THREE PASS APPROACH TO COASTAL RISK ASSESSMENT

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Abstract

Assessment of the physical sensitivity and exposure of coasts to hazards including storm surge flooding and erosion is an essential component of any properly comprehensive coastal vulnerability study. With climate change resulting in greater concern over coastal hazards a confusing plethora of coastal sensitivity assessment methods have been developed or proposed over the last few decades. However the essential requirements of physical coastal sensitivity assessment can be reduced to a simple conceptual framework involving three logical 'passes' of assessment. A First Pass comprises the identification of shores likely to be physically sensitive to coastal hazards at all. This involves geomorphic and topographic mapping to identify soft (erosion-prone) and low-lying (flood prone) coasts, and can be prepared relatively rapidly for long coasts, providing a useful indicative coastal risk assessment. Such a First Pass assessment is currently being prepared at a national scale for Australia. A Second Pass or 'regional' assessment involves identifying regional variations in the energies or processes driving the physical impacts on the potentially sensitive shores identified in the first pass. This identifies those sensitive shores most exposed to physical impacts, using information on wave, wind and storm climates, tidal regimes or vertical land movement to show severity of risks and indicative time frames under different scenarios, and making initial assessment of protection and adaptation options. Where areas have been identified as potentially hazardous with risks likely to occur within a period of say 25 years, then a more detailed Third Pass or 'site-specific' assessment would be necessary to identify and evaluate critical local variations in shoreline sensitivity and exposure, as the basis for final design and selection of appropriate responses to the identified hazards.

Key Words: coastal hazards, physical impacts, sea-level rise, climate change, sensitivity assessment, geomorphology, wave climate

Introduction

With the recognition of climate change and sea-level rise as real threats to human and ecological assets on many of the worlds coasts, the need to assess the potential impacts of these hazards has rapidly become an urgent issue. As a result the current coastal geomorphic and management literature is full of what at first sight seems to be a confusing variety of approaches to coastal sensitivity and vulnerability assessment (see for examples Abuodha & Woodroffe 2006, Harvey & Woodroffe 2008). Many look like alternate, perhaps even competing approaches, which may give rise to confusion over what methods can or should best be used to assess the sensitivity of a coast to hazards such as those resulting from sea-level rise.

However, many of the approaches discussed in the literature are better seen as complementary methods: different elements of a larger overall assessment process, and/or differing methods of achieving similar assessment goals for differing types of coast with differing specific responses to sea level rise.

The purpose of this paper is to identify the essential elements of a properly comprehensive coastal sensitivity assessment, and suggest a conceptual framework for considering these. Such a framework can reduce the apparent confusion of differing methods and make it easier to understand the role that various methods and approaches play in a coherent overall strategy of coastal sensitivity assessment; and the suitability of particular methods for particular coastal types.

A part of the apparent confusion over differing coastal sensitivity methods lies in the differing implications of terms such as “vulnerability” and “sensitivity”. This paper uses the terminology established by the Allen Consulting Groups (2005) report to the former Australian Greenhouse Office (now Department of Climate Change).

Under this terminology, coastal “vulnerability” refers to the whole of:

- the physical *sensitivity* of the coast to hazards such as sea level rise or changing wave climates (i.e., its susceptibility to physical changes and impacts such as erosion or flooding resulting from those hazards); and
- the degree of *exposure* of the coast to those hazards; and
- the natural and human (artificial) assets at risk because of their sensitivity and exposure; and
- the capacity of the society or ecosystem to respond and adapt to the risks and impacts.

This paper discusses only the first two of these, namely the assessment of the potential for physical impacts (sensitivity & exposure). These must form the essential basis of broader vulnerability assessments; however these latter also draw on additional socio-economic data (assets at risk, capacity to adapt). As with sensitivity and exposure assessment, a large literature on the broader task of coastal vulnerability assessment exists, but it is beyond the scope of this paper to attempt to draw order out of the latter.

