD-ROM (1) Web-Browser for viewing text, images, and static maps and (2) ArcExplorer GIS Data Explorer (free software included). ArcView GIS (ArcView 3.0 or higher required to interact with one component of the case study on the CD-ROM)
Documentation	See below for contacts. The CD-ROM contains a number of tutorials designed to assist in hazard planning activities. These tutorials include vulnerability assessment tutorials, LIDAR tutorials and extensions and damage assessment tool tutorial.
International studies	National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) (1997, 1999) Albury (2004) Clark et al. (1998) Cutter (1996) Cutter et al. (2000, 2003) Emrich (2000) Morrow (1999)
Contacts for Tools, Documentation, Technical Assistance	To receive a copy of the CD-ROM or any assistance contact: NOAA Coastal Services Center, 2234 South Hobson Avenue, Charleston, South Carolina 29405-2413.e-mail: clearinghouse@csc.noaa.gov . Resource persons are Tashya Allen at Tashya.Allen@noaa.gov and Cindy Fowler at Cindy.Fowler@noaa.gov
Cost	There is no cost for the CD-ROM (File size: 0.3MB)
Validity in the Australian context	Emergency Measures (SMUG model) is used in Australia. The CVAT tool would require customising to the Australian environment where there is a different suite of hazards and access to appropriate data is not as centralised.

Appendix 2.8 Climate Framework for Uncertainty, Negotiation and Distribution (FUND) Model

Description	The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is an integrated assessment model for climate change impacts and adaptation analyses with a number of linked modules. While it was designed to operate over the 21st Century under rises in sea level of greater than 1 m, it has also been adapted and applied to arbitrary extreme sea-level rise scenarios by Nicholls et al. (2005). The model runs from 1995 to 2100 (or longer) in time steps of five years. These impacts interact with one another. The coastal module of FUND examines the potential of sea-level rise in terms of dryland and wetland losses, and then applies an economically optimum assessment of the benefits of defence. An important message of the analysis is that even under extreme scenarios a benefit-cost evaluation suggests that while certain areas will be abandoned, widespread protection of developed coasts will continue. Even if unit defence costs are assumed to be 100 times those of today, about one third of the world's developed coast (or about 250,000 km) would be protected following the FUND benefit-cost analysis. FUND scenarios are an example of the post-2100 scenarios. The projections are for 16 world regions, and the population change and per capita growth were assumed to be uniform for all countries within the region. But following all these post-2100 analysis, the results are better seen as 'what if' analyses rather than conventional scenarios analysis. FUND simulations run from 1950 to 2200, in annual time steps. FUND is used to estimate and compare the effects of different assumptions about land and capital values on these optimal levels.
Appropriate Use	FUND is an impact socio-economic assessment model.
Scale	FUND covers a global scale in 16 world regions, Australia is combined with New Zealand
Key Output	FUND considers the following impacts of sea-level rise: (1) land loss, (2) wetland loss, (3) protection costs and (4) forced migration, all assuming perfect adaptation based on cost-benefit analysis.
Key Input	Carbon dioxide concentrations, global mean temperature and sea-level rise are calculated with the FUND model.
Ease of Use	Requires knowledge of climate change impacts.
Training Required	May require some training.
Training Available	No training available. See contact for tools for help.
Computer Requirements	Computer required for modelling.
Documentation	The IMAGE database of population, income, energy-use and emissions (Batjes and Goldewijk, 1994) is the basis for the calibration of the model to the period 1950 - 1990.
International studies	Darwin and Tol (2001) Leggett et al (1992) Link and Tol (2004) Tol and Dowlatabadi (2001) Tol, R. S. J. (1997, 1999)
Contacts for Tools, Documentation, Technical Assistance	Roy F. Darwin, U.S. Department of Agriculture Economic Research Service 1800 M Street, NW, Washington, DC, USA Richard S. J. Tol, Centre for Marine and Climate Research, Hamburg University, Germany. Email: tol@dkrz.de
Cost	See contacts above for cost enquiries.
Validity in the Australian context	Estimates of the economic effects of sea level rise give values of dryland, wetlands and protection costs for Australia/New Zealand combined (Darwin and Tol, 2001).

