Prioritising Coastal Adaptation Development Options for Local Government

2013

A Multi-Criteria Analysis of Coastal Adaptation Options for Local Government

Australian Government
Department of Climate Change and Energy Efficiency

Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

University of the Sunshine Coast
Sustainability Research Centre

Sydney Coastal Councils Group

Coastal Adaptation Decision Pathways Project **(CAP)**

A Multi-Criteria Analysis of Coastal Adaptation Options for Local Government

A Report for the Sydney Coastal Councils Group

Prepared by

Benjamin L. Preston[1]; Megan Maloney[1]; Dana Thomsen[2];

Tim Smith[2]; Robert Mangoyana[2]; Brian Conlon[3]

[1]Oak Ridge National Laboratory; [2]University of the Sunshine Coast; [3]University of Tennessee-Knoxville

For further information regarding this report, please contact:

Geoff Withycombe
Regional Coastal Environment Officer / Executive Officer
Sydney Coastal Councils Group Inc.
Level 14, 456 Kent Street
GPO Box 1591
SYDNEY NSW 2001
DX 1251 Sydney
Ph: +61 2 9246 7791
Fax: +61 2 9265 9660
Email: geoff@sydneycoastalcouncils.com.au

The suggested citation for this report is as follows:

Preston, B.L., Maloney, M., Thomsen, D., Smith, T., Mangoyana, R., Conlon, B. (2013) *A Multi-Criteria Analysis of Coastal Adaptation Options for Local Government*. Prepared for the Sydney Coastal Councils Group by Oak Ridge National Laboratory and the University of the Sunshine Coast, Oak Ridge, Tennessee and Sippy Downs, Queensland.

Acknowledgements:

This report was prepared through funding from the Australian Department of Climate Change and Energy Efficiency to the Sydney Coastal Councils Group. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

A large number of data sets were used in the generation of this report and its various analyses. The following organizations are credited with the provision of such data to the project:

- Australian Bureau of Rural Sciences
- Australian Bureau of Statistics
- Bega Valley Shire Council
- CSIRO
- Geoscience Australia
- New South Wales Department of Planning
- New South Wales Land and Property Information
- New South Wales Department of Environment and Heritage
- Sunshine Coast Council

Table of Contents

Table Index

Figure Index

Executive Summary

Australia's coastal communities have been identified as particularly vulnerable to the effects of climate change due to concentration of the nation's assets and infrastructure in the coastal zone and the inevitability of rising sea levels and their influence on coastal processes and dynamics. While researchers and practitioners are increasingly engaged in adaptation planning for coastal communities, such planning has rarely progressed beyond the simple identification of general risks and potential management options that could be implemented by decision-makers. For over two decades, coastal managers have been discussing the utility of options such as protect, accommodate, or retreat when thinking about managing the risks associated with sea-level rise. In Australia, the rapid growth in interest in adaptation has amplified such discussions. Yet, little progress has been made toward the more critical evaluation of these broad strategies, much less specific policies or measures that might be implemented to address place-based challenges posed by climate change. Meanwhile, decisions regarding local planning and development are proceeding, and conflicts regarding appropriate decision-making for Australia's coasts are increasingly making their way into the courts.

The Department of Climate Change and Energy Efficiency's Coastal Adaptation Pathways (CAP) program was launched in 2011 to advance methods and tools for the evaluation of the costs and benefits of different coastal adaptation options. As one of the CAP projects facilitated by the Sydney Coastal Councils Group (SCCG), *Prioritising Coastal Adaptation and Development Options for Local Government* sought to address this challenge through the application of Multi-Criteria Analysis (MCA) methods. The project undertook an MCA of coastal adaptation options in conjunction with Local Government in three Australian regions: metropolitan Sydney, Bega Valley Shire Council in coastal New South Wales and Sunshine Coast Regional Council in Queensland. The diversity of case study regions enabled the MCA to explore how different Local Government perspectives interact with assessments of place-based hazards and assets at risk to influence the utility of different illustrative adaptation options.

Evaluating what constitutes an appropriate strategy for coastal adaptation is a significant analytical and policy challenge. Coasts are valued in a number of ways by communities, organisations, individuals. They provide economic and recreational benefits. They are where people live and work. They support diverse and prized ecological systems that enhance the natural amenity of coastal areas. Furthermore, managing coastal systems for the risks of climate change necessitates thinking over multiple time scales, including a long-term view that is inherently clouded by uncertainty. As a consequence of these complexities, traditional policy analysis tools such as cost/benefit analysis are difficult to implement in a meaningful way. Many of the values people hold with respect to the costs and benefits of policy choices are difficult to capture in economic units. In addition people's perceptions of risks, and hence acceptable policies and actions, will change over time.

Such challenges have led some to explore alternative policy analysis tools, one being MCA.[1] The goal of MCA is to attempt to directly incorporate multiple values held by stakeholders into the analysis of management alternatives while avoiding the reduction of those values into a standard monetary unit. In so doing, one can consider different coastal adaptation options in the context of economic criteria as well as other criteria such as social, political or environmental aspects. Stakeholders can also assign explicit weights to those values to reflect their preferences and priorities. Therefore, MCA provides opportunities for the direct participation of stakeholders in the analysis.

[1] Multi-criteria analysis is also referred to as multi-objective analysis or multi-criteria decision analysis.

Prioritising Coastal Adaptation and Development Options for Local Government undertook two different approaches to MCA of coastal adaptation options.

- The **Stage I** MCA elicited perspectives from Local Government staff in the three study regions regarding the performance of 15 illustrative adaptation options against 16 criteria spanning governance, financial, social and environmental dimensions. The analysis therefore provided a benchmark of Local Government attitudes toward different adaptation options and their respective trade-offs.

- The **Stage II** MCA extended the Stage I analysis to generate place-based evaluations of the utility of different adaptation options at the property scale. Geospatial information on sea-level rise, storm surge, and erosion was used to assess risks to financial, social and environmental assets. Additional constraints on the performance of different adaptation options were also introduced to enable the place-based performance of adaptation options to reflect local landscape characteristics.

Upon applying these analyses, a number of key findings emerged:

1) Staff in Local Government seek to balance multiple values in developing policy recommendations for coastal risk management. Nevertheless, governance and political processes may ultimately force trade-offs in decision-making.

2) The perceived utility of different coastal adaptation options is similar across different regions and communities, suggesting there is a common understanding among Local Government staff with respect to what constitutes appropriate and sustainable adaptation.

3) Capacity building activities are generally viewed as low-cost measures that perform well across a range of different criteria and create the necessary bottom up community support and evidence base for more substantive actions.

4) The most unfavourable coastal adaptation options are those that create long-term investment obligations for councils, incentivize risk-seeking behaviour and/or create 'moral hazard' by positioning Local Government as the insurer of last resort.

5) The utility of different adaptation options is sensitive to the time horizon used in the adaptation planning process, but uncertainty about the future poses is a cross-cutting factor that reduces confidence in the appropriateness of many adaptation options.

6) From the perspective of Local Government staff, the performance of adaptation options against financial and environmental criteria tended to be the most significant factor influencing the prioritisation of different options. However, adaptation options that performed well against various financial criteria also performed well from an environmental perspective.

7) The spatial distribution of coastal hazards, assets of value and appropriate adaptation options varies significantly from one location to another as well as over time. Therefore, spatial adaptation planning is necessary to advance adaptation efforts.

8) While tools such as MCA can be helpful in prioritising adaptation options for specific locations, subsequent deliberation and planning is needed to develop 'risk weighted adaptation pathways' that outline how portfolios of options can be deployed over the near, medium, and long-term.

9) The determination of priority adaptation options should be accompanied by appropriate monitoring and evaluation mechanisms to assist in tracking the success of policies and practices and/or detecting unintended consequences.

1 Introduction

- **Despite intensive focus in recent years on the vulnerability of coastal communities to climate change, relatively little has been invested in developing methods, tools, and practice for the evaluation of alternative adaptation options.**
- **Multi-criteria Analysis (MCA) is one approach to decision support that can aid in managing complex decision challenges where multiple values are at stake.**

Australia's coastal communities have been identified as particularly vulnerable to the effects of climate change due to concentration of the nation's assets and infrastructure in the coastal zone, the legacy of past management decisions and the inevitability of rising sea levels and their influence on coastal processes and dynamics (DCCEE, 2009). Since the early 1990s, organizations have been planning strategies to adapt to climate change and the anticipated impacts to coastal communities. Much of this history of adaptation planning has been limited, however to identifying the different adaptation options that could be implemented to reduce vulnerability, with most of those adaptation options being long-standing practice in coastal management more broadly. Hence, for over two decades, coastal managers have been discussing the utility of options such as protect, accommodate, or retreat when thinking about managing the risks associated with sea-level rise (IPCC, 1990). In Australia, the rapid growth in interest in adaptation has amplified such discussions, yet little progress has been made toward the more critical evaluation of these broad strategies, much less more specific policies or measures. Meanwhile, decisions regarding local planning and development are proceeding, and conflicts regarding appropriate decision-making for Australia's coasts are increasingly making their way into the courts (Peel and Godden, 2009).

Evaluating what constitutes an appropriate strategy for coastal adaptation is a significant analytical and policy challenge.[2] Coasts are valued in a number of ways. They provide economic and recreational benefits. They are where people live and work. They support diverse and prized ecological systems that create the natural amenity of coastal areas. To add another layer of complexity, managing coastal systems for the risks of climate change necessitates thinking over multiple time scales, including the long-term view that may stretch out over multiple decades. Yet over those time scales, the future is very uncertain. As a consequence of these complexities, traditional policy analysis tools such as cost-benefit analysis are difficult to implement (Morgan et al., 1999; Yohe, 2003; Hallegatte, 2011). Assessing the costs of a particular policy over its life span is challenging enough. Assessing benefits, however, is even more difficult when one must entertain a broad range of future outcomes. Meanwhile, many of the values people hold with respect to the cost are difficult to capture in economic units. Such challenges have led some to explore alternative policy analysis tools, one being multi-criteria analysis (MCA).[3]

[2] Here we use the term evaluation to refer to an assessment of the anticipated performance of a particular adaptation option. In formal policy analysis terminology, this is often described as appraisal, with evaluation reserved for a retrospective examination of how well a particular policy actually performed.
[3] Multi-criteria analysis is also referred to as multi-objective analysis, multi-attribute analysis, or multi-criteria decision analysis.

The goal of the Coastal Adaptation Pathways (CAP) project, *Prioritising Coastal Adaptation and Development Options for Local Government*, was to trial approaches to undertaking an MCA of coastal adaptation options in conjunction with Local Governments in three Australian regions (Figure 1). The three regions, metropolitan Sydney, Bega Valley Shire Council in coastal New South Wales and Sunshine Coast Regional Council in Queensland represent a gradient of urban to regional landscapes. This diversity of case study regions enables the MCA to explore differences in values and perceptions of the utility of different adaptation options in different regional and governance contexts.

This project represents one of a number of examples where MCA tools are being applied to support decision-making regarding natural resources management and regional planning, both internationally and in Australia, specifically (Greiner et al., 2005; New South Wales Department of Planning, 2006; Marinoni et al., 2009; Mosadeghi et al., 2009; Huang et al., 2011; Straton et al., 2011). While a number of aspects of the MCA approach reported here are common to other MCA studies, the methods have been developed to specifically address the unique challenges posed by coastal adaptation within Australian Local Government.

Figure 1. Location of three case study regions associated with the *Prioritising Coastal Adaptation and Development Options for Local Government* project. The three case study regions represent a total of 17 local government areas (LGAs) – 15 were members of the Sydney Coastal Councils group (SCCG) in Sydney, New South Wales, while the other two represented the regional councils of Bega Valley Shire Council in New South Wales and Sunshine Coast Regional Council in Queensland.

The project seeks to generate the following outcomes and flow-on benefits for both researchers and adaptation practitioners:

- Improved understanding of the diversity of values associated with coastal landscapes and the transparent identification of the criteria used by Local Government (LG) in coastal management decision-making as well their relative importance;
- Enhanced ability of coastal decision makers in LG to evaluate adaptation options based on

governance, social, economic and environmental criteria over multiple time horizons;

- Improved capacity for coastal decision makers to understand the implications of their responses to climate change through monitoring and evaluation, including the economic costs and benefits of their response as well as potential trade-offs; and
- Improved engagement of end users in the understanding of coastal climate change issues and in the development and refinement of practical tools to assist coastal decision-making in response to climate change at the LG scale.

This report summarises the range of activities undertaken as part of the project. The report is divided generally into the following sections:

- **Section 1** – Provides background on MCA methods and the rationale for using this general approach to policy analysis.
- **Section 2** – Summarises findings from a survey of stakeholder values and their role in decision-making at the Local Government level.
- **Section 3** – Discusses Stage I MCA methods and results
- **Section 4** – Discusses Stage II MCA methods and results
- **Section 5** – Reflects upon the project results in the context of flexible decision pathways
- **Section 6** – Synthesises the project findings and key messages
- **Section 7** – Identifies potential next steps to carry this work forward

It should be noted that this report is one of three reports completed through the CAP project. The other two reports in this series include the following:

- *Literature Review of Adaptation to Climate Change in the Coastal Zone*
- *A Guide to Monitoring and Evaluating Coastal Adaptation*

1.1 Principles of Multi-Criteria Analysis (MCA) in Decision-Making

The goal of MCA is to attempt to directly incorporate multiple interests and beliefs held by decision-makers into the analysis of management alternatives without necessarily assigning monetary values to all of those interests (Department of Communities and Local Government, 2009). Hence, unlike alternative economic policy analysis tools such as cost-benefit analysis or cost-effectiveness analysis, MCA allows decision-makers to work directly with heterogeneous values as well as both qualitative and quantitative information. This enables MCA to side-step the questionable act of assigning monetary values to non-market assets and services, which may be contested. Nevertheless, while MCA conveys a greater measure of flexibility to policy analysis, caution is warranted in interpreting the results of any policy analysis for climate change applications. Fundamental challenges of long time-scales, 'deep uncertainty' as well as complex and dynamic governance should deter one from over-interpreting a policy analysis exercise for climate change (Lempert, 2002; Kandlikar et al., 2005).

A wide variety of approaches to MCA are available, with varying degrees of complexity, time-commitment and data/information needs. However, all approaches generally attempt to develop a structured way for incorporating multiple and diverse decision criteria into a decision analysis. Multi-criteria analysis evaluates alternative management options by testing a specified suite of options against a defined set of decision criteria that represent the range of values and interests decision-makers consider relevant to the analysis. Individual criteria can be assigned subjective weights to elevate or discount criteria based upon their perceived degree of importance. Results from those tests of performance can then be aggregated into different groups to explore different dimensions of performance or aggregated into a single group to explore overall performance.

Table 1. Stages in the decision-making process for coastal adaptation and their operationalisation within the current study (based on Department of Communities and Local Government, 2009).

