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COASTAL VULNERABILITY PRINCIPLES FOR CLIMATE CHANGE

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INTRODUCTION

On the coast, the most important impact of climate change is sea level change. During the late Quaternary, the east coast of Australia has been tectonically stable with sea level changes determining the location of the coastline on the continental shelf. Higher sea levels are represented by stranded coastal features inland of the present coast formed during past high sea levels. The inland extent of the late Pleistocene marine sediments marks the position of the last high sea level some 120 000 years ago. The area between the old inland coastal dunes and the present coast should be considered vulnerable to future sea level rise.

Despite hundreds of coastal vulnerability reports worldwide, the focus has been on impractical theoretical models with many assessments failing to provide decision makers with clear pathways. In Australia, these studies do not clearly set out the influence of the accelerating rate of sea level rise, and generally:

- use short term data bases for projecting long term change.
- do not adequately address the influence of sea level rise on the coast over the last two centuries.
- ignore multi decade climate variability phases.
- call for more research and expensive time consuming detailed data collection.

Some studies of coastal vulnerability use the concept of risk. Sea level rise should be considered as a certainty; it has been rising, for the last two centuries and regardless of any climate change mitigation strategy will continue to rise over future centuries.

BACKGROUND

Sea level rise over the last 1000 years

For the last 6 000 years, sea level has been $\pm 1\text{m}$ and in the last 1000 years stable within $\pm 200\text{mm}$ on a slightly falling trend. Sea level began rising around 1820 (Figure 1)

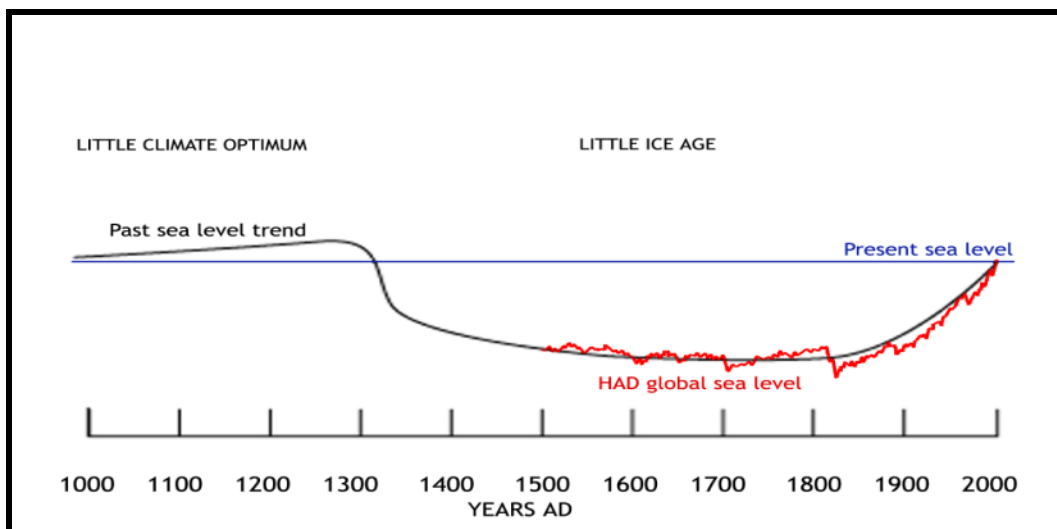


Figure 1 HADCM 3 modelled global sea level overlaid on one thousand year sea level trend for the Tasman Sea. Derived from Aboriginal beach shell middens and geomorphic evidence for central east coast Australia (Helman 2007).

Past two hundred years

Coastline indicators and observation show that east coast sea level has been rising for the last 200 years resulting in: permanent coastal changes: breaching coastal dunes, barrier island formation, loss of tombolos and growth of flood tide deltas in creek estuaries and bays. The coastline has been moving inland throughout this period largely unperceived as the rate of sea level rise has been low and masked by the wide range of climatic variability. Little concern has been raised as most of the eroded coastal land is public reserve, which has acted as a defacto coastline buffer.

Assessments from accurate surveys demonstrate that over the last century unconsolidated sections of the ocean coastline have been moving inland between 50m to +300m, depending on compartment position. In some places it has resulted in the complete loss of coastline public reserve (Helman 2007).

Widespread public debate on the impact of climate variability and climate change has not occurred as it has in United States and other countries. One reason for this is that sea level in the Atlantic Ocean has been rising faster than in the south western Pacific Ocean. For example, sea levels on the east coast of the USA have risen around 300mm during the last century (Titus 1998) compared to around 100mm for the east coast of Australia (Helman 2007). The east coast USA states have been managing sea level rise challenges for several decades. We will face similar challenges in future decades.