Appendix 2.9 Decision Support Models: COSMO (Coastal Zone Simulation Model)

Description	COSMO is a decision-support model that allows coastal zone managers to evaluate potential management strategies under different scenarios, including long-term climate change. COSMO demonstrates the main steps in the preparation, analysis and evaluation of Coastal Zone Management (CZM) plans. The program is an interactive tool that allows coastal zone managers to explore the impacts of development projects and environmental and coastal protection measures. It calculates various criteria, including long term effects of climate change, reflecting the use of the coastal zone. The user can explore a number of predefined cases as an educational tool, or specify new development scenarios and combinations of measures as a decision-making tool. A more complex version of COSMO has been developed to demonstrate some more realistic characteristics, constraints and limitations of institutional arrangements for CZM. The program simulates day-to-day management of a coastal zone from the perspective of four organizations: (1) the city government, (2) the public works department, (3) the environment department and (4) the private sector. Each of these four roles takes annual decisions, within their means/budget and mandate, to further their own objectives.
Appropriate Use	Useful as educational tools about relationship of adaptation to climate change in coastal zone management. Helps determine the advantages and disadvantages of adaptation alternatives, either as an educational or decision-support tool, in conjunction with other, more quantitative analyses.
Scale	COSMO can be applied in site-specific case studies or at national scale.
Key Output	The outcome of a range of different management options.
Key Input	The user's chosen management strategy.
Ease of Use	Easy to use for educational purposes, although unsuitable for analysis of actual management plans by itself. Might be used within other frameworks, such as studies based on the UNEP Handbook Methodology.
Training Required	For educational purposes it requires little training, although as a decision support tool it requires more knowledge of physical and socioeconomic characteristics of the situation.
Training Available	For training and education services contact: Coastal Zone Management Centre, P.O. Box 20907, NL-2500 EX, The Hague, The Netherlands; Tel: (1-70)311.4364; Fax: (31-70)311-4380.Email. f.vdmenlen@rikz.rws.minvenw.nl
Computer Requirements	Standard PC (Pentium or better).
Documentation	See international studies below
International studies	Used in training for CZM, including adaptation to climate change. Examples of studies: Resource Analysis and Coastal Zone Management Centre, Hoozemans et al. (1993)
Contacts for Tools, Documentation, Technical Assistance	Coastal Zone Management Centre, The Hague; Tel: 31.70.3114.364.
Cost	US$150 from Coastal Zone Management Centre.
Validity in the Australian context	A valid model but is yet to be applied on the Australian coast

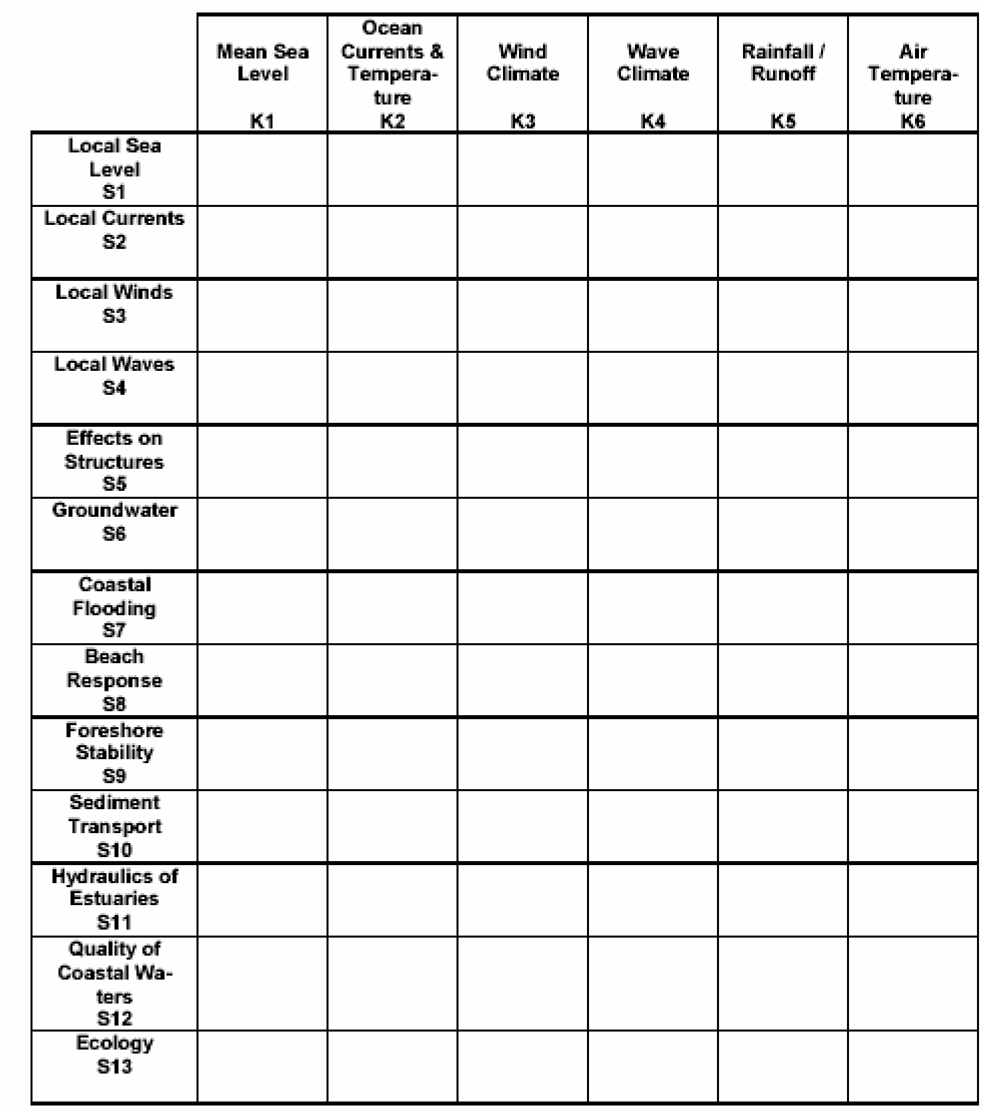
Appendix 2.10 The South Pacific Island Methodology (SPIM)