The conceptual framework presented in this paper has been developed over the course of a number of projects, including an indicative coastal vulnerability assessment for Tasmania (Sharples 2006), a national First Pass coastal sensitivity assessment currently being finalised for the Department of Climate Change and Geoscience Australia, and a coastal hazards assessment project currently being finalised for the Clarence City Council area in Tasmania. Between them, these projects cover many elements of the differing levels of assessment discussed in this paper.

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Conceptual Framework[1]

The framework proposed here suggests that the risk of physical coastal impacts resulting from sea-level rise or other natural hazards can be (and indeed, are) assessed by, in essence, a two-fold process of identifying the distribution and characteristics of shoreline types (landforms) which are potentially most sensitive to physical impacts, and of identifying the variations in exposure of those shores to the processes or forces that will drive the physical impacts on them. However there are practical reasons for both, on the one hand, assessing these factors at a regional or larger scale (to allow strategic identification of potential risk ‘hot spots’), and on the other hand assessing them at a detailed site-specific scales (to enable modelling of the likely scale and nature of potential impacts at specific high priority locations). Taking both scales of assessment into account, it is possible to identify three

[1] Elements of the conceptual framework presented here have previously been presented by Sharples (2006, 2007) using slightly different terminology; the terms used in this paper reflect those now used by the Department of Climate Change, based on the Allen report (Allen Consulting Group 2005)

distinctive levels or "passes" as being involved in any properly comprehensive assessment of the risk of physical impacts on coasts from hazards such as sea-level rise. These can be described as follows:

First Pass or Regional Sensitivity Assessment: Identifies (at regional or larger scales) coastal segments potentially sensitive *in principle* to physical instabilities such as erosion, or to flooding, in virtue of their geomorphology (i.e., their form and fabric – what they are made of). In this sense, a First Pass is a *sensitivity* assessment in the terminology of the Allen Consulting Group (2005), with the softer and the more low-lying parts of the coast being identified as those exhibiting the *fundamental sensitivity factors* that make them in principle susceptible to instabilities such as erosion and/or to flooding.

Second Pass or Regional Exposure Assessment: Identifies (at regional or larger scales) the magnitudes and variability of the processes or energies driving potential coastal hazards such as erosion and flooding (i.e., primarily oceanographic factors including sea-level rise, tidal processes, wave and storm climate, but also including some other climatic factors and additional drivers such as vertical land movement). In this sense, a Second Pass is an assessment of regional variations in *exposure* to the drivers of coastal change (which will impact most significantly on the most *sensitive* coastal types). These drivers are here termed *regionally variable exposure factors*.

Third Pass or Site-Specific Assessment: However, there are many geomorphic and exposure factors which can vary considerably between nearby coastal sites, which cannot practicably be mapped or assessed at large regional scales, and yet which may have a significant influence on the response of a particular shore to sea-level rise or other coastal hazards. Such local factors may include bedrock topography, local sediment budget, longshore drift, shoreline planform and bathymetry, dune height and many others.

Consequently, where coastal sites have been identified as potentially at risk by a first and/or second pass regional-level assessment, and are seen to be of high priority by reason of high value assets that may be at risk, the next logical stage is to assess all relevant factors (geomorphic sensitivity, exposure to drivers of impacts or change) at the site-specific level of detail. In this sense, a Third Pass or site-specific assessment measures, maps and assesses as many relevant *fundamental, regionally and locally-variable sensitivity & exposure factors* pertaining to a site as are required or practical to produce an (ideally) detailed model of how that particular shoreline is likely to respond to coastal hazards such as sea-level rise. In the terminology of the Allen Consulting Group (2005), a Third Pass assesses *site-specific* sensitivity and exposure.