COASTAL VULNERABILITY ASSESSMENT

Widespread coastal erosion has been observed on most of the world's coastlines as well as Australia (Bird 1993, IPCC 2001). The various approaches to model the inland movement of coastlines are summarised by Abudha and Woodruffe (2006). Most methods for assessing impacts on beaches and sandy coasts are underpinned by the basic premise of the Bruun rule, with methods becoming increasingly sophisticated to include responses of different kinds of coasts.

Assessment of coastal vulnerability needs to be based on an understanding of the long term interaction between coasts and climate. Based on scientific evidence, the world's climate is warming with the result that sea level will continue to rise. The question that need to be answered are: at what rate, by how much, over what time scale might this occur, and what will be the likely coastline response?

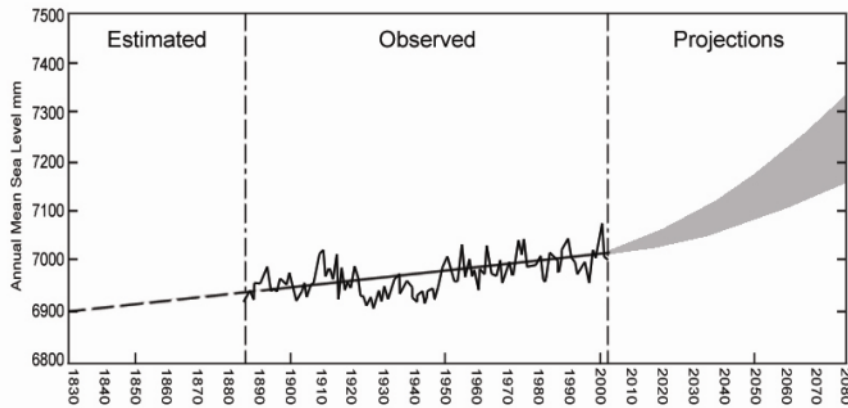


Figure 2 Three centuries of sea level – East coast sea level trend 1830 to 2100: estimated, observed and projected (after Helman 2007).

On the east coast of Australia, Figure 2 shows two centuries of rising sea level trends from early 1800's to present and these are compared to IPCC predictions of further accelerating sea level rise.

The rate of sea level rise over the next 100 years compared to the last 150 years on the east coast of Australia is shown in Table 1. Estimates for 50 year periods between 1850–2100 shows a slowly accelerating rate of sea level rise (see Figure 2) that will continue into future centuries until warming is slowed. The increasing rate of rise will result in corresponding increasing rate of inland coastal migration.

Table 1: Rates of sea level rise (50 year periods) from 1850 and projected to 2100

Period	Yearly rise (mm/yr)	Rise over 50yrs (mm)	Reference
1850 - 1900	0.7 -1.0	35	Estimated after Pugh and others 2001
1901- 1950	0.8 - 1.1	55	Form 1886 Hamon 1986
1951 - 2000	1.8	90	Helman 2007
2001 - 2050	4.6	230	CSIRO (Satellite altimeter data 1992-2007) and IPCC projection
2051 - 2100	12	600	Estimated from upper projection IPCC

Between 1820 and 1945 (125 years) sea level rose some 90mm, and between 1945 and 2008 rose another 90mm. Sea level is likely to continue rising at an increasing rate and it is projected to rise another 90mm by 2040 and another 90mm by 2055.

CLIMATE VARIABILITY

Oscillations in the Pacific Ocean (measured by the Inter Pacific Oscillation Index) are associated with differing rates of sea level rise. The nature of these phases indicates that over decades sea level could rise at much faster rates than trend. As a precautionary approach, the maximum projected rate of sea level rise should be used for coastline planning to allow for this oscillation.

The impact of sea level rise during the last few decades has not been expressed due to low storm energy (Callaghan and Helman 2008). Climate variability determines when

and how sea level change will occur on the coast. Sea level oscillates with decadal and annual climate variability. Over decades, sea level changes are related to oscillation phases of IPO (Figure 3). It has been shown that during phases of negative IPO La Niña events are more frequent (Verdon 2007), sea level rises at a faster rate than the long term trend (Goring and Bell 2001) and is higher than the long term trend with high storm energy, are periods of coastal erosion (Helman 2007). The longest period of negative IPO recorded was from the late 1850's to the early 1890's and the most recent was from the late 1940's to the late 1970's. Both of these periods resulted in major changes and erosion of the coastline (Helman 2007).