Description	The South Pacific Island Methodology is an index-based approach that uses relative scores to evaluate different adaptation options in a variety of scenarios. The coastal zone is viewed as six interacting systems. There are three "hard" systems, the natural environment, the people, and infrastructure, and three "soft" systems, which encompass the less tangible elements of the coastal system, the institutions, the socio-cultural factors, and the economic system. These are further divided into subsystems. The user gives each subsystem a vulnerability and a resilience score from -3 to +3, based on expert judgment, for the following scenarios: (1) today's situation, (2) the future with sea level rise and no management, and (3) the future with sea level rise and optimum management. For each subsystem, the two values are combined to produce a sustainable capacity index for each scenario.
Appropriate Use	Particularly useful in coastal settings with limited quantitative data but considerable experience and qualitative knowledge. Can be used during initial evaluation phases to analyse a range of possible adaptation options. Should be followed by a more quantitative analysis of the chosen option.
Scale	SPIM is regional in scale and most relevant to the South Pacific Islands.
Key Output	Defines a sustainable capacity index for the subsystems defined.
Key Input	Expert judgment and qualitative information on the relative performance of various adaptation options.
Ease of Use	Relatively easy to use because it requires very little quantitative data.
Training Required	Limited training is required, although background knowledge of physical, social, and economic characteristics of the area is helpful.
Training Available	No formal training currently.
Computer Requirements	None
Documentation	Documented in Yamada et al, 1995.
International studies	Used in several Pacific Island countries, including Fiji. Yamada et al (1995) Kay and Hay (1993) Nunn et al (1994a, 1994b, 1996) Mimura and Harasawa (2000)
Contacts for Tools, Documentation, Technical Assistance	Prof. N. Mimura, CWES, Ibaraki University 4-12-1 Nakanarusawa, Hitachi, Ibaraki 316, Japan; Tel: 81.294.38.5169. Prof. P. Nunn, University of the South Pacific, Suva, Fiji; Tel: 679.313.900; Fax: 679.301.305.
Cost	No cost for documentation, although cost of the analysis itself will depend on the availability and cost of data and local experts.
Validity in the Australian context	Most valid for Island states

Appendix 2.11 Shoreline Management Planning (SMP)