It would be impractical, time consuming and very expensive to map and integrate all these locally variable factors into a regional or national level assessment. Nevertheless, for strategic and planning reasons it is useful to be able to identify potentially sensitive and exposed coasts at regional and national scales. Hence, an optimum approach is to map and assess those basic sensitivity and exposure factors which *can* be mapped at regional or larger scales in a First and Second pass assessment (geomorphic and oceanographic factors etc), then use the results of those assessments to identify priority locations at which the more detailed data collection and assessment methods required for a site-specific assessment (including modelling of coastal responses using more or less sophisticated modelling techniques & software) will be warranted.

Although the terms "pass" or "level" used here imply a logical sequence of studies, in reality many of the components of coastal assessments are being undertaken simultaneously at all three levels. The "three pass" conceptual framework is presented here not so much as a proposal for how coastal risk assessments should proceed, but more as a synthesis of perceived logical inter-relationships between those actual assessments that have been and that are being done.

The following sections cite examples of recent or current coastal hazard or risk assessments being undertaken in Australia at each of these levels of assessment.

First Pass – Regional Identification of Sensitive Coastal Types

As noted above, a First Pass assesses those *fundamental sensitivity factors* (geomorphic factors) that can be assessed at regional to national scales. In virtue of a long history of geological and topographic mapping, basic geomorphic *fabric* (what it's made of) and *form* (topography) data is available at some scale (at least 1:250,000, but commonly better) for most of the Australian coast. In contrast, usefully detailed information on geomorphic *processes* affecting particular coastal sites – which may strongly control a shoreline's local response to sea-level rise – is only available in any detail for a few classes of features (e.g. beaches: Short, 1996, 2000, 2006, 2007) or for scattered coastal locations (e.g., Short *et al.* 2000).

Thus, while coastal geomorphic process information is important in understanding the sensitivity of coasts to hazards such as sea-level rise, in practice a 'Third Pass' level of assessment is required to obtain and use this sort of information. In contrast, basic information on the fabric and form of coasts – what they are made of and what their shapes are – is equally important in determining coastal behaviour, is readily available at regional to national scales to inform, and consequently is the appropriate focus for First Pass assessments intended to strategically identify coasts potential sensitive to instabilities such as erosion, or to flooding by sea-level rise or storm surge, at a regional to national scale.

A coastal vulnerability study focussed on the Spencer Gulf region of South Australia identified homogeneous coastal geomorphic units within a coastal region characterised by extensive tidal flats as good indicators of degree of sensitivity to inundation and erosion (Harvey *et al.* 1999, Harvey & Woodroffe 2008). As such, this study was in essence a regional First Pass assessment, albeit the variations between mapped geomorphic units were themselves related to variable tidal and wave exposures.

Subsequently, Sharples (2006) produced a coastal geomorphic GIS map of Tasmania which identified a range of differing sensitive coastal landform types, each with potential to respond in differing ways to sea-level rise. The map identifies sandy erosion-prone shores, steeper semi-lithified slump-prone shores, sea-cliffs, and other sensitive classes, as well as identifying stable hard-rock shores likely to be minimally impacted by sea-level rise.

Currently, a team led by Chris Sharples and Richard Mount at the University of Tasmania is assembling a similar consistently-classified coastal geomorphic and stability map for the whole of Australia from existing data, as part of a First Pass coastal vulnerability assessment being undertaken by the Commonwealth Department of Climate Change and Geoscience Australia. This is being prepared in a GIS line format referred to as a "Smartline", which captures information on landform fabric (constituents) and broadly-defined topographic form classes. This map can identify erosion prone shores at potentially high levels of detail in the alongshore direction, but does not capture detailed topographic data of the sort required to map flood-prone areas.

In the past there has little coastal topographic data available at levels of detail sufficient to map potential coastal flood hazard zones with any degree of confidence, apart from very limited site-specific surveys. However, with the advent of high resolution LIDAR mapping this situation is rapidly changing, providing the opportunity to map sea-level rise and storm surge inundation scenarios with vertical accuracies in the order of 10 centimetres.

