# Spatial Approaches for Assessing Vulnerability and Consequences in Climate Change Assessments

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**EXTENDED ABSTRACT**

Understanding the socio-economic implications of climate change at the regional level requires integrating information regarding climatic hazards with information regarding environmental, social, and economic systems that are exposed to those hazards. Achieving such spatial integration is non-trivial due to issues of data availability, compatibility and scale. Here, we examine two different approaches, one 'vulnerability-based' and one 'impact-based', from ongoing regional integrated assessment projects in Australia.

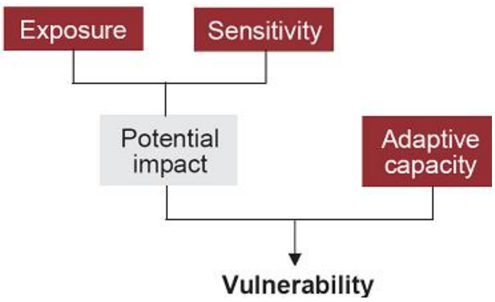


**Figure 1.** Components of vulnerability (Allen Consulting, 2005).

A 'vulnerability-based' approach has been employed in the Sydney Coastal Councils Group region, New South Wales to map the potential for future harm across the region to five climate change impacts: extreme heat and health effects, sea-level rise and coastal management, extreme rainfall and urban stormwater management, bushfire and ecosystems and natural resources. Multiple indicators were integrated to generate spatial maps of the three components of vulnerability: exposure, sensitivity and adaptive capacity (Figure 1). These were subsequently combined to generate a map of net vulnerability. Indicators included current regional climate gradients, projections of future climate change, topography, land use and cover, demographic information as well as indicators of council resources and performance. While the vulnerability approach captures a broad range of potential factors that may contribute to harm, it does not actually predict consequences. As such, it is flexible to data inputs and uncertainties and allows the incorporation of diverse sources of information, even in the absence of knowledge regarding how those data sources interact. Nevertheless, the interpretation of vulnerability in the context of decision-making can be difficult.

In contrast, an 'impact-based' approach is being utilised in the Western Port region of Victoria, which utilises quantitative spatial projections of future climate change and climate hazards in the quantification of affected land areas, infrastructure and populations. This predictive approach gives an indication of the scale of consequences and identifies specific assets that may be affected. These qualities allow easier interpretation and incorporation into existing risk management frameworks. However, predictions of consequences are often dependent upon access to high-quality data, and results are associated with significant uncertainties. Furthermore, it is difficult to incorporate other factors (such as the capacity for adaptation) that may influence impacts.

Both vulnerability and impact-based approaches can provide useful information to stakeholders. Deciding which is appropriate for informing stakeholders is a function of the assessment and the questions for which stakeholders seek answers as well as potential temporal financial or technical constraints on the assessment process.

## 1. INTRODUCTION

Climate risk arising from both climate variability and change is spatially heterogenous across a diverse range of geopolitical scales. At the international level, for example, climate risk is generally believed to be more acute in the developing world which has significant exposure to climate hazards, but is also associated with a socio-economic context that exacerbates those hazards (Preston et al., 2006). At the national level, various ecosystems, sectors, and sub-populations within Australia have been identified as being more or less at-risk in a changing climate (Allen Consulting, 2005; IPCC, 2007). However, few studies have attempted to explore the spatial heterogeneity of climate risk at smaller spatial scales, such as a metropolis (for examples, see Rosenzweig et al., 2000; CLIMB, 2004).

As part of the Australian Greenhouse Office's Impacts and Adaptation Program, a suite of projects is being funded in conjunction with other partners to elucidate climate risk at the regional scale. These projects are linked through an emphasis on the integration of knowledge about changes in the climate system with knowledge about the regional socio-economic context in which those changes will occur. Two of these projects, one in the Sydney Coastal Councils Group of New South Wales and one in the Western Port region of Victoria, focus on climate risk and adaptation in the coastal zone. The former emphasises the impacts of climate change and the identification of adaptation strategies for ameliorating those risks. The latter focuses on the institutional issues associated with adaptation, including constraints and barriers on decision-making.

The regional nature of the projects and the focus on impacts and adaptation relevant to local government makes the spatial elements of climate risk critical for prioritising at-risk areas and infrastructure for the allocation of resources and further investigation. Meanwhile, understanding the potential obstacles to managing climate risk through adaptation requires an understanding of the complexity of the local environment and institutional decision-making as well as how the biophysical environment and human agency interact to influence risk and adverse outcomes. Due to the contrasting emphasis of the two projects as well differences in investigators, timing and funding, each study utilises different approaches to exploring climate risk; one takes an 'impact-based' approach, while the other a 'vulnerability-based' approach (IPCC, 2007). This paper summarises these two approaches to elucidating climate risk and compares and contrasts the resulting information and its potential uses.