Description	Shoreline Management Planning is a generic approach to the strategic management of the combined hazards of erosion and flooding hazards in coastal areas, which are key concerns under climate change and sea-level rise. New approaches to shoreline management have developed in the United Kingdom over the last 10 years. This involves dividing the coast of England and Wales into a series of natural units (cells and sub-cells). Based on these units, a number of shoreline management plans are then developed which collectively cover the entire coastal length. Each shoreline management plan further divides the coast based on land use and selects a series of strategic options to be applied over the next 50 to 100 years: (1) advancing the line; (2) holding the line; (3) managed realignment; (4) limited intervention; and (5) no active intervention. The practical implementation of these options is not directly considered — this is considered at lower levels of planning. Whatever is proposed must be consistent with a suite of Project Appraisal Guidance Notes (PAGN) that provide guidance (listed at http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm). The Eurosion consortium have taken these approaches and developed them for application across the European Union (http://www.eurosion.org/).
Appropriate Use	SMP has been designed for developed countries with extensive coastal defence infrastructure. However, these approaches should find widespread application around the world's coasts, especially if slightly adapted to local circumstances. SMPs are designed as "living" plans, including regular update, so the whole process will stimulate the development of long-term coastal management appropriate to responding to climate change and sea-level rise.
Scale	SMP is applied typically at sub- national to national scales pertinent to strategic flood and erosion management.
Key Output	Strategic approaches for flood and erosion management for the next 50 to 100 years.
Key Input	A range of information is required, including, ideally, historical shoreline change, contemporary coastal processes, coastal land use and values, and appropriate scenarios of change. However, the first generation of SMPs in England and Wales was conducted with incomplete datasets.
Ease of Use	The methods are designed assuming significant expertise and would be best implemented by consultants.
Training Required	With appropriate consultants this would not be necessary.
Training Available	None offered at present.
Computer Requirements	Depends on the approach adopted.
Documentation	See International studies
International studies	Department for Environment, Food and Rural Affairs DEFRA (2001) Ministry of Agriculture, Fisheries and Food (MAFF, 1995) Leafe et al (1998) Burgess and Hosking (2002) http://www.eurosion.org/
Contacts for Tools, Documentation, Technical Assistance	DEFRA, Flood and Coastal Defence Division (http:/www.defra.gov.uk/). Stephane Lombardo, National Institute for Coastal and Marine Environment/RIKZ, Kortenaerkade, 1, 2500 EX The Hague, The Netherlands; Tel: + 31.70.3114.369; Fax: +31.70.3114.380; e-mail: S.Lombardo@rikz.rws.minvenw.nl.
Cost	Free download of DEFRA (2001) from http://www.defra.gov.uk/environ/fcd/pubs/smp/revisedsmpguidancefinal.pdf.
Validity in the Australian context	Shoreline management plans have been used in various parts of the Australian coast.

Appendix 3. Impact Assessment Interaction Matrix Template (NCCOE, 2004; Appendix C)



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

Appendix 4 List of Acronyms

ACA	Australian Coastal Atlas
ACVAP	Australian Coastal Vulnerability Assessment Project
AGO	Australian Greenhouse Office
AGPS.....................	Australian Government Publishing Service
AOGCM	Atmosphere-Ocean General Circulation Model
APN.......................	Asia-Pacific Network for Global Change Research
ASCE.....................	American Society of Civil Engineers
ASIS	Assateague Island National Seashore
ASLR.....................	Accelerated Sea-Level Rise
ATEAM.................	Advanced Terrestrial Ecosystem Analysis and Modelling
BOM......................	Bureau of Meteorology
CAMRIS................	Coastal and Marine Resources Information System
CGE.......................	Computable General Equilibrium
CHIS......................	Channel Island National park
CIAT......................	International centre for Tropical Agriculture
CICERO	Centre for International Climate and Environmental Research
CIESIN	Centre for International Earth Science Information Network
CIS.........................	Coastal Information System
CLIMBER	Climate and Biosphere model
CM.........................	Common Methodology
COP ………..	Conference of the Parties
CORINE	Coordination of Information on the Environment
COSMO.................	Coastal Zone Simulation Model
CPACC..................	Caribbean Planning for Adaptation to global Climate Change
CSC	Coastal National Service
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSoVI....................	Coastal Social Vulnerability Index
CUIS......................	Cumberland Island National Seashore
CVAT	Coastal Vulnerability Assessment Training
CVI	Coastal Vulnerability Index
CWES....................	Center for Water Environment Studies
CZM	Coastal Zone Management
CZMS	Coastal Zone Management Subgroup
DC	Direct Cost
DEFRA..................	Department for Environment, Food and Rural Affairs
DEH.......................	Department of the Environment and Heritage
DEM	Digital Elevation Model
DINAS-Coast	Dynamic and Interactive Assessment of National, regional and global vulnerability of Coastal Zones to Climate Change and Sea-level Rise
DIVA.....................	Dynamic Interactive Vulnerability Assessment
DMSP	Defence Meteorological Satellite Program
DOC	Document
DRTO	Dry Tortugas National park
EAJ........................	Environmental Agency, government of Japan
EHI	Erosion Hazard Index
ENSO	El Niño Southern Oscillation
EROS.....................	Earth Resources Observation and Science
ETOPO-5...............	Canadian Topographic Digital Maps
EU..........................	European Union
EUCC	European Union for Coastal Conservation
EUROCOAST	European Coastal Association for Science and Technology
EUROSION...........	European initiative for sustainable coastal erosion management
EV..........................	Equivalent Variation
EVI	Environmental Vulnerability Index
FAO.......................	Food and Agriculture Organisation
FARM....................	Future Agriculture Resources Model
FUND	Climate Framework for Uncertainty, Negotiations and Distribution
FUTURECOAST ..	Predicting the Future Evolution of the Shorelines of England and Wales