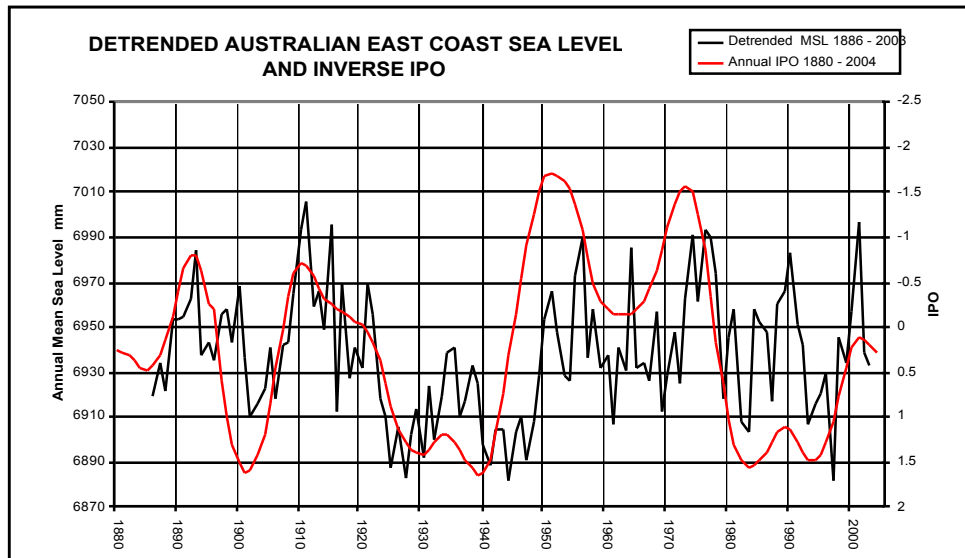


Figure 3 Episodic oscillation of IPO (plotted inverse) and Sydney sea level from 1886 (with sea level rise trend removed) (Helman 2007).

The smooth trend of sea level projection is not an adequate buffer for the protection of coastal development from the combined influence of climate variability and climate change on sea level. During negative IPO phase 50 years of annual sea level trend may be expressed on the coast in less than a decade.

BURNETT MARY COASTAL VULNERABILITY

Coastlines are vulnerable to long-term sea level rise from climate change. In developing a vulnerability assessment for the Burnett Mary coastline, the following features were examined:

- Past climatic conditions; sea level and storm history to describe multi-decadal climatic variability.
- Projected climate change; expressed as sea level rise.
- Likely changes at regional, sub-regional and individual sites with specific characteristics.
- Anticipated coastline recession and realignment from sea level will depend on the nature of coastal landforms.

The vulnerability assessment distinguished between the two following landforms to avoid some shortcomings of other studies where bedrock geology or specific geomorphic features of past high sea levels have not been considered:

Bedrock geology sections of coast are not vulnerable in the short term (building on coastal cliffs in urban areas requires geotechnical assessment), as asserted by PWD (1987) when bedrock areas were excluded from consideration. PWD determined from previous and shallow drilling the depth of bedrock below surficial sediments.

Coastal unconsolidated sediments are vulnerable, especially the areas that were inundated during past high sea levels in the late Pleistocene (120 000 years ago).

VULNERABILITY CLASSES FOR UNCONSOLIDATED SEDIMENTS

Most Vulnerable Low lying Holocene dunes, will experience significant erosion and inland movement. Impacts are likely to be dramatic with severe erosion of exposed areas: Inskip Pt, southern end and north coast Fraser Island.

Vulnerable (B) Late Pleistocene dunes inland (past higher sea level) and (B) River mouths and wetlands impacted by storm tide inundation.

Sandmass Coast Sea level rise cause limited coastline movement, but active erosion of dune faces and beach changes. This is presently occurring at Coloured Sands, with active erosion of the dune face and beach vehicle movement restricted.

Table 2: Vulnerability Classification

CLASS	CATEGORY	FEATURES
A	Most vulnerable	Recent coastal sand. Holocene Dune – inland movement and subject to potentially major washovers during severe storms
B	Old Dunes	Old dune inland of the coast represent where the coastline position was 120,000 years ago when sea level was higher than present.
C	Vulnerable River Mouth and Floodplains	River mouths – storm tide inundation and floods Potential channel realignment during severe floods
D	Sandmass Coast	High dunes coast north Cooloola, east and north and parts of the west coast Coloured sands of Fraser Island

Note: Bedrock excluded from vulnerability assessment but low lying section of rocky coast may be affected by storm surge.