These uses of geomorphic and topographic data to identify shores potentially sensitive to erosion and/or flooding can all be considered as "First Pass" style assessments in the terminology used by this paper, when they are used to identify coasts which are sensitive in virtue of being "soft" (in various ways) or low-lying, but without integrating this sensitivity with data on actual exposure to erosive or flood-inducing wave climates and storm surge regimes.

Second Pass – Regional Assessment of Exposure to Change Drivers

A Second Pass assessment as defined here assesses the exposure of coastal landforms to those drivers of coastal change and impacts which can be assessed at regional or larger scales. Such *regionally variable exposure factors* (or 'drivers') include sea-level rise, wave climate (wave energy, height, direction), storm climate (storm surge frequencies, directions and magnitudes), tidal ranges, vertical land movement (subsidence, tectonic uplift) and potentially other climatic changes such as precipitation and wind climate changes that may drive dune mobility changes. A regional or Second Pass assessment is a practical means of identifying broad coastal regions more and less exposed to drivers that have the potential to impact sensitive coastal landforms to greater or lesser degrees.

This style of 'Second Pass' assessment needs to be integrated with First Pass' geomorphic sensitivity data to be of practical use in coastal risk assessment; after all, a sloping granite shore is probably going to remain stable and robust for a long time in the most energetic wave climates, whereas sandy shores may change rapidly in response to much less energetic drivers.

Taken together with a First Pass assessment of the distribution of sensitive landforms, coastal regions with higher and lower potential for impacts resulting from coastal hazards such as sea-level rise can thus be identified at a strategic level, allowing prioritisation of more detailed (Third Pass) assessments in the most at-risk coastal regions.

A good example of such an integrated Second Pass assessment is provided by Coastal Vulnerability Index (CVI) mapping which integrated tidal range, wave height, coastal topography, geomorphic type, and historical erosion rates (as indicators of land subsidence and other factors) to produce mapping of alongshore - variation in coastal sensitivity and exposure (*sensu* this paper) along the US coast (e.g., Gornitz & Kanciruk 1989, Thieler 2000). However, the coarse scale of the available CVI mapping limits its practical use for planning purposes.

In contrast to places such as the eastern USA seaboard, vertical land movement is generally negligible for Australian coasts, with the exception of a few locations such as Port Adelaide. Some relatively coarse national-scale data on tidal ranges and wave climate parameters such as average and maximum annual wave height has been available for some time (e.g., see Harris et al. 2000), and could be used to generate Second Pass style assessments for Australia at a coarse scale comparable to US CVI mapping.

However in the last few years climate change and sea-level rise issues have driven an increased focus on generating finer-scale national-level mapping of coastal wave and storm climate data, tidal and sea-level rise variations around the Australian coast, particularly by the CSIRO Marine and Atmospheric Research Division (e.g., Hemer *et al.* 2007a, b, McInnes *et al.* 2008). The potential to use this increasingly high-resolution oceanographic data in combination with detailed coastal geomorphic (sensitivity) mapping to identify coasts most susceptible to climate change impacts has been recognised as one of the rationales for undertaking this work (Mark Hemer, CSIRO, *pers. comm.*).

Most Australian states have set up data collection programs which can provide excellent baseline data for such studies. These include the wave and water level data collection programs in NSW and Queensland. For example, a network of more than seven wave buoys is operated off the NSW coast. The first wave buoys were installed in the early 1970s off Sydney and Brisbane. The collected data has been summarised and presented at Australasian coastal engineering conferences or in government agency publications (e.g. Kulmar et al, 2005). Similarly, a well coordinated network of water level stations is operated throughout Australia by the Bureau of Meteorology, state government agencies and port authorities. However, much of the high quality data being collected by many agencies receives little analysis.

To date, application of data on drivers such as wave climate and water level has generally been undertaken on a local level –

considering a single coastal compartment (usually with a known history of coastal hazards), or a single local government area.