GA	GeoScience Australia
GATE	Gateway national recreation area
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GCM	Global Circulation Model
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GENESIS	Global Environment and Ecological Simulation of Interactive Systems
GEO	Global Environmental Outlook
GIS	Geographic Information System
GPW	Grided Population of the World
GSA	Global Species Assessment
GTOPO	Global Digital Elevation Model
GUI	Graphical User Interface
GUIS	Gulf Islands National Seashore
GVA	Global Vulnerability Assessment
HadCM	Hadley Climate Model
HYDE	Hundred Year Database of the Global Environment
IFPRI	International Food Policy Research Institute
IAEA	International Atomic Energy Agency
IGBP	International Geosphere Biosphere Program
IMAGE	Integrated Model for Assessment of the Greenhouse Effect
IMCRA	Interim Marine and Coastal Regionalisation for Australia
IMO	International Maritime Organisation
IOC	Intergovernmental Oceanographic Commission
IOD	Indian Ocean Dipole
IPCC	Inter-governmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
LC	Low Confidence
LIDAR	Light Detection and Ranging
LOICZ	Land-Ocean Interactions in the Coastal Zone
MA	Massachusetts
MAFF	Ministry of Agriculture, Fisheries and Food
MAGICC	Model for the Assessment of Greenhouse gas Induced Climate Change
MC	Medium Confidence
MEA	Millennium Ecosystem Assessment
MESH	Micro-level geography covering all of Australia
MoAFFA	Ministry of Agriculture, Fisheries and Forestry
MODSIM	Modelling and Simulation
MSL	Mean Sea Level
NASA	National Aeronautics and Space Agency
NC	National Communication
NCCOE	National Committee on Coastal and Ocean Engineering
NCCR	Switzerland climate science and social impacts summer school
NCVACSP	National Coastal Vulnerability Assessment Case Studies Project
NEPC	National Environmental Protection Council
NEPM	National Environmental Protection Measure
NLWRA	National Land and Water Resources Audit
NOAA	National Oceanic and Atmospheric Administration
NSW	New South Wales
OECC	Overseas Environmental Cooperation Centre, Japan
OECD	Organization for Economic Cooperation and Development
PAIS	Padre Island National Seashore
PAGN	Project Appraisal Guidance Notes
PCA	Principal Components Analysis
PDO	Pacific Decadal Oscillation
RFQ	Request for Quote
RICE	Radius of influence of coastal erosion
RIKZ	Netherlands National Institute for Coastal and Marine Management
RIVM	Netherlands National Institute of Public Health and the Environment

RSWG	Response Strategies Working Group
SBEACH	Storm-induced Beach Change model
SC	South Carolina
SCOR	Scientific Committee on Oceanic Research
SI	Sensitivity Index
SIDS	Small Islands Developing States
SimClim	Simulator of Climate Change Risks and Adaptation Initiatives
SMP	Shoreline Management Planning
SMUG	Seriousness, Manageability, Urgency and Growth
SoE	State of the Environment
SOPAC	South Pacific Applied Geosciences Commission
SoVI	Social Vulnerability Index
SPIM	South Pacific Island Methodology
SPOT	French Remote Sensing Satellite
SPREP	South Pacific Regional Environmental Programme
SRES	Special Report on Emissions Scenarios (IPCC)
SRTM	Shuttle Radar Topography Mission
SURVAS	Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies
TAR	Third Assessment Report
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Program
UNESCO	United Nations Education, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USA	United States of America
USCS	United States County Studies
USGS	United States Geological Survey
VA	Vulnerability Assessment
VHC	Very High Confidence
VIIS	Virgin Island national park
VLC	Very Low Confidence
WCMC	World Conservation Monitoring Centre
WMO	World Meteorological Organisation
WRI	World Resources Institute