Vulnerability to extreme events

There are few accounts of significant storm surges and those recorded are significantly less than the possible maximum. There is no record of a Category 5 tropical cyclone crossing the subtropical Queensland coast. The most severe storm recorded on the SE Queensland coast, TC *Dinah* category 4, passed over Sandy Cape but headed SE into the Tasman Sea (Callaghan and Helman 2008).

Long coastal records elsewhere in the world and storm modelling show that the occurrence of a very severe tropical cyclone on east coast Australia is certain, although the recurrence interval for such an event may be 1 in 500 or 1 000 years. However,

understanding the potential impacts of a maximum intensity tropical cyclone is an important question for Emergency Services and vulnerability assessments to consider. An adequate buffer for such infrequent events is difficult to justify in coastline planning. However, when combined with the need to make space for centuries of sea level rise, the provision of wide coastline needs to be seriously considered.

DISCUSSION

Long-term erosion has been identified in regional coastal studies both on the Gold Coast (Delft 1970) and Byron Bay (PWD 1978). Severe storms during the late 1960's and early 1970's produced shoreline erosion that resulted in many private and public asset losses along much of the southern Queensland and NSW coasts. Initially, conventional wisdom suggested that the damage to dwellings and other assets was because they were constructed too close to the beach, within the swept prism of natural beach fluctuations (Gordon 1988); one of the findings of the Hervey Bay Beaches report (BPA 1989).

Leaver (2005) argues that natural hazard risk reduction, by risk based landuse planning, contributes to community safety and sustainability. Climate change induced coastal hazard impacts on infrastructure, public and private property may be severe and must be considered in the planning process. By identifying areas in the coastal zone vulnerable to erosion and hazards, Local Government can effectively reduce risk from climate change impacts (Leaver 2005).

Planning guidelines and interactive planning model

Generic guidelines developed by Helman and Tomlinson, (2006) have been adapted for the Burnett Mary coast. These guidelines provide a framework for local authorities to address coastline vulnerability in future planning and management strategies.

Planning Guidelines:

1: When calculating setbacks a very conservative approach that provides the maximum practical space is justified.

2: Immediate review and upgrading of Emergency Management Plans. Develop strategies for dealing with major coastline erosion, inundation events and the potential for loss of some existing coastline developments.

3: Review mitigation measures, beach management, and planning mechanisms to limit impacts of erosion on beach amenity or accept a loss of beach amenity in some locations.

4: Prepare storm surge inundation maps for input to emergency and strategic planning schemes. Bundaberg Council has recently (early 2009) commenced a 'storm tide' study to provide this information.

5: Review of mitigation measures, estuary management, and planning mechanisms to limit impacts on estuarine responses.

Proactive planning is required to reduce impacts of highly unpredictable events. While this approach may seem unnecessary and costly, such a precautionary approach will avoid the considerable cost of reactive responses or recovery measures.

Coastal economies may be faced with more erratic and severe business cycles with uncertain economic growth, especially for those economies dependent on wide beaches to sustain their existence. The level of economic activity in coastal areas can be linked to the existence and perceptions of existence (through the media) of 'a wide sandy beach'. The damage caused by major storms can be economically disastrous both in terms of the cost of rehabilitation, but also the downturn in tourist visitation.

CONCLUSIONS

More recent studies show that erosion can now be attributed to more rapidly rising sea level causing the coast to move inland. With significant loss of the public coastal reserves on the eastern Australian coast, any future erosion will increasingly threaten private property (Gordon 2000 and NSW Government 1999). If we are to retain beaches and natural functioning of coastal ecosystems, our coastal reserves will also have to move inland – like the USA rolling easement approach. In the future, many more foreshore landowners will be involved in debates about how to manage encroaching shorelines. Increasingly, state and local government will be under pressure to prevent erosion through the construction of engineering works.

Lack of strategic planning in approaching these issues has the potential to produce responses that will not retain the beach or will retain the beach only at considerable expense to the community with nourishment. There are numerous terminal revetments constructed at the back of beaches, which show how wall construction halts immediate erosion. However, without continual nourishment, the beach in front of the wall is reduced and erosion continues at the wall ends.

Adequate statutory provisions do not support strategic set backs, rolling reserves or other approaches to provide space for inland coastal movement. If this space is not provided, the inland moving geomorphic and ecological coastal system will be 'squeezed' against existing coastal development and the natural values of the 'beach' and coastal ecosystems will be increasingly reduced. This has been identified in North America (Titus 1998) and in Europe (Eurosion 2004)

The combined conditions of negative IPO over the next few decades and climate change will contribute to coastline erosion and rates of inland movement not previously experienced during the last two centuries of European settlement on the east coast of Australia (Helman 2007).

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