Stage	Approach of the Current Study	Source of Assumptions or Information
Identifying objectives	Objective defined generally as *the identification of adaptation options over different time horizons that best reflect expressed values of stakeholders in local government*	Researcher defined
Identifying options for achieving the objectives	A review of coastal adaptation literature and policy instruments including peer-reviewed academic publications, adaptation plans of Local Government and outputs from other CAP projects	Researcher defined
Identifying the criteria and weights to be used to compare the options	A large number of putative criteria were identified by researchers that spanned considerations around governance, infrastructure, social/cultural values, human resources, financial/economic considerations and natural resources and biodiversity. These were incorporated into an online survey, the results of which were used to reduce the dimensions of the MCA and select specific criteria and their weights.	Researcher defined after stakeholder input
Analysis of the options	Three different MCA analyses were conducted of varying intensities to analyse options. One was based on raw analysis of option performance against criteria. A second added weights to those criteria. A third added risk weighting that accounted for spatial elements of vulnerability.	Researcher defined the structure of the analysis, option performance and criteria weights were based on stakeholder inputs
Making choices	'Choices' in the context of this project simply represents the prioritization of adaptation options. Implementation of specific options is beyond the project scope.	MCA output
Feedback	Feedback in the current study was based on local government stakeholder reflections upon the MCA methods and findings and their implications and relevance for Local Government adaptation.	Stakeholder defined

It should be noted that many aspects of MCA involve subjective judgments: management objectives, selection of decision criteria, assignment of weights and methods of integration and aggregation to name several. This subjectivity is both the strength and weakness of MCA. All decision-making involves such subjective judgment. As such, rather than attempt to exclude such subjective values from policy analysis, MCA seeks to incorporate them. Hence, to the extent that an MCA is structured such that it accurately and transparently reflects the subjective judgments of decision-makers, the results can be interpreted with some degree of confidence. If, however, those judgments are made independent of decision-makers without their participation, then MCA becomes a technical exercise that may provide interesting insights, but which may not be a reliable reflection upon the values and interests of those actually charged with decision-making. As such, MCA lends itself well to participatory processes where those charged with decision-making provide direct input into the MCA. In so doing, participants can craft their own scenarios, and test the sensitivity of results to alternative assumptions.

1.2 The Decision-Making Process

Policy analysis tools exist to guide the selection and implementation of a particular policy or measure. As such, they are generally applied as part of the decision-making process. To facilitate the MCA for the current project, a conceptual decision-making process was developed. Although this project is not linked explicitly to any pending decision on coastal adaptation in the case study regions or among Local Government participants in the project, this conceptual process helps to illustrate how MCA approaches could be applied in a formal decision setting. For the purposes of this project, the decision process for coastal adaptation was deconstructed into a series of sequential stages (Table 1). The execution of each stage was tailored to the specific MCA challenge represented by the current study. Different stages had varying degrees of input from Local Government staff, with the earlier stages largely framed by researchers engaged in the project, and the latter stages dominated more by Local Government staff participation and input.

2 Context Building: Survey of Local Government Stakeholder Values

- **Key triggers for changes in policy and practice at the local government level include new information regarding coastal hazards, changes in state policies and guidance, as well as concerns about liability.**
- **Staff in Local Government recognize the need to balance a range of values in internal planning processes for coastal management that include economic, social, environmental, and political considerations.**
- **Despite the desire to take a balanced approach, the policies and practices that are implemented are often biased toward a particular value or interest that emerges through the political process.**

An initial step in pursuing the MCA for coastal adaptation options was to build understanding regarding the fundamental values that influence decision-making within Local Government. To this end, a questionnaire was developed to elicit such information from individuals working in the 17 Local Government Areas (LGAs) participating in the project.

2.1 Methods

The design of the questionnaire of Local Government values was undertaken by researchers from the University of the Sunshine Coast and Oak Ridge National Laboratory, with questions framed to build general understanding of Local Government decision-making as well as generate data that could be readily incorporated into an MCA (see Appendix I). The Local Government questionnaire was conducted online and participants from each Local Government Area (LGA) were solicited via emails sent to key points of contact (POCs). Those POCs were asked to encourage other colleagues within the same Local Government to also complete the questionnaire. The IP addresses of participants' computers were logged by the questionnaire software to prevent multiple versions of the questionnaire from being completed on the same computer. The questionnaire went 'live' on 28 October, 2011 and access was terminated on 15th December, 2011.

The questionnaire was divided into four sections:

Section 1: Background information on the LGA, department and job role of the questionnaire participant.

Section 2: Questions regarding factors affecting LGA decision-making which included multiple questions pertaining to governance, financial/economic factors, environmental factors, social factors, human/cultural factors and physical/infrastructure factors.

Section 3: Questions regarding decision-making related to coastal hazards including questions regarding the relative importance of different coastal hazards to LGA planning, the effectiveness of existing polices for addressing these hazards, the role of different elements of the governance network in risk management and key triggers for changes to Local Government policy.

Section 4: Questions regarding monitoring and evaluation within Local Government including the manner in which M&E influence Local Government decision-making and key constraints regarding M&E.

With the exception of questions in Sections 1 and 4, most questions within the questionnaire asked respondents to rank the importance of different decision criteria, coastal hazards and elements of the governance network to Local Government decision-making. Importance was expressed in the questionnaire as qualitative statements (e.g., ranging from "not important at all" to "critical"). In addition, questionnaire respondents had the option of providing additional comments that could include additional context regarding the response or additional factors that influence decision-making not captured in the questionnaire. All responses were consolidated into a database for analysis.

2.2 Results

A total of 120 individuals responded to the questionnaire, with 74 individuals providing complete answers to all questions. The number of respondents varied significantly among different LGAs, ranging from 1 to 17, with an average of 5 (based upon those individuals who reported an LGA affiliation). Almost 90% of survey respondents reported working in the environment, planning, or infrastructure departments of councils (Figure 2).

Ninety-eight percent of respondents considered themselves "very" or "somewhat" knowledgeable regarding the risks of climate change to their LGA. A slightly lower percentage (92%) of respondents considered themselves "very" or "somewhat" knowledgeable regarding the role of adaptation in reducing risk. Participants therefore were likely more informed about climate change than the general public. Hence, the results must be interpreted in the narrow context of Local Government staff, and results would likely vary significantly if another group was surveyed.

With respect to the importance of different values in influencing decision-making, questionnaire respondents indicated that staff in Local Government generally seek to balance a plurality of values. No one value dimension appeared to have substantially greater or lesser importance than others. The environment dimensions tended to have slightly greater importance than other dimensions, which is likely a reflection of the strong representation of questionnaire respondents from environment departments of Local Government. Nevertheless, responses did vary significantly among individual survey respondents. For each dimension, respondents spanned almost the full range of potential importance rankings, from "critical" to "not important at all", although the most frequent response for each value dimensions was "high importance" (Figure 3).

Despite this fairly equitable perspective on what are often viewed as competing values, respondents also indicated that current efforts to manage the coast were only partially effective. It was unclear from the questionnaire whether the perceived need to balance such values was interfering with generating optimal policy outcomes or if some other factors were interfering in the effective realization of multi-objective decision-making. This issue was therefore raised as a discussion topic at subsequent workshops during February of 2012 (see 3.1.1), in which workshop participants were queried with respect to the potential source of this apparent disparity. Local Government staff who participated in these discussions generally noted the distinction between the planning and decision-making processes of staff in Local Government versus decision-making process at the political level, as in executive decisions made by elected Councilors and/or decisions made at the state government level that local government must subsequently implement. The former have a responsibility to attempt to balance different values. However, decisions made at the Councilor level sometimes favour some values over others. Therefore, the values expressed in the survey are useful for benchmarking the opinions of Local Government staff, but are not necessarily representative of how decisions will be made regarding specific policies.

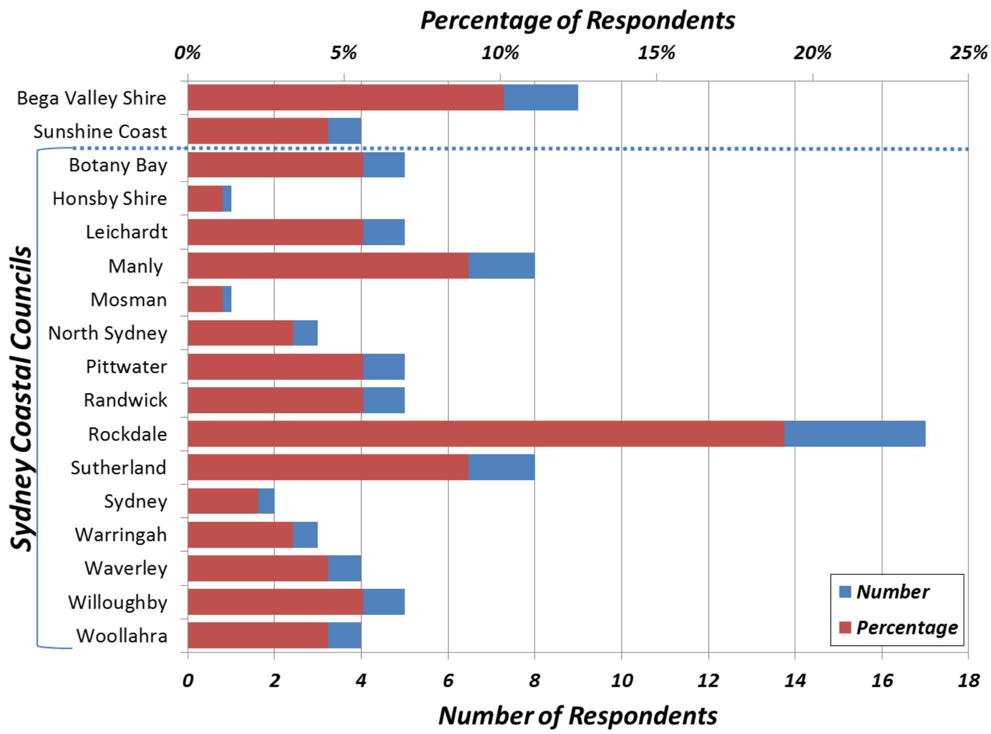


Figure 2. Distribution of questionnaire respondents among the 17 Local Government Areas associated with the three case study regions considered in the current study.

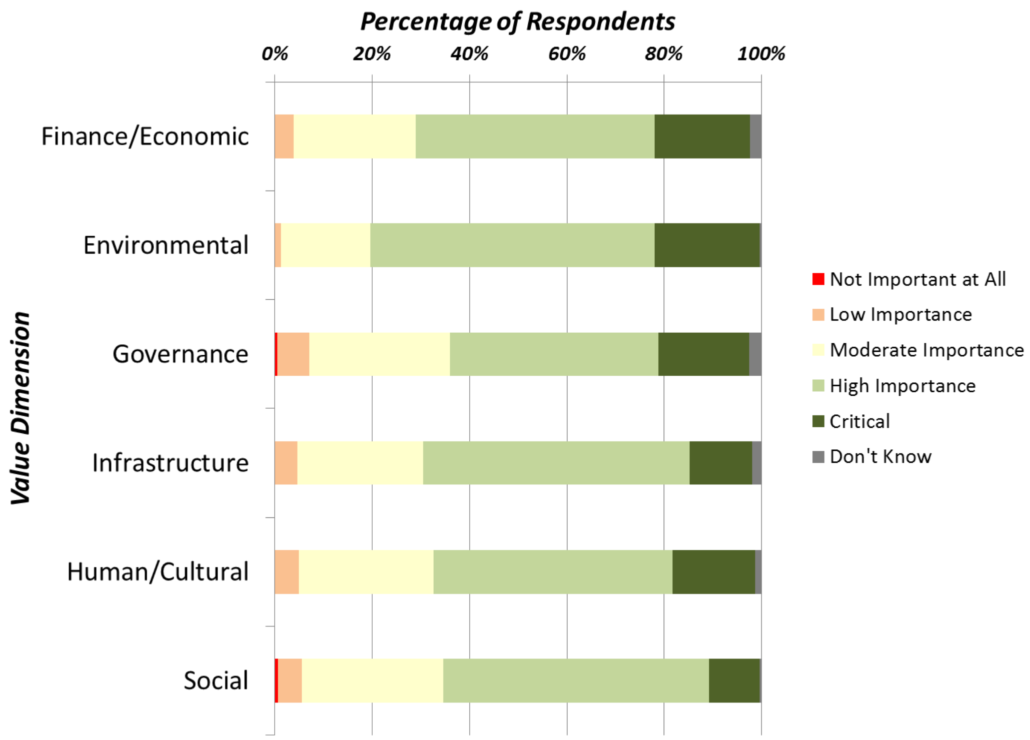


Figure 3. Relative importance of different value dimensions to Local Government decision-making as reflected by questionnaire respondents.

As noted above, in addition to exploring values that influence decision-making in Local Government generally, the questionnaire also focused attention on coastal hazards specifically and decision-making processes around their management. When asked about the relative importance of different types of coastal hazards recognised within the New South Wales State Government *Coastal Protection Act 1979*, questionnaire respondents clearly ranked beach erosion, shoreline recession and inundation as having greater overall relevance to Local Government than others (Figure 4). However, respondents also clearly recognised the potential challenges posed by the interactions among different types of hazards.

When asked specifically about the risks associated with sea-level rise, responses reflected mixed opinions regarding the importance of sea-level rise over the near-term (over the next 1 to 10 years). Only 25% of respondents considered sea-level rise to be of “high” or “critical” to Local Government. However, the importance of sea-level rise increases markedly when respondents were asked to consider longer time horizons, with approximately 75% of respondents ranking sea-level rise as having high” or “critical” with a time horizon of 25 years or more. Respondents also considered uncertainty about sea-level rise to be an important challenge to coastal management. In contrast, uncertainty regarding future socioeconomic trends was considered to be of significantly lower importance, perhaps because such trends were not seen as a responsibility of Local Government. Yet, increasing population and assets in locations at risk due to development are a fundamental challenge in many parts of coastal Australia.