## 2. CLIMATE VULNERABILITY IN THE SYDNEY COASTAL COUNCILS GROUP

To assist in stimulating discussion among local government stakeholders within the 15 member local government Councils of the Sydney Coastal Councils Group, a vulnerability assessment and mapping exercise was undertaken (Preston et al., 2007). Vulnerability was framed in the manner presented by the Intergovernmental Panel on Climate Change (IPCC): *"the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2001)."* Vulnerability is recognised as being comprised of three components: exposure, sensitivity and adaptive capacity (Figure 1). Exposure refers to the presence of a climate hazard. Sensitivity refers to the responsiveness of a system to that hazard. Adaptive capacity refers to the ability of a system to change in a way that makes it better equipped to manage its exposure and/or sensitivity to climatic hazards and/or cope with adverse impacts.

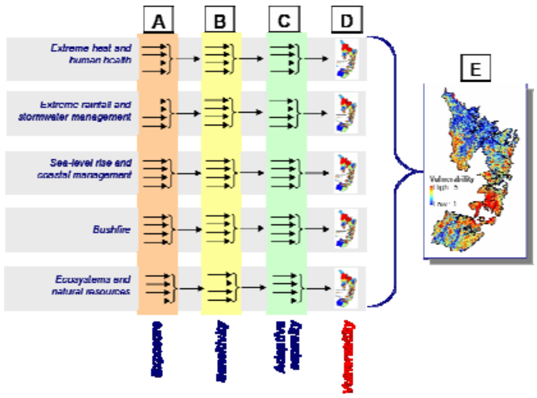


**Figure 2.** Framework for integration of indicators into exposure (A), sensitivity (B), and adaptive capacity (C) layers. These layers were integrated into a map layer representing net vulnerability for each of the five impacts (D). These vulnerability layers were integrated to generate a map of overall climate change vulnerability throughout the SCCG region (E).

The advantage of the vulnerability-based approach was that it allowed a broad array of potential risk factors to be explored (Tuner et al., 2006). This is conducive to diagnosing the various factors and interactions that contribute to vulnerability and climate risk as a means of generating thought regarding processes that affect risk and its management within local government.

The above model of vulnerability was operationalised by the identification of indicators of exposure, sensitivity and adaptive capacity for five potential climate change impacts: extreme heat and health effects, sea-level rise and coastal storms, extreme rainfall and urban stormwater management, bushfire and degradation of ecosystems and natural assets (Figure 2; Appendix A). Indicators included current regional climate gradients, projections of future climate change, topography, land use and cover, demographic information as well as indicators of council resources and performance. Furthermore, data for indicators reflected a range of formats, including raster data of varying resolutions and vector (point and polygon) data. To facilitate integration, all data sources were converted to a common spatial reference (90 metre grid utilising the WGS 1994 datum) over the SCCG region.

Indicators were subsequently scored qualitatively with a ranking from 1 to 5 (based upon quintiles), with 1 representing a low contribution to vulnerability and 5 representing a high contribution. To prevent differential numbers of indicators for each component from biasing outcomes, indicators for each component of vulnerability (exposure, sensitivity and adaptive capacity, Figure 1) were first summed and rescaled to a range from 1 to 9. In so doing, no assumptions were made regarding the relative importance of individual indicators, in part due to a lack of knowledge regarding their relationships and ultimate implications for risk. The three components were subsequently summed and rescaled to estimate net vulnerability for each impact. Individual components were assigned differential weights based upon expert judgment regarding their relative significance for vulnerability.

As illustrated by the vulnerability map for sea-level rise and coastal management (Figure 3; Appendix A), vulnerability varies across the SCCG landscape. In this instance, vulnerability was concentrated in the coastal margins, particularly in low-lying areas around Botany Bay and Pittwater Bay. Secondary vulnerability is observed in estuaries and upstream regions, whereas higher elevation areas and those inland are naturally associated with lower vulnerability. Nevertheless, land areas and infrastructure several kilometres inland are not necessarily immune to coastal hazards (e.g., winds associated with storms).