Most coastal compartments within NSW with a known history of coastal hazards have had second or third pass style assessments undertaken, however, some of these studies are 10 to 30 years old, with much of the focus on present day hazards rather than future climate change (CSIRO 2007).

In Queensland, a high level of exposure to tropical cyclones has resulted in a strong focus on storm surge risk assessments, which in the terminology used here can be considered as regional to local-level Second Pass studies (e.g., McInnes *et al.* 2003; see also Harvey & Woodroffe 2008).

In Tasmania, the current Clarence City local government area Coastal Hazards Assessment project involves the first significant use of oceanographic data in coastal risk assessment. This project uses water level data analysis from Hunter (2007), combined with wave data collected by CSIRO, BOM and the NSW Government, and sets up a SWAN wave transformation model on both a regional and local scale to generate a near shore wave climate. Future IPCC sea-level rise projections have then been considered in addition to the present day hazard. This detailed analysis of oceanographic data is being used in combination with site-specific geomorphic data to produce third-pass style assessments for selected Clarence beaches (see further below).

Third Pass – Site-Specific Assessment

Whereas a regional (first and/or second pass) assessment may usefully identify a stretch of coast as being potentially at a generally high (or low) risk of impacts from sea-level rise, localised factors can make specific sites within that coastal stretch considerably less (or more) at risk. Where potentially costly decisions hinge on the likely risk of sea level rise impacts at a site, a site-specific assessment is therefore necessary to confirm or modify the risk assessment derived from first or second pass assessments.

Factors which may influence the sensitivity and exposure of a coast at the local level include bedrock topography, shoreline planform and bathymetry (including substrate profile), dune height, local sediment budget, longshore drift and other local coastal processes such as river discharges and tidal channel processes. Such local factors can dominate the response of a particular site to sea-level rise or storms, yet may vary significantly over short distances along a coast. In many cases it is not practical to map or assess the effect of such variation at a regional or national scale of assessment.

Thus for example, a coastal region which is generally highly exposed to wave energies may include much more sheltered locations behind rocky islands and headlands or in sheltered re-entrants; sandy coasts that are generally highly susceptible to shoreline erosion may include sections where the beach is immediately backed by hard bedrock and is therefore unlikely to recede; a beach receiving a net input of sand from some source may not recede while an adjacent beach with is subject to a net loss of sand through longshore drift may undergo very rapid erosional recession as sea level rises; differing coastal planforms, bathymetries and substrate profiles may refract and absorb wave energies in differing ways, causing the same wave climate to affect adjoining shores in contrasting ways.

In some circumstances, a very quick site-specific assessment may be all that is needed to confirm the likely future response of a particular site to sea-level rise. For example, a beach which may be indicated to be potentially sensitive to coastal recession on the basis of regional – scale information may turn out upon inspection to be immediately backed by a hard rising bedrock surface, and thus susceptible to some beach lowering but not to any significant recession within the next century or so.

However, many shores are rather more complex and require thorough mapping and assessment of numerous site-specific variables to develop a model of the likely behaviour of the shoreline in response to sea-level rise or other coastal hazards. The Shoreface Translation Model of Cowell *et al.*

(1995) and GIS-based coastal behaviour modelling by Hennecke *et al.* (2004) are good examples of “Third Pass” style approaches to modelling site-specific coastal behaviour.

The Clarence (Tasmania) project includes modelling of storm-bite erosion and long term Bruun-style recession at selected beaches using both regional and site-specific factors. The regional (“second pass”) oceanographic factors considered in the modelling include the offshore wave climate, tides, regional scale storm surge and future sea level rise. Local site-specific factors modelled include sand grain size, the subaqueous and sub-aerial shore profiles, the exposure to storm waves, and the average and extreme near-shore wave climate.