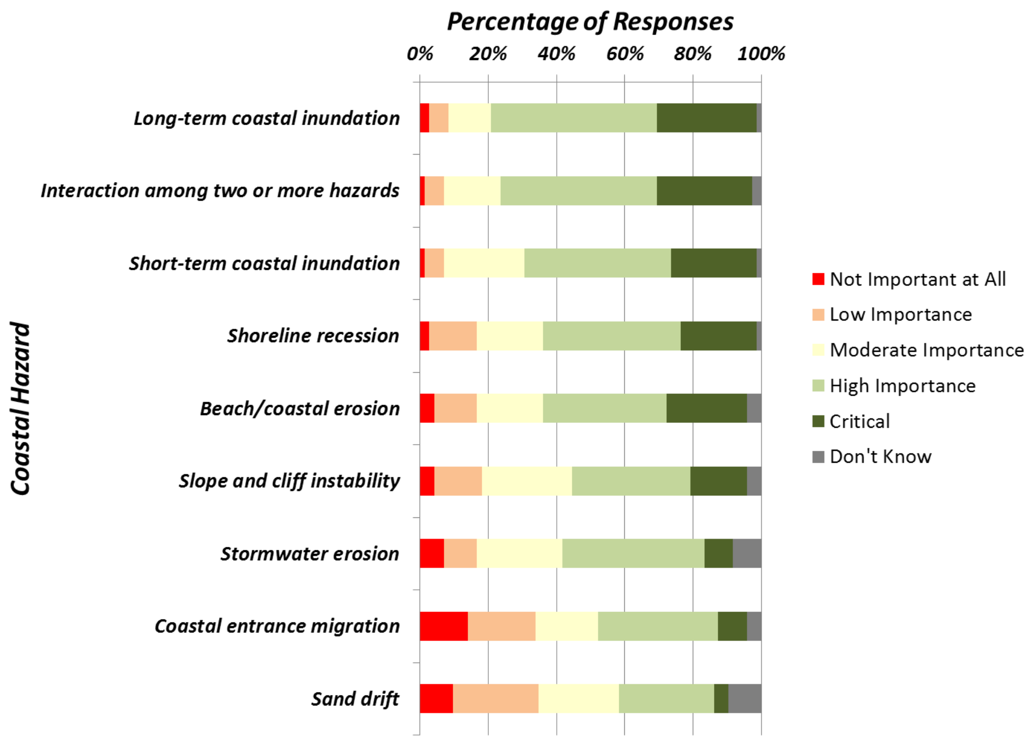


Figure 4. Relative importance of different types of coastal hazards to Local Government coastal adaptation and risk management policies and measures.

In addition to considering the relative importance of different hazards, respondents were also asked to rank the importance of different triggers for changes in existing policies for coastal management. Among these, the strong influence of State Government was readily apparent, as changes in State Government policies and/or legislation were given the highest importance as a trigger for policy changes within Local Government. This was followed by acquisition of information about coastal hazards and/or associated risk as well as concerns about legal liability for Local Government arising from the changing nature of coastal hazards. This suggests that knowledge and information (and the legal implications of that knowledge) are important drivers of the policy process for coastal management. Surprisingly, changes in elected representatives of Local Government (i.e., Councilors) received the lowest overall importance of the triggers considered in the questionnaire. Whether or not this is an accurate reflection of the role of elected officials is arguable. Councilors, for example, do have significant influence on key decisions within Local Government and also influence the overall policy agenda (Figure 5).

When asked about which individuals and/or organizations have the greatest bearing on Local Government decision-making, questionnaire respondents ranked council staff, Councillors and State Government agencies as among the most influential. Following this cluster, Federal Government agencies and regional bodies had secondary influence. Among the least relevant organizations were private businesses and non-governmental organizations. Nevertheless, rankings for various organizations varied significantly among individual respondents (Figure 6).

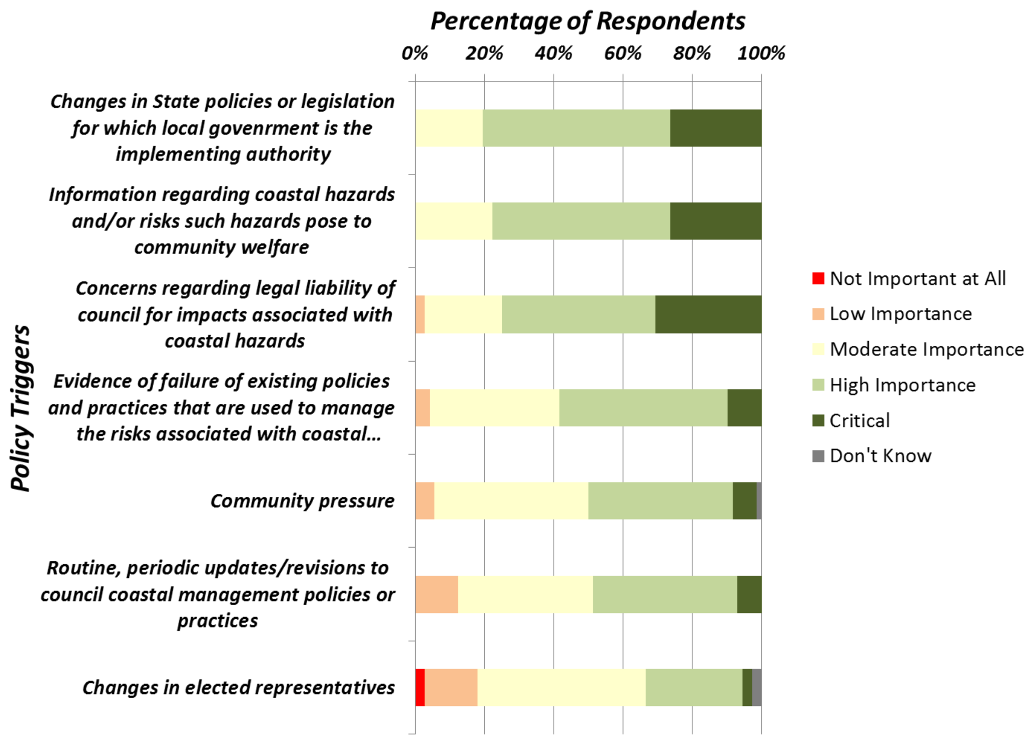


Figure 5. Relative importance of different triggers of decision-making and/or policy reform within Local Government with respect to coastal management and adaptation.

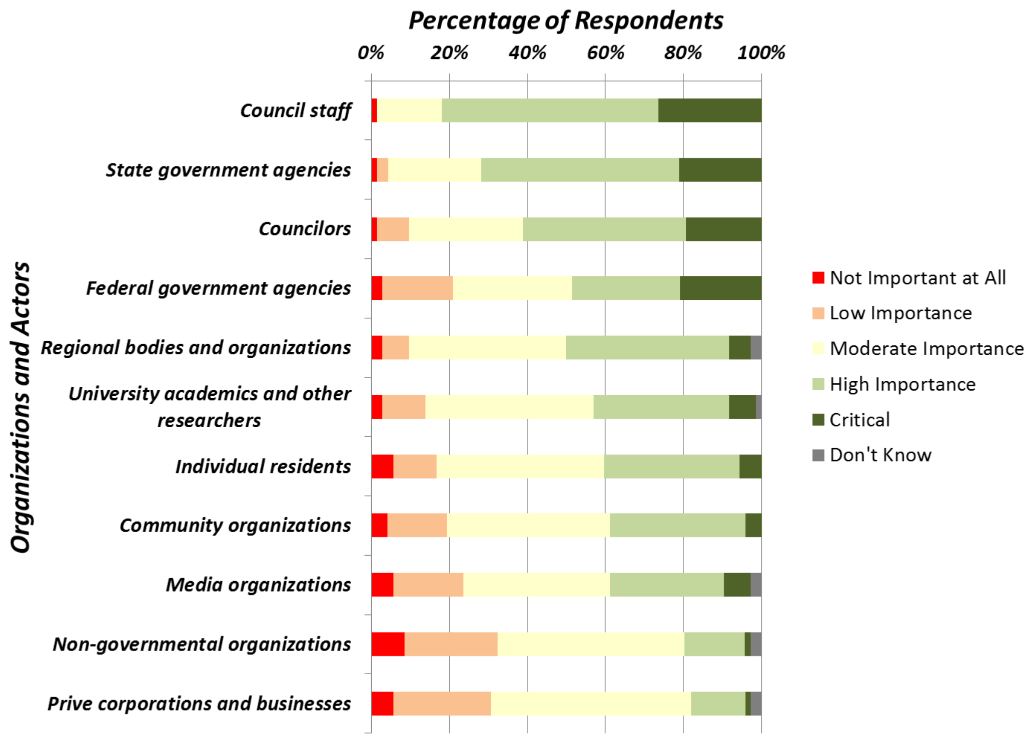


Figure 6. Relative importance of different actors and organizations to Local Government decision-making on coastal management and adaptation.

A range of decision-support tools were identified by respondents as being important to Local Government planning and policy development. Of these, scientific/technical analyses and application of a risk management paradigm in decision-making were considered particularly useful. Similarly, economic/financial analysis tools such as cost/benefit analysis were also identified as having a high degree of importance in decision-making. This highlights the importance of having a strong evidence base to support Local Government decision-making. Nevertheless, respondents also indicated that other tools such as adaptive management, use of best practice, public consultation and monitoring and evaluation (to name a few) were also considered important (Figure 7Figure 7). That said, it's unclear how many of these different tools are actively in use among Local Governments participating in this study.

Certain aspects of the questionnaire results are important for subsequent applications of MCA analysis techniques. First, the results highlight the potential utility of using MCA approaches for guiding adaptation decision-making. Given financial/economic values were generally not considered to be of greater or lesser importance than other values, methods that can represent such diversity in values within a decision-making process could be argued to be more relevant than those which focus exclusively on economic criteria. Second, the data collected from the questionnaire regarding the importance of different values provide a mechanism for weighting different decision criteria within an MCA (see Section 4). Third, the results demonstrate that individuals vary with respect to the values they hold and/or how they perceive those values to influence decision-making. This ultimately reflects a degree of irreducible uncertainty with respect to what values should be considered in decision-making processes and who is entitled to make that judgment. Hence, in attempting to reflect multiple values within an MCA, methods should be employed that enable that uncertainty to be captured.

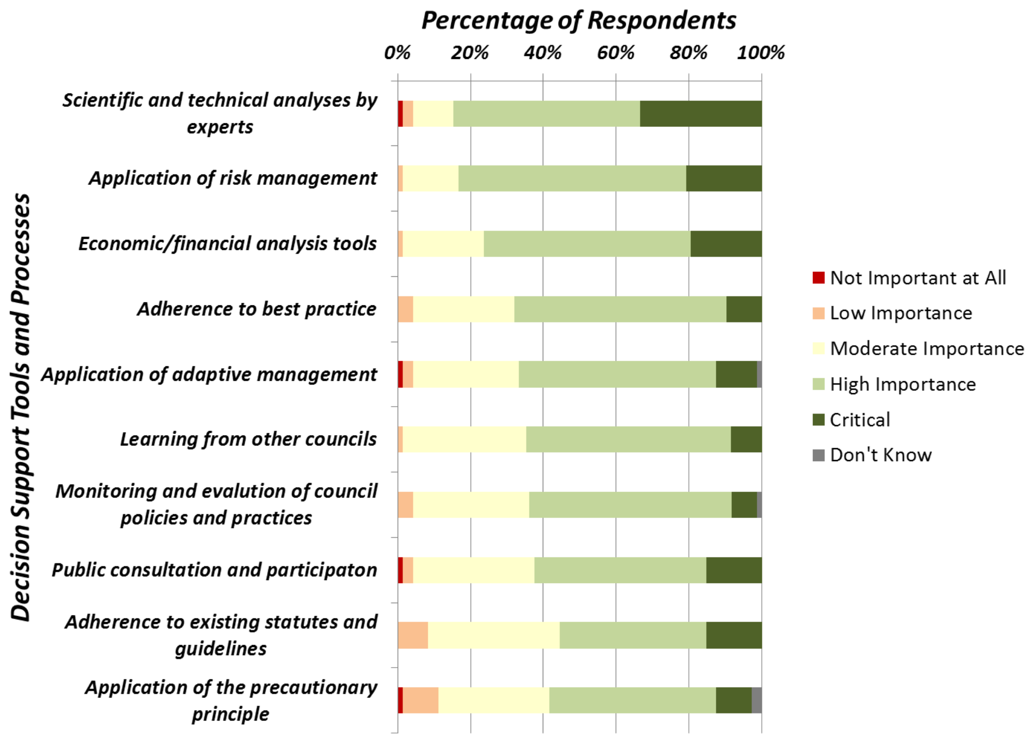


Figure 7. Relative importance of different decision-support tools to Local Government decision-making on coastal management and adaptation.

3 Developing a MCA Coastal Adaptation Framework - Stage I

- **A series of workshops involving local government staff from the three case study regions was used to elicit perspectives regarding the performance of different adaptation options against a range of criteria.**
- **Results indicated that staff in all three regions have reservations regarding the utility of coastal protection measures (e.g., hard infrastructure options).**
- **The performance of different options generally declined with longer time horizons due to perceptions of increasing risk, increasing costs of adaptation, and increasing uncertainty.**
- **Options that performed poorly against financial criteria also tended to perform poorly against environmental criteria.**
- **Cross-cutting, non-structural adaptation options generally performed quite well across all time horizons.**

The first stage in the development of the MCA coastal adaptation framework involved two types of analyses. The first represented an initial stakeholder evaluation of the performance of different coastal adaptation options against a series of criteria representing four different dimensions of decision-making (governance, financial, social and environmental). This evaluation was performed in a workshop setting with individual participants evaluating different adaptation options against the criteria associated with one of the aforementioned dimensions. This evaluation was then used in an initial performance assessment for each adaptation option. The second analysis involved taking the evaluations carried out during the workshop and incorporating responses into a Bayesian Belief Network (BBN) (see Section 3.1.2 for more details) along with weights for each of the criteria. The BBN was used to assess the utility of different adaptation options given performance evaluations and weights while also incorporating the variance in individual responses. Methods for undertaking each of these analyses and their subsequent results are presented below.

3.1 Methods

3.1.1 Analysis 1: Initial Performance Assessments

Participatory evaluations of different coastal adaptation options were undertaken in three workshops conducted between 28 February, 2012 and March 1, 2012. Three separate workshops of approximately four hours in length were carried out in each of the three case study regions. Each workshop included between 11 and 14 participants from Local Government. Additional observers were presents at some workshops (e.g., from State Government or universities), but their evaluations were not reflected in the results presented here. Although workshops were largely devoted to evaluating the utility of coastal adaptation options, the workshops also provided an opportunity to discuss a number of other topics:

- *Project progress to date and future steps.* Participants were reminded of the project goals, tasks and how information obtained in the workshops would be used.
- *Results from the values questionnaire, particularly regarding the apparent disparity between stated values and policy outcomes.* Participants in each case study region noted that the

balancing of multiple values in decision-making was largely an aspirational target. In practice, trade-offs often occurred for political reasons and mandates from State Government policy were at times inconsistent with Local Government values.

- *Potential opportunities for developing guidance for the monitoring and evaluation of adaptation within Local Government.* Current M&E activities were discussed with workshop participants as well as what approaches to M&E would be most useful for Local Government. Participants generally indicated that M&E requirements are limited at present, but future M&E for adaptation should seek to be simple and integrated within existing management systems of Local Government.