Similar maps were generated for the other four impacts, and results were averaged over each of the 15 SCCG Councils to generate aggregate vulnerability scores for local government. The presentation of the vulnerability assessment and mapping to local government stakeholders through a series of 15 workshops enabled stakeholders to jointly consider the nature of that vulnerability as part of a social learning process (Keen et al., 2005). The contribution of individual components and even individual indicators to spatial patterns of vulnerability enabled investigators and stakeholders to understand the diversity of risk-factors for climate impacts and some of the key linkages. Ultimately, this exercise was designed to encourage stakeholders to think about the local environment as a complex system comprised of multiple drivers, responses and interactions.

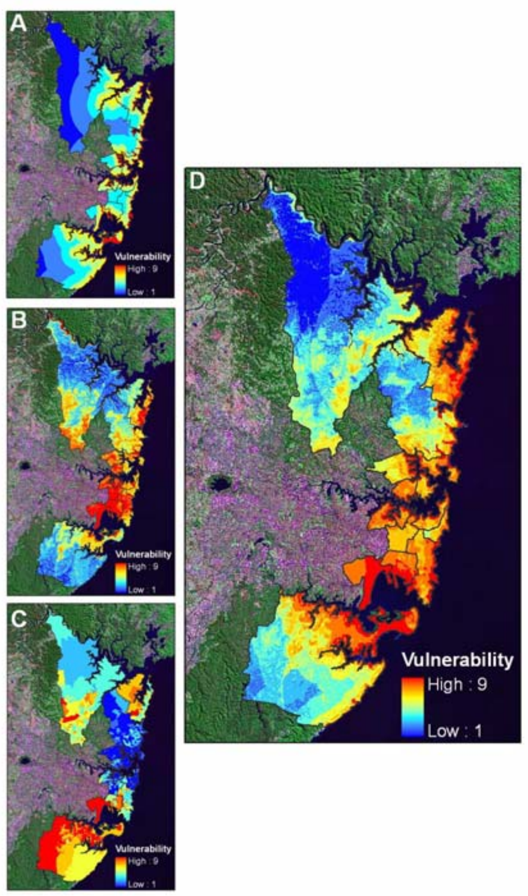


**Figure 3.** Vulnerability of the SCCG coastline to climate change, sea-level rise and storm events. Figures A, B, and C represent the three components of vulnerability: exposure, sensitivity, and adaptive capacity, respectively. Each of these components is determined independently of the others. D represents the integration of these components into net vulnerability. High values indicate a relatively high degree of coastal vulnerability to while low values indicate a low degree of vulnerability.

## 3. CLIMATE IMPACTS IN WESTERN PORT

The Western Port integrated assessment project is examining the impacts of climate change on the region's built environment to inform the five local Councils with respect to potential climate change consequences and management options. To the extent possible, the project is attempting to generate quantitative predictions of impacts in response to a suite of climate change scenarios (e.g., IPCC, 1994). Rather than examining the various interactions among climate, social, and economic drivers that influence risk, the assessment primarily examines the biophysical implications of climate change, the infrastructure or property exposed to those changes, and estimates of their subsequent asset values.

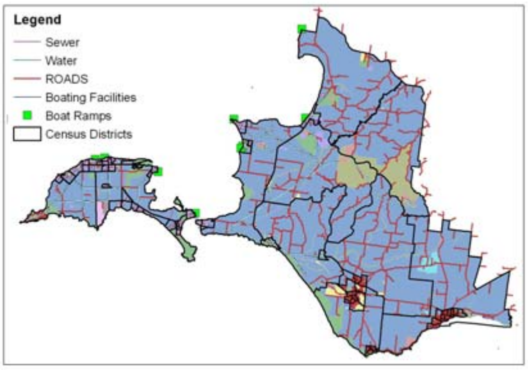


**Figure 4.** Spatial distribution of different planning zones; water, sewer, and transport infrastructure; as well as boundaries for census collection districts in the Bass Coast Council of Western Port.

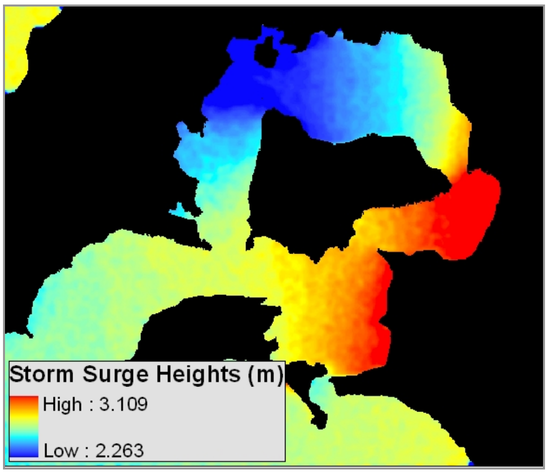


**Figure 5.** Spatial distribution of 1 in a 100 year storm surge heights in Western Port Bay in 2070 (assumes 49 cm of sea-level rise).