However, notwithstanding the sophistication of some of the techniques now available to model coastal behaviour and processes at local scales, there will always remain some significant irreducible uncertainty in any projections of future impacts on and changes to shorelines as a result of sea-level rise (or any coastal hazard). This is a consequence of the number of variables influencing shoreline behaviour, and the range of uncertainties in understanding and quantifying many of those variables. Hence an important part of any Third Pass style site-specific assessment of coastal risks must be not only the provision of some indication of the style and magnitude of impacts likely to occur, but also some indication of the degree of uncertainty inherent in such predictions (Cowell *et al*. 2006).

Significance for the Coastal Planning Process

What have here been termed “First” and “Second” pass assessments can broadly be seen as efficient means of providing strategic information on potential coastal risks over long stretches of coast. These levels of assessment should be capable of identifying areas potentially at risk to the end of the century, at least in broad terms (stretches of coast more and less likely to be at risk from specific hazards, not necessarily ‘risk envelope’ lines on maps inland from the coast). Given their strategic nature, it is appropriate that first and second pass assessments be done under auspices of State and/or Commonwealth Government bodies for reasons of consistency, efficiency, cost and the need for public access to the information created. These analyses may need to be wholly or partly redone should significant new relevant data become available, or if climate changes develop differently to initial assumptions, perhaps after a ten year interval.

Given their strategic nature, it is also important that public expectation about what such data can reveal is carefully managed. There is a tendency for the public – including many planners – to assume that first and second pass – style assessments provide the definitive risk assessment for particular locations. The indicative nature of such assessments, the appropriate purposes for which they can be used, and the need for further site-specific data to inform site-specific risk assessments – needs to be highlighted at all times.

The third pass or site-specific level of assessment is that level at which it becomes possible (within a range of irreducible uncertainties) to specify likely risks with a sufficient level of detail as to provide a basis for planning responses and adaptation (e.g., erosion hazard and flooding envelopes on maps). Hence, this is the level of assessment that should be triggered when more strategic levels of assessment suggest that significant impacts are likely within a time frame for which planning responses can and should now begin to be implemented. A third pass assessment should provide a basis for ‘site-response’ assessments and detailed response option modelling and evaluation.

Ideally, a third pass or site-specific level of assessment should be done under the auspices of Local Governments in high-value areas considered likely to be at risk in the next 25 years, with priority given to those at risk in the next 5-10 years. This level of assessment should be ‘invoked’ as conditions bring new areas into the 25 year time frame or for any areas where proposed developments would be affected in the life of the development.

There are grounds for seeking contributions from developers for the cost of these assessments, but the analysis should ideally be done across a reasonable local area (not just a study for a single development site paid for by developers), because there will be a wider public interest than just the developer's site (including established private structures and public assets both built and natural). Moreover if the analysis is prepared for a body (such as a Local Council) with broad planning responsibilities for a wider coastal area, the standard of analysis may be higher and less subject to legitimate concerns that interpretation of the results is biased in favour of the particular developers interests.

Conclusion

All three levels of coastal risk assessment described in this paper may be – and indeed are being – assessed simultaneously or in mixed order at various scales and in various places. The "three pass" notion is essentially a conceptual ordering of a logical process.

At each of the three levels, differing coastal geomorphic systems and oceanographic or climatic processes may require differing assessment methodologies to achieve similar ends. This is one reason for the apparent plethora of differing coastal assessment methodologies currently being developed and tested, however there remains an underlying consistency in what is actually being achieved, which the "three pass" concept is an attempt to identify.

This conceptual framework can assist planners and others to appreciate where existing studies and assessments for particular regions or locations sit within the overall framework of coastal risk and vulnerability assessments. This can make it easier to evaluate the utility and limitations of whatever risk assessment work has already been done, so as to determine whether existing information is adequate for planning needs, or to identify knowledge gaps, and set priorities for what still needs to be done to achieve a level of risk assessment that is necessary or desirable for a coastal region or location.

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