For the evaluation of adaptation options, workshop participants were divided into four groups reflecting different value dimensions for decision-making: governance, finance, social and environmental.[4] Each group examined adaptation options within the narrow context of that dimension. For each dimension, participants were provided with four different criteria, which were informed by the responses obtained from the questionnaire on Local Government values (Table 2). Criteria were comprised of normative statements. For example, one of the financial criteria was stated as follows:

> *"Criteria F1: This adaptation option is effective at protecting coastal properties and/or critical infrastructure from financial damage caused by coastal hazards"*

The veracity of this statement is dependent upon the adaptation option under consideration and the subjective judgment of the evaluator. A total of 15 different adaptation options were evaluated (Table 2). These included examples from the traditional typology of protect, accommodate, and retreat measures that are often the basis for discussions around coastal adaptation (IPCC, 1990). Specific adaptation measures within each category were identified from a review of coastal adaptation planning that was also undertaken as part of this project (Mangoyana et al., 2012). In addition, three different 'cross-cutting' adaptation measures were considered, which represented actions that are often identified within adaptation planning efforts of Australian Local Governments, but which don't necessarily lead to the direct reduction of vulnerability (Preston et al., 2011). Participants were also asked to consider the performance of each adaptation option over three different time horizons: 'near-term' (1 to 10 years); 'medium-term' (10 to 25 years); and 'long-term' (25+ years). While a time horizon of 25 years is rarely considered 'long-term' in the context of climate change science, few planning processes in either Local or State government extend beyond this horizon.

For each adaptation option, participants were asked to evaluate the extent to which they considered the option to be consistent with the stated criteria for the given time horizon. Potential responses could range from "strongly agree" to "strongly disagree" (Table 4). These normative responses were then converted into quantitative scores ranging from +2 to -2. To assess coastal adaptation option performance, the raw scores of options reported by individual workshop participants were pooled and a weighted average was used to summarise the range of responses (see Appendix II for more details). These data could also be stratified to examine the performance of different adaptation options by each criterion, governance dimension, case study region, or time horizon.

[4] These dimensions roughly correspond with the principle of the 'triple bottom line' approach to corporate decision-making, but the addition of governance recognises that decision-making in Local Government doesn't occur in a vacuum.

Table 2. Criteria used in the evaluation of the performance of different coastal adaptation options.

Governance	
Criterion G1	This adaptation option is consistent with, and could be readily implemented under, existing local and state planning policy
Criterion G2	This adaptation option could be independently implemented by council without involving other levels of government or external organizations
Criterion G3	This adaptation option is an effective strategy for limiting council liability for losses associated with coastal hazards and sea-level rise
Criterion G4	Implementing this adaptation option would not infringe upon existing rights of property owners
Financial	
Criterion F1	This adaptation option is effective at protecting coastal properties and/or critical infrastructure from financial damage caused by coastal hazards
Criterion F2	Implementing this adaptation option would not impose a significant financial burden on council
Criterion F3	Implementing this adaptation option would not impose a significant financial burden on individual property owners or businesses affected by the adaptation option
Criterion F4	Implementation of this adaptation strategy would keep the door open for the pursuit of alternative adaptation options in the future (i.e., preservation of 'real options')
Social	
Criterion S1	This adaptation option is effective at protecting socially or culturally significant locations from damage caused by coastal hazards
Criterion S2	This adaptation option is effective at protecting public health and safety from coastal hazards
Criterion S3	This adaptation option could be implemented without reinforcing or enhancing social inequities within the community (e.g., unequal distribution of costs and/or benefits)
Criterion S4	Implementation of this adaptation option would be readily accepted by the community and/or individual property owners
Environmental	
Criterion E1	This adaptation option is effective at enabling ecological assets (e.g., native vegetation and wetlands) to cope naturally with coastal erosion and inundation
Criterion E2	Implementing this adaptation option would enhance the natural amenity and/or ecological value of a given location or community
Criterion E3	Implementing this adaptation option at one location would not contribute to adverse ecological outcomes at other locations
Criterion E4	Implementing this adaptation option would provide existing and/or future development with a natural buffer from coastal processes and hazards

Table 3. Coastal adaptation options evaluated during stakeholder workshops.

Protection	Retreat
1) Shoreline stabilization 2) Beach nourishment	9) Acquisition of at-risk properties 10) Increase setbacks on at-risk properties
3) Groynes or artificial headlands	11) Block development on at-risk properties
4) Sea walls or revetments	12) Implement rolling easements
Accommodation	**Cross-Cutting Options**
5) Elevation of structures	13) Community education about risk
6) Removable structures in at-risk areas	14) Assessments of vulnerability and risk
7) Risk spreading mechanisms	15) Integrated coastal zone management
8) Water proofing of at-risk properties	

Table 4. Scoring metrics used in the evaluation of adaptation options.

Response	Score	Interpretation
Strongly Agree	+2	Highly favourable
Agree	+1	Moderately favourable
Neither Agree Nor Disagree	0	Neutral
Disagree	-1	Moderately unfavourable
Strongly Disagree	-2	Highly unfavourable

3.1.2 Analysis 2: Bayesian Evaluation

For each adaptation option, participants were asked to evaluate the extent to which they considered the option to be consistent with the stated criteria for the given time horizon. Potential responses could range from “strongly agree” to “strongly disagree” (Table 4). These normative responses were then converted into quantitative scores ranging from +2 to -2. To assess coastal adaptation option performance, the raw scores of options reported by individual workshop participants were pooled and a weighted average was used to summarise the range of responses (see Appendix II for more details). These data could also be stratified to examine the performance of different adaptation options by each criterion, governance dimension, case study region, or time horizon.

The initial performance assessment generated from the data collected during the workshops explored the extent to which individual adaptation options are consistent with different decision criteria. In so doing, however, it aggregated individual responses into an overall score, without providing information on the uncertainty associated with the responses of individual workshop participants. Hence, one cannot determine whether the evaluation is a consensus view among all participants, or simply an aggregated score that masks significant variation in performance scores among workshop participants. Furthermore, the performance assessment treats each criterion as having equal weight, despite evidence from the questionnaire that there are subtle differences in the importance attached to different values in Local Government decision-making by different individuals and case study regions.

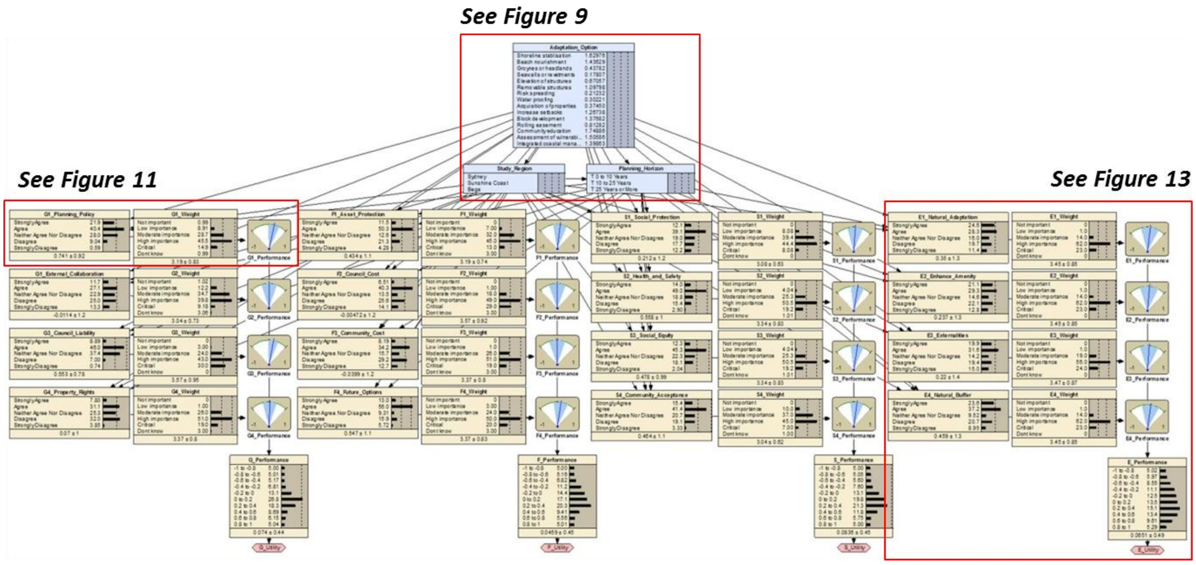


Figure 8. The Bayesian Belief Network (BBN) used in the evaluation of coastal adaptation options. The three blue nodes at the top of the figure represent the different the independent decision variables in the analysis (adaptation option, region and time-scale). The remaining nodes represent decision criteria, associated weights and summary metrics for MCA dimensions. The elements of the network enclosed in red boxes are discussed further in Figures 9–13.

In order to capture these complexities of differential criteria weights and variance in opinions among individuals, a second MCA analysis was conducted that extended the original analysis through the use of Bayesian Belief Networks (BBNs). Like MCA, BBNs have also seen significant use within Australia and elsewhere to guide natural resource management decisions as well as land suitability analyses (McCann et al., 2006; Nyberg et al., 2006; Ticehurst et al., 2006; Pollino et al., 2007; Johnson et al., 2011). The use of a BBN was based upon the benefits BBNs offer in terms of building a flexible analysis tool from the bottom-up (e.g., Watthayu and Peng, 2004). A Bayesian network can be tailored to meet the specific needs of the analysis, particularly with respect to incorporating aspatial and a spatial information, as opposed to ‘off the shelf’ MCA or spatial optimization software that is more structured and therefore requires analyses to be tailored to suit the software.

A BBN was developed for MCA of coastal adaptation options using the software Netica (v. 4.16). The BBN was constructed to represent the flow of information in the analysis among independent and dependent variables, each represented by a node in the network. The foundation for the BBN was three ‘decision’ nodes that represented the three independent variables upon which information could be stratified: adaptation options, study region and time horizon (Figure 9). The sixteen evaluation criteria associated with the four value dimensions (i.e.,

Table 2) were represented as 'nature' nodes in the network, and responses from the workshops regarding the performance of adaptation options against each criterion were entered into each of these criteria nodes. Again, information input into each criterion node was stratified by study region and time horizon, with the nodes including conditional probability tables (CPT) that are used to define the likelihood of different performance outcomes for each permutation of adaptation option, case study region and time horizon (Figure 10). Rather than being combined into an aggregate score, the criterion nodes maintained all of the individual responses of workshop participants, which were expressed in Netica as a probability distributions. Hence, an inspection of each criterion node allows one to easily visualise the range of responses among workshop participants with respect to performance of adaptation options against that criterion. For example, assessments of the performance of an adaptation option such as "seawalls and revetments" against the F1 criterion varied among different study regions (and even among different participants in the same region) and time scale. The BBN can be used to organize this information and rapidly update the evaluation of adaptation options by changing the selections in the decision nodes.

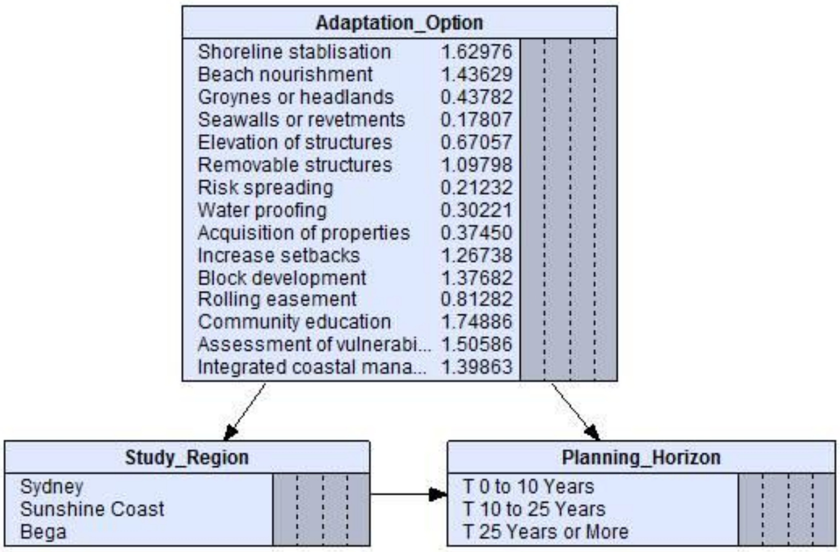
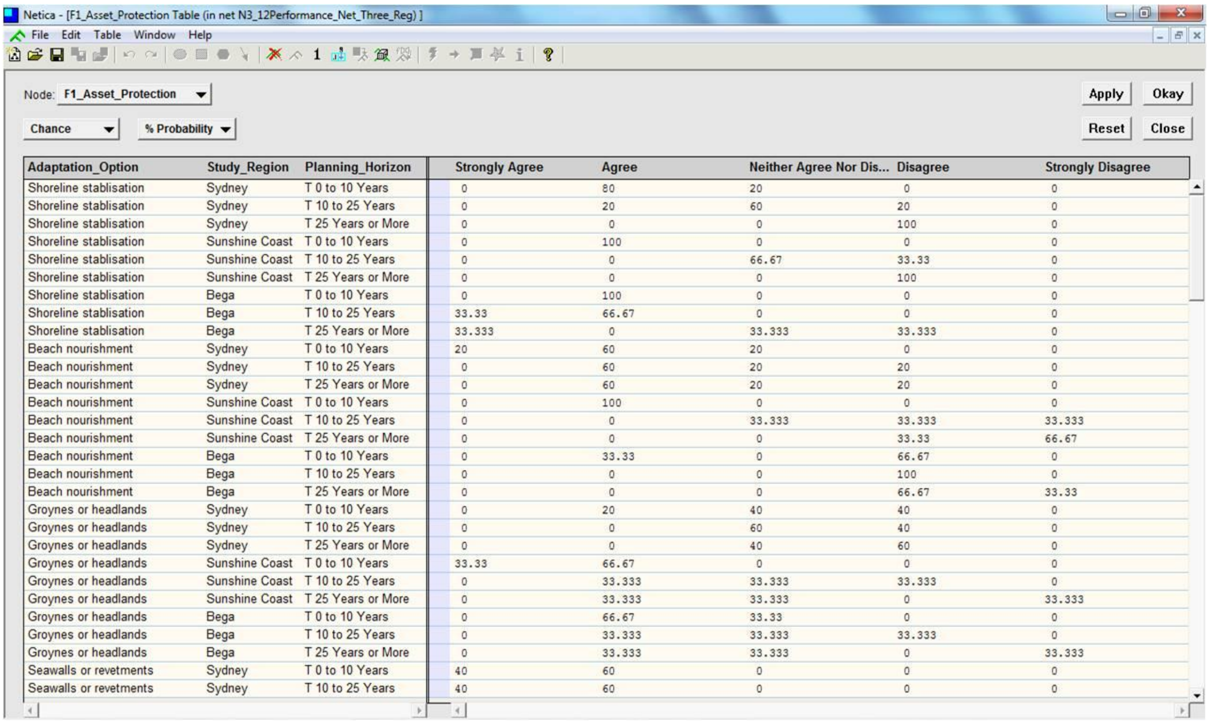


Figure 9. Illustration of the three principle decision nodes used in the Stage I Bayesian model. The node at the top represents the key decision node which represents the various adaptation options considered in the model. Each of these is associated with a quantitative utility score, which represents the aggregate utility across all study regions and time horizons. The other two nodes at the bottom represent the different study regions and time horizons used in the model. The arrows reflect the interdependence of these nodes, such that the utility of a given adaptation option is a function of the study region and time horizon under consideration.