To this end, the impact assessments rely upon quantitative scenarios of climate change, including projections of changes in average temperature, rainfall, evaporation and humidity in 2030 and 2070 (Hennessy et al., 2005; Victorian Government, 2007). Additional modelling was conducted to generate scenarios of changes in extreme rainfall events and storm surge events across the WP region (examples of approaches appear in McInnes et al., 2005 and Abbs et al., 2006). The implications of these scenarios for impacts to the built environment were estimated through two mechanisms: a) qualitative discussions informed by the existing literature on climate change consequences; and b) for storm surge and extreme rainfall scenarios, quantitative estimates of land area affected, water and sewer infrastructure affected, transport infrastructure affected, properties affected, and, to the extent possible, estimates of asset values (e.g., Figure 4).

**Table 1.** Illustrative impact estimates in Bass Coast Council due to sea-level rise and 1 in a 100 year storm surge events. Present impacts assume a 1 in a 100 year event with current sea levels. Impacts in 2030 and 2070 are based upon 1 in a 100 year storm events assuming a mean sea-level rise of 17 and 49 cm, respectively.

| Impact | Present | 2030 | 2070 |
|---|---|---|---|
| Area inundated ($km^2$) | 4.4 | 5.3 | 8.2 |
| Affected planning zones (#) | 48 | 50 | 52 |
| Affected sewer (km) | 3.9 | 4.3 | 5.4 |
| Affected storm water (km) | 10.1 | 11.0 | 13.2 |
| Affected roads (km) | 11.4 | 12.1 | 15.5 |
| Affected boating facilities (#) | 5 | 6 | 5 |
| Potential affected population (#) | 6,673 | 7,408 | 7,539 |
| Total present unimproved value of affected land ($10^6$$) | $109 | $115 | $152 |

Preliminary results for the storm surge modelling that accounted for future mean sea-level rise, changes in wind speed, and the resulting inundation for one of the Councils in the region are typical of the type of results generated through such a quantitative, impacts-based approach

(Figure 5; Table 1). For Bass Coast Council, by 2030, a 1 in a 100 year storm surge event increases the area inundated at present by 20%. More importantly, the mapping of this inundation in space allows one to identify existing assets and infrastructure affected by these scenarios. A 1 in a 100 event in 2030 affects 50 different planning zones, primarily distributed across agricultural, residential and public land, with some impacts on industrial land. The potential land value at risk increases by 6%, and based upon the underlying census collection districts, an additional 735 people are affected compared to the same event at present. In addition, a number of assets in the coastal zone come under threat, including a number of boating facilities, and segments of the water, sewer, and road networks. By 2070, the area affected by a 1 in a 100 year storm surge increases by 86%, the land value at risk increases by 33%, with a larger population affected and increased impacts to infrastructure. Interestingly, however, the additional affected infrastructure is small compared to the increase in inundated area.

Similar analyses have been conducted for all the Councils in the region for a range of climatic changes and potential impacts. Based upon such information, local government stakeholders are proceeding through a risk assessment exercise to identify key climatic changes and impacts of concern and explore targeted adaptation options for reducing future risk to areas, land uses and infrastructure.

## 4. COMPARISON OF APPROACHES

Both vulnerability and impact assessment have seen significant use internationally as well as throughout Australia, and thus these approaches for exploring climate change and consequence presumably have merit. Perhaps the most relevant question is under what conditions one method should be employed over another.

Vulnerability assessment and mapping often create more questions than they answer, as one is challenged to identify the factors that account for observed spatial patterns of vulnerability. In the SCCG project, this was considered a benefit, as it forced stakeholders and investigators to deconstruct vulnerability and examine the factors that contribute to vulnerability estimates and how they interact. This helps to build a shared understanding of the system and how it is or can be managed, which in the SCCG project was judged more important than specific projections of what is damaged.

Furthermore, vulnerability assessment enables diverse sources of information, including indicators of adaptive capacity, to be readily incorporated into an assessment, even if the relationships among different variables are not well-defined. The adaptive capacity indicators, for example, attempt to capture the potential for households and Councils to successfully manage risk both now and in the future. However the difficulty of interpreting vulnerability, the lack of recognisable metrics (e.g., economic costs), and the lack of specific outcomes or consequences creates challenges for using information about vulnerability in the actual design and implementation of adaptation responses. For example, knowing that a particular area is comparatively more or less vulnerable to sea-level rise does not indicate the costs and benefits of potential adaptation actions to manage that vulnerability. Yet information that can justify such decisions is a key desire of local governments.