For each criterion node in the BBN (there is also a node representing an assigned weight (Figure 11). Weights were derived from the questionnaire of Local Government values (Section 2). As the questionnaire effectively asked respondents to state the importance or value of different factors to Local Government decision-making, participant responses could be interpreted as value statements that can be used to weight different criteria. The importance assigned to individual value statements by questionnaire respondents were mapped to the relevant MCA criteria (see Appendix II). For example, one of the questions on the questionnaire regarding how important it is that Local Government policies or practice "*preserve or Improve health and safety*" were mapped to the S1 criterion in the MCA: "*This adaptation option is effective at protecting public health and safety from coastal hazards.*" In those instances where one or more questionnaire responses appeared relevant to a particular MCA criterion, responses were pooled to develop the weight. To incorporate criteria weights into the MCA, the qualitative responses from the questionnaire were converted to a quantitative scale, ranging from 1 to 5 (Table 5). Questionnaire responses of 'Don't know' were assigned a value of 3, equivalent a result of 'moderate importance'. Otherwise, weight nodes were treated similar to performance nodes, with weight values input into the node as a probability distribution.



Adaptation_Option	Study_Region	Planning_Horizon	Strongly Agree	Agree	Neither Agree Nor Dis...	Disagree	Strongly Disagree
Shoreline stablisation	Sydney	T 0 to 10 Years	0	80	20	0	0
Shoreline stablisation	Sydney	T 10 to 25 Years	0	20	60	20	0
Shoreline stablisation	Sydney	T 25 Years or More	0	0	0	100	0
Shoreline stablisation	Sunshine Coast	T 0 to 10 Years	0	100	0	0	0
Shoreline stablisation	Sunshine Coast	T 10 to 25 Years	0	0	66.67	33.33	0
Shoreline stablisation	Sunshine Coast	T 25 Years or More	0	0	0	100	0
Shoreline stablisation	Bega	T 0 to 10 Years	0	100	0	0	0
Shoreline stablisation	Bega	T 10 to 25 Years	33.33	66.67	0	0	0
Shoreline stablisation	Bega	T 25 Years or More	33.333	0	33.333	33.333	0
Beach nourishment	Sydney	T 0 to 10 Years	20	60	20	0	0
Beach nourishment	Sydney	T 10 to 25 Years	0	60	20	20	0
Beach nourishment	Sydney	T 25 Years or More	0	60	20	20	0
Beach nourishment	Sunshine Coast	T 0 to 10 Years	0	100	0	0	0
Beach nourishment	Sunshine Coast	T 10 to 25 Years	0	0	33.333	33.333	33.333
Beach nourishment	Sunshine Coast	T 25 Years or More	0	0	0	33.33	66.67
Beach nourishment	Bega	T 0 to 10 Years	0	33.33	0	66.67	0
Beach nourishment	Bega	T 10 to 25 Years	0	0	0	100	0
Beach nourishment	Bega	T 25 Years or More	0	0	0	66.67	33.33
Groynes or headlands	Sydney	T 0 to 10 Years	0	20	40	40	0
Groynes or headlands	Sydney	T 10 to 25 Years	0	0	60	40	0
Groynes or headlands	Sydney	T 25 Years or More	0	0	40	60	0
Groynes or headlands	Sunshine Coast	T 0 to 10 Years	33.33	66.67	0	0	0
Groynes or headlands	Sunshine Coast	T 10 to 25 Years	0	33.333	33.333	33.333	0
Groynes or headlands	Sunshine Coast	T 25 Years or More	0	33.333	33.333	0	33.333
Groynes or headlands	Bega	T 0 to 10 Years	0	66.67	33.33	0	0
Groynes or headlands	Bega	T 10 to 25 Years	0	33.333	33.333	33.333	0
Groynes or headlands	Bega	T 25 Years or More	0	33.333	33.333	0	33.333
Seawalls or revetments	Sydney	T 0 to 10 Years	40	60	0	0	0
Seawalls or revetments	Sydney	T 10 to 25 Years	40	60	0	0	0

Figure 10. Example of a conditional probability table (CPT) within the Stage I Bayesian MCA model. The table represents the CPT for the F1 criterion within the MCA. The left hand side lists all of the possible permutations of states of the various decision nodes (Adaptation Options, Study Region and Planning Horizon). The right hand size lists the likelihood of performance outcomes for each permutation of decision node states.

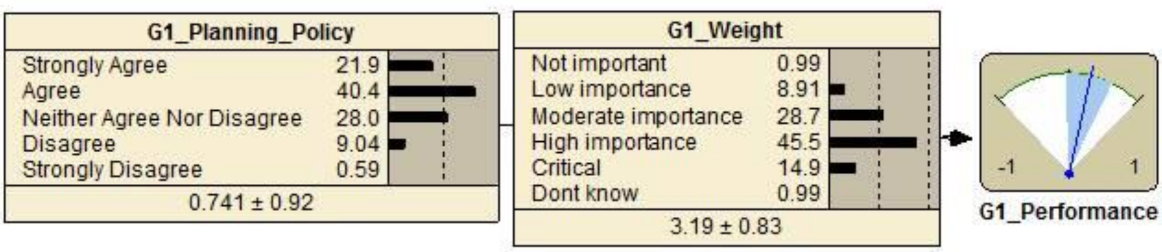


Figure 11. Illustration of a criterion node, weight and net performance score for the G1 criterion. The criteria node on the far left (G1_Planning_Policy) contain information regarding how each adaptation option performs against this criterion. The belief bars in the node reflects the distribution of beliefs regarding performance across all of the adaptation options, study regions and time horizons. The criterion node has a weight node associated with it (G1_Weight), which contains information from the survey regarding the importance of the values represented by a given criterion are to Local Government decision-making . These are aggregated into a weighted performance score (G1_Performance), ranging from -1 to +1.

Differences among case study regions were evident in some of the weights (Figure 12). This seemed largely due to differences in sample sizes with respect to the number of questionnaire respondents within each region. As a consequence, the distributions for weights were, at times, more truncated that one would expect given opportunities for greater participation. For example, Sunshine Coast Regional Council only had complete responses to the questionnaire from two individuals, which were likely too few individuals to acquire a robust representation of council values and, subsequently, criteria weights. Nevertheless, for most weights, the shapes of distributions were roughly similar among the regions.

Performance nodes and weight nodes for each criterion were integrated by multiplying each criterion node by the corresponding weight and dividing by 3 (the midpoint of the range of possible weight values). This approach caused the performance scores to be shifted upward if the weight indicated a criterion was particularly important or down if the criterion was particularly unimportant. The resulting distribution was normalised to a scale from 0 to 1 and divided into five categories based upon quintiles. This distribution represents the perceived utility of a given adaptation option based upon each criterion and its corresponding weight (with 0 representing low utility and 1 representing high utility). The utilities of individual criteria within a dimension were aggregated by simply averaging across the four criteria in each dimension, with results again being normalised to a scale of 0 to 1 (Figure 13). This provided a single node which could be used to evaluate net performance for a specific dimension. In addition, a utility node was inserted in the network with node values also based upon the normalised sum of criteria utility scores. Netica then integrated results across these four utility nodes by maximising the expected value (i.e., the average value that will occur, where the average is weighted by the probability of occurrence) while searching for the best decision rule for each of the decision nodes (i.e., region and time horizon). Hence, for any given combination of region and time horizon, Netica generates utility scores for each adaptation option based upon the distributions for criteria performance and associated weights.

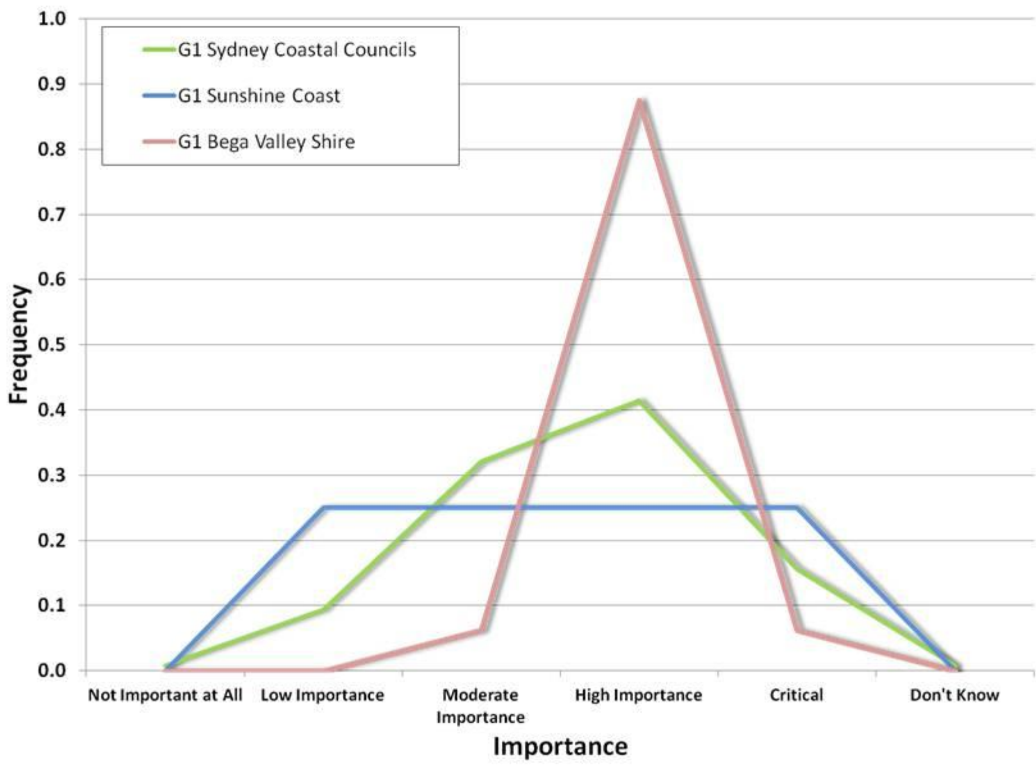


Figure 12. Comparison of calculated weights on the G1 criterion among the three case study regions. Note that the distribution for Bega Valley Shire is substantially narrower than for the other two regions.

Table 5. Scoring metrics used in the evaluation of criteria weights options.

Questionnaire Response	Score
Not important at all	1
Low importance	2
Moderate importance	3
High importance	4
Critical	5
Don't know	3

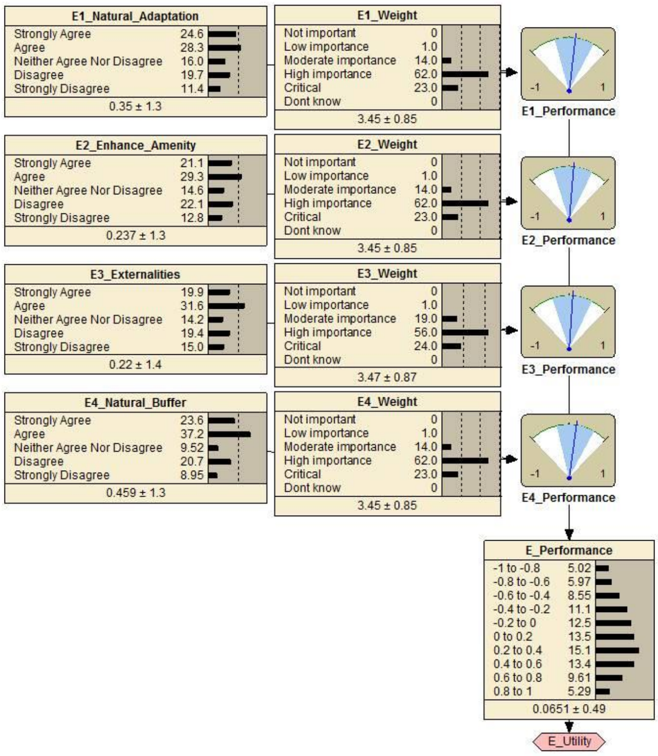


Figure 13. Illustration of the various environmental criteria and weights contributing to the environmental dimension of the MCA. The dimension is comprised of four criteria nodes (E1, E2, E3, and E4) and their associated weights. Their integration results in a performance score for each criterion. These are then averaged to yield an overall dimension performance distribution which is used to calculate utility for each adaptation option, study region and time horizon.

Using the BBN in Netica, it was therefore possible to undertake a range of analyses of adaptation options including the following:

- Generation of a quantitative metric of the relative performance of different adaptation options based upon individual criteria and/or value dimensions
- Calculation of overall utility of individual adaptation options based upon underlying uncertainty in option performance against specified criteria and their associated weights
- Stratification of adaptation options utilities based upon case study region and time horizon
- Testing of the sensitivity of utility scores to underlying performance scores for individual criteria and/or weights.

3.2 Results

3.2.1 Analysis 1: Initial Performance Assessments

The results from the initial performance assessment of adaptation options based solely upon information emerging from the workshops can be summarised as 'performance matrices' (Tables 6-8), which represent the performance of each adaptation option against each of the 16 decision criteria. Matrices were colour-coded to enhance the visualisation of the criteria (or dimensions) against which a given adaptation option performs well versus those against which it performs poorly. Table 6 demonstrates that soft protection options such as shoreline stabilization and cross-cutting measures such as community education and vulnerability assessment generally perform well across all of the criteria. In contrast, hard protection options as well as a number of the accommodate measures tended to perform poorly against financial and/or environmental criteria.

By generating a correlation matrix for the performance matrices (Table 9), it was possible to quickly compare and contrast criteria with respect to how they influence assessments of the performance of different adaptation options. For example, performance scores for social and environmental criteria tended to be highly correlated. The one exception was the S1 criteria (*This adaptation option is effective at protecting socially or culturally significant locations from damage caused by coastal hazards*), which was not correlated with environmental criteria and was even poorly correlated with other social criteria. Performance against the G2 criterion was poorly correlated with performance against most of the other criteria, and performance against the G4 criterion was inversely correlated with results for other criteria. This suggests that these criteria were particularly important for discriminating among different adaptation options with respect to performance.

Comparing results over the near-term (Table 6) versus the long-term (

Table 8) reveals that the performance of many adaptation options declines over time. This is a function of stakeholder perceptions of the costs of certain measures increasing over time; stakeholder perceptions of the effectiveness of certain options declining over time; and/or increasing uncertainty about the future that challenges attempts to evaluate utility. The exceptions to this phenomenon were the 'cross-cutting' options which tended to be viewed as equally valuable across most of the criteria even over different time horizons. Ultimately, this is indicative of the fundamental difficulties of making confident judgments about the effectiveness of different management options in the distant future. Even if societal values were to remain constant, understanding of what a 'good' management decision is may change over time. For example, any number of past decisions regarding coastal management have generated unintended consequences, despite those decisions appearing rational and beneficial at the time.

The performance scores for individual adaptation options across the different criteria were aggregated to an overall performance score (Figure 14). This provides a general assessment of the performance of different adaptation options across all of the value dimensions considered in the workshop. These results further illustrate the perceived strength of cross-cutting adaptation options. The results also reemphasise the general loss of performance that occurs over time with different adaptation options. This phenomenon is explored further in Figure 15, which plots the change in the utility scores of different adaptation options between the near-term and long-term time horizons. Greater declines in utility are associated with shoreline stabilization and beach nourishment. Additional context for these responses was provided by discussions with workshop participants. For shoreline stabilization, this decline is attributed to the perception that this option will not be successful in satisfying criteria with higher levels of sea-level rise projected to occur in future decades. For beach nourishment, the decline is attributed to the growing financial obligations required by using beach nourishment as a means of maintaining beaches given a changing climate and sea-level rise. The accommodation measures also decline in utility over time due to similar concerns about declining efficacy, their potential to incentivise risky behaviour and/or 'moral hazard'. In contrast, retreat options and the cross-cutting options tended to either remain neutral or increase slightly in utility over time, suggesting their benefits are persistent over time.

Table 6. Performance matrix for different coastal adaptation options for all 16 evaluation criteria for a 'near-term' time horizon. Results are based upon the weighted average of performance scores for all case study regions. Positive values (in shades of green) represent a favourable assessment of performance. Negative values (in shades of orange) indicate an unfavourable assessment of performance.

Adaptation Option	G1	G2	G3	G4	F1	F2	F3	F4	S1	S2	S3	S4	E1	E2	E3	E4
Shoreline stabilization	1.6	-0.1	0.9	0.5	0.9	0.7	0.6	1.4	1.6	1.1	0.9	1.3	1.3	1.4	1.2	1.2
Beach nourishment	1.5	-0.7	1.1	1.0	0.6	-0.7	-0.5	-0.1	1.0	0.8	0.7	1.0	0.6	0.3	-0.5	0.2
Groynes or artificial headlands	1.3	-1.5	0.8	0.5	0.5	-1.0	-0.3	-0.5	1.0	0.4	0.5	0.5	-0.1	-0.8	-1.2	-0.6
Sea walls or revetments	1.4	-1.0	0.9	-0.1	1.3	-1.1	-0.5	-1.0	0.7	0.8	0.1	0.4	-0.4	-1.1	-0.8	-0.6
Elevation of structures	1.1	0.7	0.9	-0.4	0.9	-0.9	-0.6	0.0	0.4	0.3	0.0	0.2	0.2	-0.3	0.6	0.3
Removable structures in at-risk areas	1.0	0.6	1.0	-0.3	0.5	0.6	0.1	1.0	0.9	0.3	0.8	0.7	0.2	0.4	0.1	0.4
Risk spreading mechanisms	-0.2	-0.5	0.5	0.2	0.7	-0.4	-0.5	0.3	0.0	-0.3	0.4	0.1	-0.8	-1.0	-0.1	-0.6
Water proofing of at-risk properties	1.1	0.9	0.7	0.7	0.5	-0.5	-0.5	0.2	-0.1	0.1	-0.2	-0.1	-0.6	-0.4	0.1	-0.2
Acquisition of at-risk properties	0.6	0.7	-0.3	-0.5	0.5	-1.8	0.0	-0.5	-0.1	0.8	-0.5	-0.1	0.6	0.3	0.5	0.7
Increase setbacks on at-risk properties	0.4	-0.3	0.7	-0.6	1.1	1.0	-0.5	1.2	0.4	1.2	0.7	0.6	1.5	1.0	0.5	1.0
Block development on at-risk properties	1.0	-0.1	0.7	-0.9	0.0	0.8	-1.4	1.2	-0.3	1.1	0.9	0.4	1.0	1.0	1.0	1.0
Implement rolling easements	-0.5	-0.8	0.3	-1.0	0.1	0.9	-0.7	0.9	-0.1	1.1	0.8	0.5	0.7	-0.1	0.5	0.3
Community education about risk	1.5	1.5	1.1	1.2	0.4	0.5	0.8	1.5	0.9	1.3	1.1	1.1	0.8	1.0	1.1	1.0
Assessments of vulnerability and risk	1.5	1.2	0.8	0.8	0.9	-0.3	0.7	1.3	0.5	0.7	1.2	0.9	1.2	1.2	1.2	1.2
Integrated coastal zone management	1.1	-0.6	0.6	0.1	0.9	-0.3	0.9	1.4	1.1	0.9	1.2	1.1	1.5	1.4	1.5	1.4

Table 7. Performance matrix for different coastal adaptation options for all 16 evaluation criteria for a 'medium-term' time horizon. Results are based upon the weighted average of performance scores for all case study regions. Positive values (in shades of green) represent a favourable assessment of performance. Negative values (in shades of orange) indicate an unfavourable assessment of performance.

Adaptation Option	G1	G2	G3	G4	F1	F2	F3	F4	S1	S2	S3	S4	E1	E2	E3	E4
Shoreline stabilization	1.2	-0.3	0.6	0.5	0.3	0.2	0.8	1.4	1.0	0.9	0.7	0.9	1.1	1.2	0.7	0.9
Beach nourishment	1.3	-0.9	0.7	0.9	-0.4	-1.0	-0.6	0.2	0.9	0.7	0.6	0.8	-0.2	-0.2	-0.7	-0.3
Groynes or artificial headlands	1.1	-1.4	0.3	0.5	-0.2	-0.5	-0.4	-0.1	0.9	0.2	0.3	0.3	-0.6	-0.9	-1.3	-0.8
Sea walls or revetments	1.2	-0.8	0.4	0.0	0.8	-1.0	-0.5	-0.6	0.5	0.8	0.0	0.3	-0.6	-1.2	-1.2	-0.8
Elevation of structures	0.8	0.6	0.6	-0.5	0.7	-0.8	-0.8	0.0	0.4	0.1	-0.2	0.1	-0.1	-0.3	0.3	0.0
Removable structures in at-risk areas	0.7	0.5	0.9	-0.5	0.5	0.9	0.5	1.0	0.9	0.2	0.6	0.6	0.1	0.4	-0.2	0.2
Risk spreading mechanisms	0.1	-0.5	0.5	0.2	0.4	-0.5	-0.7	-0.1	0.1	-0.5	0.3	0.1	-0.7	-1.0	-0.3	-0.7
Water proofing of at-risk properties	0.9	0.9	0.7	0.6	-0.5	-0.5	-0.2	-0.1	-0.8	-0.3	-0.4	-0.5	-0.9	-0.5	-0.1	-0.4
Acquisition of at-risk properties	0.5	0.6	-0.3	-0.5	0.4	-1.6	0.0	-0.2	-0.3	0.8	-0.3	0.0	0.9	0.7	0.5	0.8
Increase setbacks on at-risk properties	0.7	-0.2	0.9	-0.5	0.9	1.0	-0.1	1.3	-0.1	1.1	0.9	0.7	1.0	0.9	0.8	0.9
Block development on at-risk properties	0.8	0.2	0.7	-0.7	0.8	0.7	-0.9	1.2	-0.4	1.1	0.9	0.4	1.2	1.2	1.0	1.1
Implement rolling easements	-0.4	-0.5	0.3	-0.8	-0.3	0.9	-0.5	0.9	-0.4	1.0	0.8	0.4	0.7	0.3	0.2	0.3
Community education about risk	1.3	1.3	0.9	1.2	0.9	0.9	1.0	1.4	0.9	1.4	1.0	1.1	0.7	1.0	1.1	1.0
Assessments of vulnerability and risk	1.2	0.9	0.7	0.6	0.8	0.4	0.9	1.2	0.1	0.8	1.1	0.8	1.2	0.9	1.2	1.1
Integrated coastal zone management	1.1	-0.5	0.7	0.1	1.0	0.0	0.9	1.4	0.8	0.8	1.0	0.9	1.4	1.5	1.5	1.4

Table 8. Performance matrix for different coastal adaptation options for all 16 evaluation criteria for a 'long-term' time horizon. Results are based upon the weighted average of performance scores for all case study regions. Positive values represent a favourable assessment of performance. Positive values (in shades of green) represent a favourable assessment of performance. Negative values (in shades of orange) indicate an unfavourable assessment of performance.

Adaptation Option	G1	G2	G3	G4	F1	F2	F3	F4	S1	S2	S3	S4	E1	E2	E3	E4
Shoreline stabilization	0.8	-0.3	0.5	0.5	-0.6	-0.1	0.7	1.2	0.2	0.3	0.5	0.5	0.2	1.0	0.5	0.5
Beach nourishment	0.8	-0.9	0.5	0.9	-0.6	-1.5	-0.6	-0.3	0.4	0.1	0.6	0.5	-1.1	-0.3	-0.9	-0.7
Groynes or artificial headlands	0.5	-1.4	0.1	0.5	-0.5	-0.8	-0.2	0.3	0.2	-0.2	0.2	0.0	-0.9	-0.9	-1.4	-1.0
Sea walls or revetments	0.6	-0.7	0.3	-0.1	0.3	-0.9	-0.3	-0.5	0.3	0.3	-0.1	0.1	-0.5	-1.3	-1.2	-0.8
Elevation of structures	0.5	0.6	0.3	-0.5	0.3	-0.4	-0.5	-0.2	0.2	-0.1	-0.1	0.0	-0.5	-0.5	0.2	-0.3
Removable structures in at-risk areas	0.5	0.6	0.7	-0.5	0.5	0.9	0.6	1.1	0.7	0.2	0.5	0.5	0.0	0.5	-0.2	0.1
Risk spreading mechanisms	0.3	-0.3	0.5	0.2	-0.2	-0.5	-0.8	-0.4	-0.1	-0.5	0.4	0.1	-0.8	-1.2	-0.5	-0.8
Water proofing of at-risk properties	0.5	0.7	0.6	0.5	-0.8	-0.8	-0.1	-0.4	-1.0	-0.6	-0.4	-0.7	-1.2	-0.5	-0.4	-0.7
Acquisition of at-risk properties	0.5	0.5	-0.2	-0.5	0.5	-1.5	-0.3	-0.1	-0.3	0.8	-0.2	0.0	0.8	0.8	0.5	0.8
Increase setbacks on at-risk properties	1.0	0.1	0.7	-0.6	0.9	1.0	0.4	1.3	-0.6	0.9	0.9	0.5	0.6	0.8	0.8	0.7
Block development on at-risk properties	0.9	0.3	0.5	-0.7	1.0	0.9	-0.2	0.9	-0.9	1.2	0.9	0.4	1.3	1.6	0.8	1.3
Implement rolling easements	0.0	-0.5	0.2	-0.7	-0.6	0.9	-0.3	0.8	-0.4	0.8	0.9	0.3	0.8	0.6	0.2	0.5
Community education about risk	1.3	1.2	0.9	1.1	1.0	0.9	1.0	1.4	0.8	1.2	1.0	1.1	0.8	0.9	1.2	1.0
Assessments of vulnerability and risk	1.2	0.9	0.7	0.7	0.8	0.5	0.9	1.3	0.2	0.7	1.1	0.8	0.9	0.8	1.2	1.0
Integrated coastal zone management	0.8	-0.5	0.7	0.1	1.0	0.3	1.1	1.3	1.0	0.7	1.0	0.9	1.4	1.2	1.5	1.4

Table 9. Correlation matrix for performance metrics for individual MCA criteria (long-term time horizon). Positive values (in shades of green) represent a positive correlation. Negative values (in shades of orange) indicate negative correlation.

Criteria	G1	G2	G3	G4	F1	F2	F3	F4	S1	S2	S3	S4	E1	E2	E3	E4
G1	1															
G2	0.41	1														
G3	0.63	0.39	1													
G4	0.41	0.00	0.38	1												
F1	0.64	0.47	0.36	-0.23	1											
F2	0.29	0.36	0.59	-0.29	0.51	1										
F3	0.63	0.39	0.64	0.26	0.51	0.58	1									
F4	0.53	0.28	0.57	-0.03	0.52	0.84	0.85	1								
S1	0.29	-0.10	0.26	0.40	0.24	0.04	0.47	0.26	1							
S2	0.55	0.28	0.19	-0.24	0.69	0.58	0.49	0.69	0.06	1						
S3	0.48	0.04	0.58	0.07	0.46	0.74	0.54	0.81	0.27	0.65	1					
S4	0.64	0.11	0.55	0.22	0.58	0.56	0.68	0.75	0.67	0.67	0.85	1				
E1	0.42	0.33	0.20	-0.33	0.72	0.64	0.60	0.76	0.06	0.90	0.66	0.63	1			
E2	0.49	0.40	0.36	-0.18	0.52	0.61	0.64	0.81	-0.01	0.81	0.65	0.59	0.88	1		
E3	0.54	0.60	0.44	-0.10	0.67	0.61	0.68	0.74	0.09	0.70	0.61	0.60	0.86	0.85	1	
E4	0.54	0.45	0.34	-0.20	0.69	0.63	0.67	0.80	0.05	0.87	0.67	0.64	0.96	0.95	0.94	1
Legend	-1 – -0.75		-0.74 – -0.50		-0.49 – -0.25		-0.24 – 0		0 – 0.24		0.25 – 0.49		0.5 – 0.74		0.75 – 1	

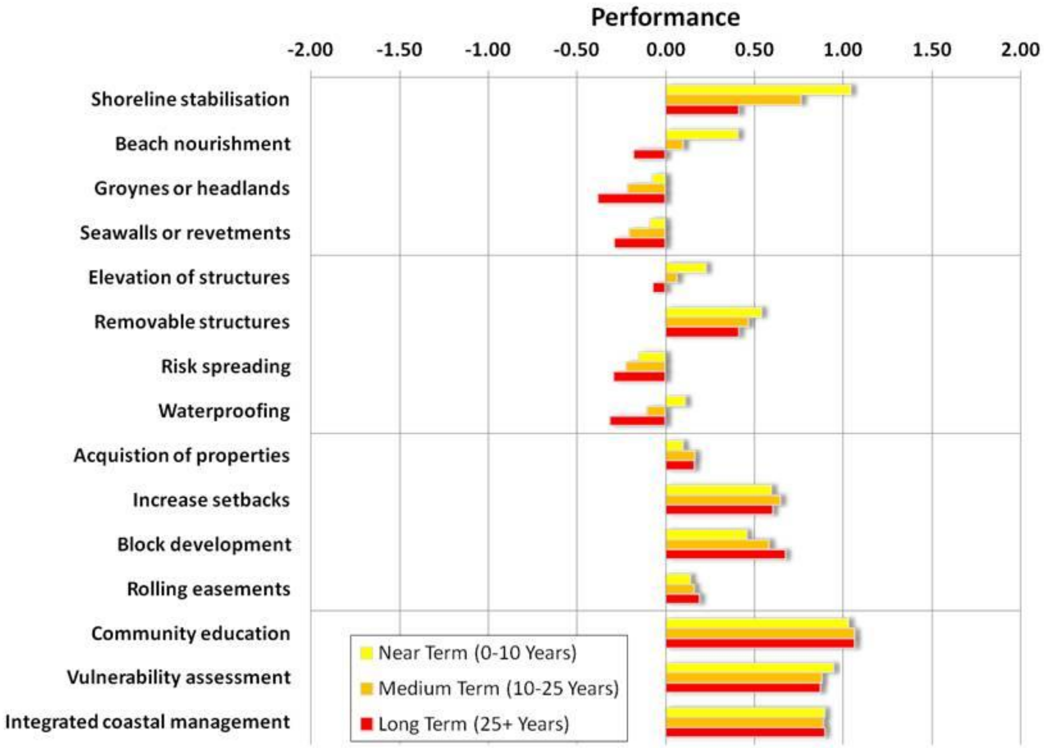


Figure 14. Comparison of average raw performance of different coastal adaptation options for different time horizons. Results are based upon the weighted average of performance scores for all case study regions. Positive values represent a favourable assessment of performance. Negative values indicate an unfavourable assessment of performance.