In contrast, impact assessment has the potential to provide such quantitative precision. However, the emphasis on quantification places some significant demands on the assessment. Not only must one have a method of generating scenarios of future climate changes, one must be able to relate those changes to consequences. In the case of coastal inundation, this process is somewhat straightforward, given knowledge of coastal topography and the distribution of infrastructure and assets. However, for water resources or agricultural applications, a process model is required for translating climate information into biophysical responses. The financial and social capital to parameterise and operate such models may be in short supply. Therefore, while there is a natural tendency for stakeholders to seek quantitative scientific data, one should be careful to select the tool or method that is best-suited to achieving the goals of the assessment. The interest within Western Port in the identification of specific areas, assets and planning decisions that may be affected by climate change made it a useful study area for quantitative impact assessment.

Nevertheless, it can be difficult to account for endogenous social and environmental change within impact assessment models. For example, how may increases in population and development within the Western Port region affect future impacts to infrastructure? How does one predict impacts to assets that do not currently exist? On the other hand, the quantitative estimation of impacts and a spatially explicit view of consequence are likely to be attractive to stakeholders as they provide a readily interpretable image of potential consequences, their scale, and hence where management efforts should be directed and how much investment may be required.

A common consideration for both vulnerability and impact-based approaches is the issue of acknowledging uncertainties. One must be cautious about over-interpreting the results of a vulnerability assessment by assigning a particular consequence or likelihood to an estimate of vulnerability. For example, even when indicators of adaptive capacity suggest a particular local government or land area has a high capacity to manage climate risk doesn't necessarily mean that such risk will in fact be well managed when the time comes. Generally, though, the fact that vulnerability assessments are often only semi-quantitative or even wholly qualitative helps insulate the assessment from questions of accuracy. The quantitative results of impact assessment, however, are vulnerable to contention over the reliability of results as well as over-confidence in the seemingly rigorous nature of the impact assessment process. For example, the storm surge scenarios generated for Western Port assume discrete increases in sea-level rise in 2030 and 2070. Such sea-level changes are highly uncertain and resulting estimates of inundation must be interpreted in the context of this uncertainty. Over emphasis on quantitative prediction can generate a false sense of security among investigators and stakeholders with respect to uncertainty, leading to the perception of greater accuracy or precision in the assessment than is truly warranted.

## 5. CONCLUSIONS

The spatial component of climate risk is critical for building understanding about climate risk and potential management options and challenges at the local level. A range of methods is available for exploring climate risk across a landscape. However, as with any scientific assessment process, the appropriate methodology is dependent upon the needs of stakeholders as well as potential constraints placed upon a project such as funding, time, data access and expertise.

Impact and vulnerability assessment are both frequently used to examine the implications of climate change across a range of spatial scales. Put simply, vulnerability assessment builds understanding about how complex systems *behave*. Hence the true value of vulnerability assessment is the social learning that develops from exploring complexity – viewing diverse factors that drive exposure, influence sensitivity and create barriers to adaptation – which contributes to the capacity of individuals and institutions to adapt and manage risk. In contrast, impact assessment builds understanding about how systems of interest to stakeholders *respond* to climate variability and change. As such, impact assessment lends itself well to situations where stakeholders need specific information on where and when climate damages may occur, provided the large uncertainties associated with predictive impact assessment can be adequately addressed.

## 6. ACKNOWLEDGEMENTS

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## APPENDIX A

| Vulnerability Indicators for Sea-Level Rise Impacts in the SCCG Region | | |
|---|---|---|
| **Exposure Indicators** | **Sensitivity Indicators** | **Adaptive Capacity Indicators** |
| 1) Distance to coastline (90 m grid)<br>2) Present relative storm surge heights along SCCG coast (100 m grid)<br>3) SEPP 71-defined sensitive coastal locations (polygon file) | 1) Coastal elevation (90 m grid)<br>2) Slope (90 m grid)<br>3) Land cover (90 m grid)<br>4) Population density (census districts)<br>5) Projected population growth to 2019 (statistical local areas)<br>6) Acid sulphate soils (polygon file) | 1) % population completing year 12 (census district)<br>2) % population with English literacy (census district)<br>3) Average mortgage (census district)<br>4) Average income (census district)<br>5) % population with internet access (census district)<br>6) Current ratios (local government areas)<br>7) Per capita business rates (local government areas)<br>8) Per capita residential rates (local government areas)<br>9) Per capita community service expenses (local government areas) |