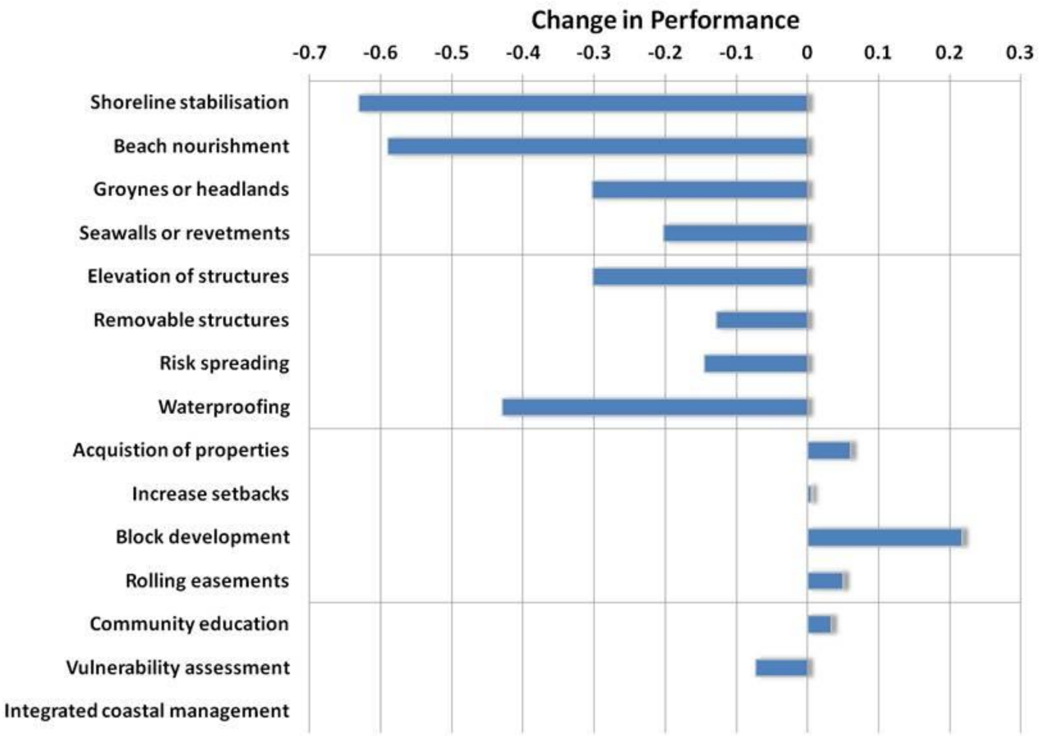


Figure 15. Change in average raw performance of different coastal adaptation options over time. Results are based upon the difference in performance over the long term vs. the short term for all case study regions. Positive values represent an increase in performance over time. Negative values indicate a decrease in performance.

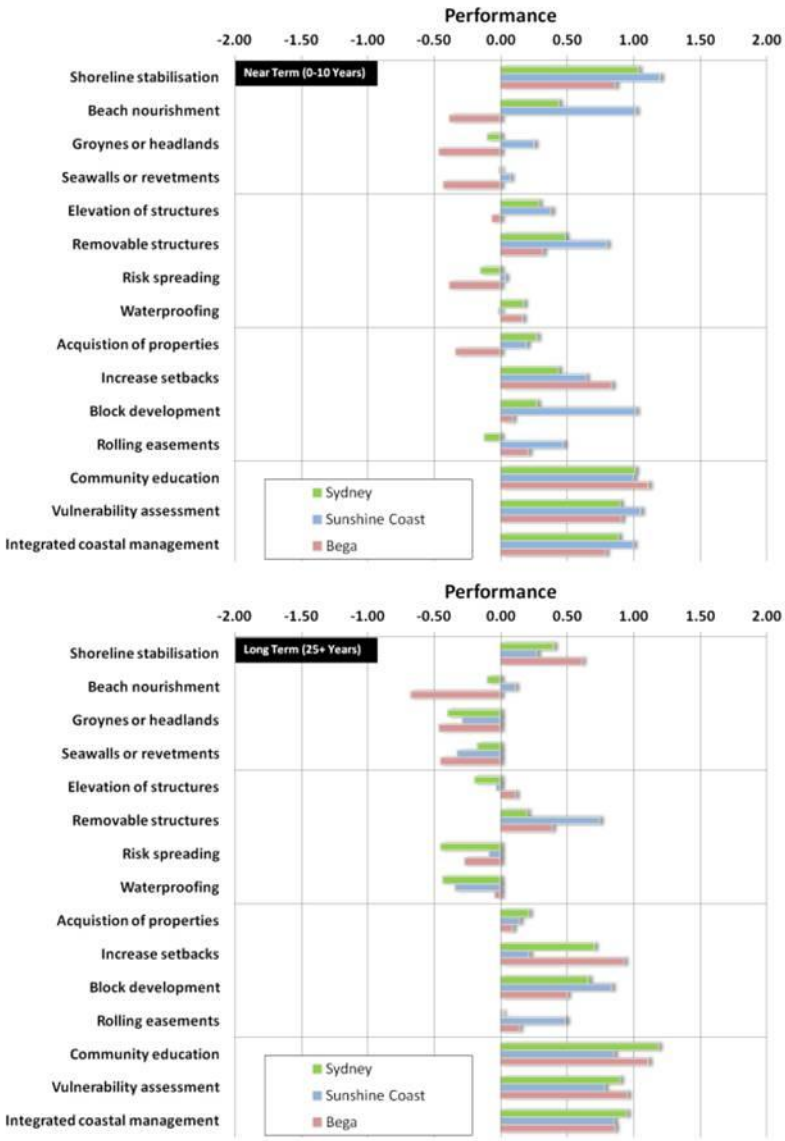


Figure 16. Comparison of average raw performance of different coastal adaptation options for different case study regions (time horizon = near term [top] and long term [bottom]). Results are based upon the weighted average of performance scores for all case study regions. Positive values represent a favourable assessment of performance. Negative values indicate an unfavourable assessment of performance.

The performance scores for different adaptation options were generally consistent from one study region to another (Figure 16), which suggests the evaluation of the utility of different options is relatively robust. Nevertheless, some subtle differences were observed among the three regions with respect to specific options. For example, Bega Valley Shire Council assigned performance scores for beach nourishment that were significantly lower than the other two study regions. Meanwhile, Sunshine Coast Regional Council generally looked far more favourable upon rolling easements than the other regions. In addition, responses among different case study regions were more similar over the long-term than the short-term, suggesting opinions converge over time.

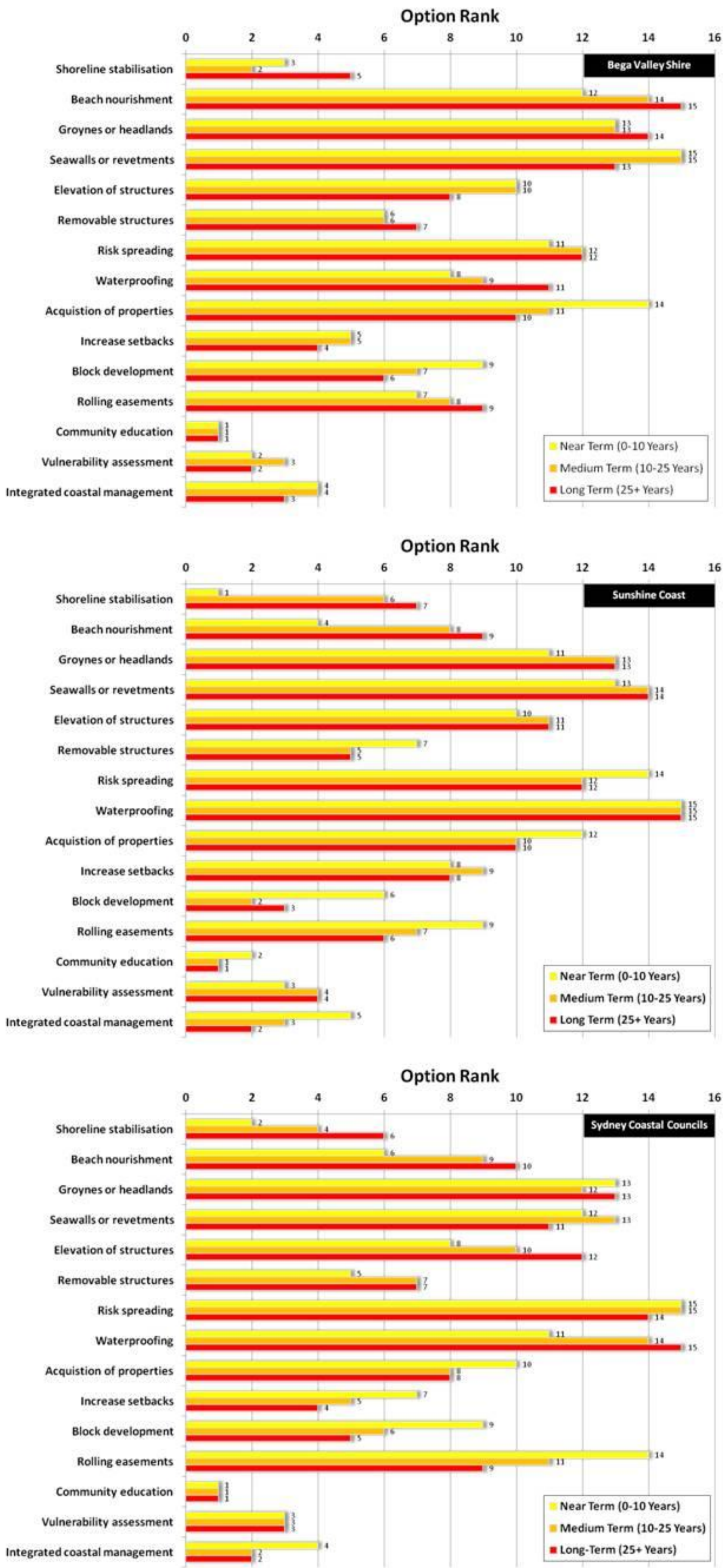


Figure 17. Comparison of the rank utility of different coastal adaptation options for the different case study regions (arranged from top to bottom). Results are based upon results from the BBN integrating performance scores with weights.

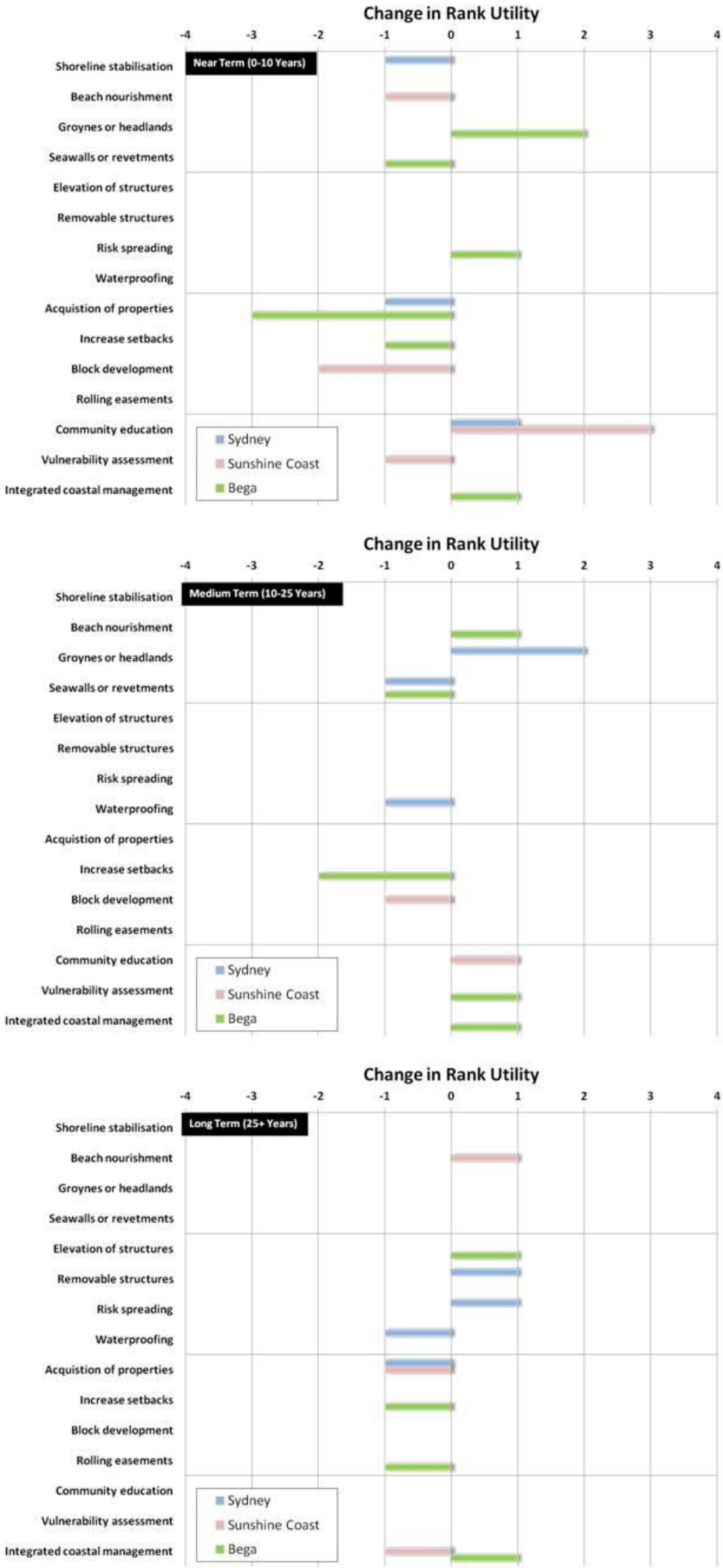


Figure 18. Comparison of changes in rank utility of different coastal adaptation options over different time horizons (arranged from top to bottom).

3.2.2 Bayesian Evaluation

The use of a BBN to integrate performance metrics with subjective criteria weights yielded results that were quite similar to the performance assessment based upon raw performance metrics alone. The results from the BBN were used to rank different adaptation options based upon their utility, with those rankings were stratified by time horizon and case study region (Figure 17). As before, the cross-cutting adaptation measures tend to be ranked most highly, and their ranking remained stable or increased with longer time horizons. Shoreline stabilization was also ranked quite highly as an adaptation option, but its utility dropped significantly with time, suggesting there are limits to its efficacy for long-term risk management. The use of removable structures to accommodate sea-level rise as well as the implementation of retreat options such as setbacks and/or rolling easements ranked moderately highly, and their ranking also tended to increase over time. The lowest ranking options tended to be hard infrastructure measures; options that provided incentives for continued development and use of at-risk areas, such as risk-spreading mechanisms and waterproofing; and options such as property acquisition that could result in high costs to Local Government and effectively cause councils to be the insurer of last resort. These options at the bottom of the ranking tended to maintain low rankings or have their ranking decline with longer time horizons.

The similarity between the Bayesian MCA analysis and the initial performance assessment is largely a function of the weights used in the Bayesian analysis being fairly similar across different criteria and value dimensions. This, in turn, is due to the generally high importance associated with a broad range of values in the earlier stakeholder questionnaire. The majority of weights were ranked in the 'moderate' to 'critical' range of importance. The exceptions were the weights on social criteria, which tended to span a broader range of importance (including 'low' importance), and the environmental criteria which were consistently ranked as being of 'high' importance. Under such circumstances, the performance of proposed management alternatives against the criteria dominates the analysis and becomes the key factor that discriminates high performing alternatives from poor performers.

Nevertheless, some degree of modest sensitivity to the incorporation of criteria weights was observed in the Bayesian analysis. For example, when the ranked adaptation options from the Bayesian analysis were compared with those from the initial performance assessment, differences in rankings were observed for a number of adaptation options in each of the case study regions (Figure 18). Generally, criteria weights resulted in a reduction in the ranking of options more frequently than an increase. This phenomenon, however, was most pronounced when the near term time horizon was considered, and the number of option rankings that differed between the two analysis methods declined with increasing time horizon as did the magnitude of the change in rank (Figure 18). This is a consequence of the differences among adaptation options with respect to their performance against decision criteria increasing with longer time horizons. For example, while the performance of hard protection items was observed to decline in the initial and Bayesian analyses with time (e.g., Figure 15, Figure 17), the retreat measures tended to increase. As such, the performance 'gap' between these two strategies widened. Meanwhile, the weights on the various MCA criteria remained unchanged with time. Hence, as noted above, the raw performance of adaptation options against decision criteria becomes an increasingly dominate force on the utility of those options as the time horizon is extended.

4 Developing a MCA Coastal Adaptation Framework – Stage II

- **The Stage I MCA was integrated with spatial data on regional assets and coastal hazards using Bayesian Belief Networks (BBNs) to prioritise different adaptation options at the property scale.**
- **The visualization of Stage II MCA results within a geographic information system (GIS) enables rapid comparison among different locations with respect to hazards, assets at risk, and the utility of different adaptation options.**
- **Although the prioritization of adaptation options is sensitive to the criteria used in the MCA, some options appear to be more robust than others in that they have high utility for a high proportion of properties, irrespective of the criteria applied.**

The results of the Stage I MCA represent the general preferences of staff working in Local Government regarding the appropriateness of different adaptation options. However, these preferences are quite broad, as they are not based upon any place-based contextual information regarding the level of risk, value, or the suitability of an adaptation option to address a particular management challenge. In other words, they represent Local Government staff's subjective opinions regarding best practice management options for coastal adaptation in the long-term interest of councils. While useful for benchmarking Local Government opinion regarding coastal adaptation, such information doesn't necessarily aid in spatial planning. For example, while the Stage I MCA suggests sea walls are generally viewed unfavourably by Local Government, there are clearly many stretches of coastline in the case study regions, particularly Sydney, that are protected by sea walls. Furthermore, it is likely that coastlines associated with high asset densities are unlikely to be simply abandoned in the future as risk increases. Rather, some investments will be made to protect assets. As such, in order to apply MCA methods in a decision support capacity, the analysis had to progress from the general to the specific in order to capture these spatially heterogeneous aspects of coastal landscapes.

The goal of the Stage II MCA was to build upon the Stage I analysis to undertake such place-based evaluation of adaptation options. The Bayesian model developed for Stage I was therefore adapted in order to spatially disaggregate the general beliefs regarding the performance of adaptation options to the property scale. In so doing, the Stage II MCA sought to incorporate a number of additional factors into the evaluation of different adaptation options:

1) Place-based hazards;
2) Place-based asset densities (financial, social and/or environmental); and
3) Appropriateness of a given adaptation option given the above characteristics.

As the Stage I MCA indicated that cross-cutting adaptation measures were viewed quite favourably by Local Government staff and given such options are not necessarily specific to any particular location, they were not included in the Stage II MCA. That left 12 of the original 15 adaptation options for evaluation in Stage II.

The methods section below describes how spatial information and data were incorporated into the Bayesian model for the evaluation of coastal adaptation options. This is followed by the presentation of various results for different case study regions.

4.1 Methods

4.1.1 Spatial Decision Criteria and Weights

Moving from a general Bayesian model to one appropriate for place-based analyses required the introduction of additional constraints that influence the performance of different options for different locations. As such context-specific details were not considered explicitly in the Local Government workshops, they were introduced into the model by the research team. This increased the influence of researcher assumptions on the MCA. Nevertheless, some information was introduced in response to comments by Local Government staff regarding the conditions under which certain adaptation options would be implemented in practice.

Two different types of decision constraints were introduced for each study region:

1) **Performance constraints** – These constraints were applied to the stakeholder performance assessments within each criterion node of the Bayesian network. Their effect was to override the general assessments of Local Government staff when certain conditions were met that suggested those assessments were not valid or relevant for a particular location. Those conditions were specified through the introduction of new decision nodes into the Bayesian network model (see Table 10). As such, the CPTs for performance nodes in the Stage II models were significantly larger than those in the Stage I model.
2) **Spatial weights** – Spatial weights were used to replace the survey based weights on the three criteria pertaining to the protection of financial (F1), social (S1) or environmental (E1) assets. The spatial weights effectively represent risk to assets, such that performance assessments for a given criterion received greater weight if risk to a given asset was high and lower weights if the risk was low. Risk was assessed through the integration of information regarding the coastal hazards to which a property was exposed and the nature of the assets on, or in proximity to, the property (see Section 4.1.3).

Collectively, these two factors forced the Bayesian models to assign prejudicially high or low performance scores to certain adaptation options when certain conditions are met and to allow the performance of options to vary depending upon risk. Performance constraints were developed based upon a review of the literature (Mangoyama et al., 2012) on coastal adaptation which provided insights into the appropriate conditions for the implementation of certain options. Additional constraints were proposed by Local Government staff during workshops in early September, 2012, which were subsequently incorporated into the analysis. A range of data sources were used in the incorporation of spatial information into the Stage II Bayesian model (see Section 4.1.2). Furthermore, incorporating some of the additional performance constraints into the model required the addition of several decision nodes not included in the Stage I model (Figure 19). Given the differential data sources and numbers of properties among the three study regions, separate Bayesian networks were developed for each study region. More details regarding such spatial data sources are provided in the following section.

Table 10. Spatial decision criteria incorporated into the Bayesian network model.

Criterion	Description	Model Parameters
Between a Rock and a Hard Place	Protection measures designed to manage risks to erodible coasts have little utility for coasts that aren't prone to erosion (e.g., beaches backed by bedrock)	All decision criteria were assigned a performance score of -2 for "shoreline stabilization", "groynes and headlands" and "beach nourishment" for properties where there is no risk of erosion.
Nowhere to Run	Increasing setbacks on properties is unlikely to be an effective strategy for properties where available land for new structures is significantly constrained.	All decision criteria are assigned a performance score of -2 for "increase setbacks" if >50% of available land is likely to be affected by coastal hazards.
This Land is Our Land	Adaptation options on public lands are less of a threat to property rights as there is no private ownership.	Criterion F3 is assigned a performance score +2 for properties corresponding with public (including Crown) land.
Weapons of Last Resort	Acquisition of properties is reserved for those locations judged to be at very high risk while seawalls are reserved for locations with very high risk and significant financial assets/infrastructure	All decision criteria are assigned a performance score of -2 for "acquisition of properties" if properties do not have a very high risk of exposure to coastal hazards. All decision criteria are assigned a performance score of -2 for "sea walls and revetments" if properties do not have a very high risk of exposure to coastal hazards and a very high density of financial assets.
High Risk, High Reward	Adaptation options have greater utility in locations where there is a greater risk of damage or loss. This risk arises from a) exposure to hazard and b) value of assets at the location.	Weights for certain decision criteria are replaced with risk indices based upon spatial information regarding the distribution of hazards and assets.

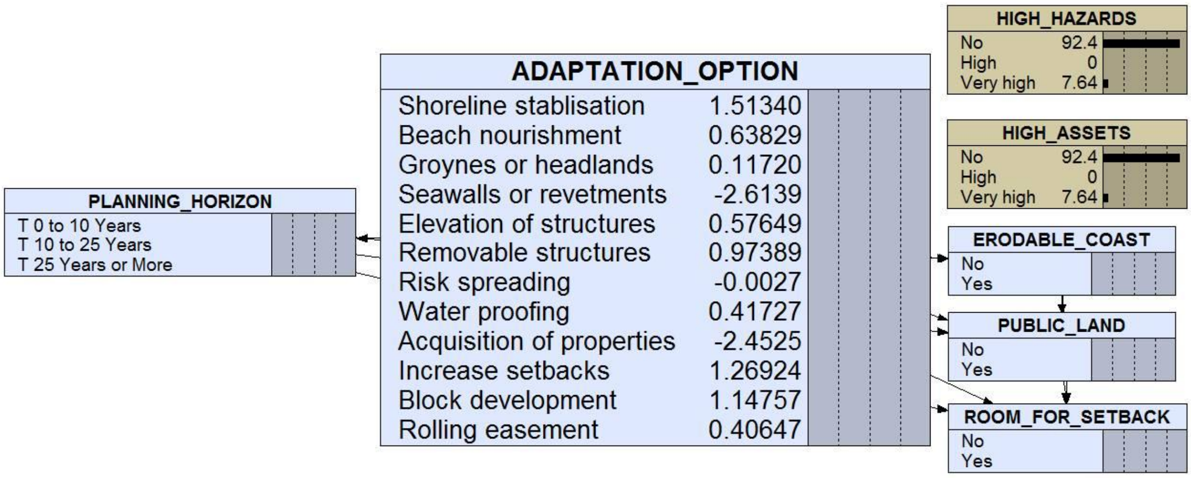


Figure 19. Decision nodes used in the Stage II MCA for all of the case study regions. These nodes differ from the Stage I MCA in several respects (e.g. compare with Figure 9). First, the number of adaptation options considered is reduced as cross-cutting adaptation options were not evaluated. Second, five additional decision nodes that were not included in the Stage I MCA analysis were added to the Stage II analysis to represent the additional decision constraints. The nodes labelled "High_Hazards" and "High_Assets" are not decision-nodes per se, as they were derived from other elements of the model, but they were used as inputs into the CPTs for performance nodes and therefore act in a similar manner as other decision nodes.

4.1.2 Data Sources and Processing

Geospatial information was provided to the research team by a number of sources including Local Government, State Government, Federal agencies and other research institutions. The various types of data needed to undertake the Stage II MCA can be divided into three categories:

1) Data on property boundaries
2) Data on coastal hazards (e.g., sea-level rise, storm surge and erosion); and
3) Data on assets (financial, social and environmental).

The spatial weights in the analysis were based upon a simple assessment of risk to assets on coastal properties in the case study regions. Risk was framed as the interaction between hazard (in the form of sea-level rise, storm surge, and erosion) and consequence (in the form of potential loss and damage to assets of value). Hence, risk was assumed to increase with increase property exposure to hazards and/or with increasing concentration of valued assets on that property.

4.1.2.1 Property/Parcel Classifications

Geographic information on property boundaries was obtained for each case study area. For Sydney and Bega, property boundaries were obtained from Land and Property Information in the NSW Department of Finance and Services. Properties falling within LGA boundaries were isolated and multipart polygon features were converted to singlepart features to separate non-adjacent/non-contiguous properties with the same identifier. Each property was subsequently assigned a unique identification number to facilitate the linking of MCA model output back to the property boundaries for visualization.

For Sunshine Coast, property boundaries were obtained from Sunshine Coast Council, which provided the council's cadastre file. The cadastre file included boundaries for both properties and easements (e.g., roads) and therefore included information not contained in the property boundaries used in those case studies based in NSW. Due to a lack of information on property values for easement areas, these were ultimately excluded from the MCA. However, Local Government staff from Sunshine Coast Council did indicate that information on risks to, and adaptation of, such assets would also be of value. As with the other case study regions, 'multipart' features were converted to 'singlepart' features and each feature in was assigned a unique identification number.

4.1.2.2 Hazard Classifications

With respect to the hazard component of risk, two types of coastal hazards were considered – inundation hazard and erosion hazard (Figure 20). These were assessed individually for each property by taking hazard overlays provided to the project team for each case study region, comparing them with the underlying property layers and calculating the percentage of each property exposed to that hazard.

Table 11. Hazard classifications applied to inundation and erosion hazards in the case study regions.

Percentage of Property Exposed	Hazard Classification
0–1%	Unexposed
1–10%	Very Low
10–20%	Low
20–40%	Moderate
40–80%	High
80–100%	Very High

4.1.2.2.1 Inundation Hazard

For inundation hazards, the type of information used varied among the study regions. For example, for Sunshine Coast and Bega councils, the inundation hazard was based upon an existing 1:100 year flood hazard layers currently used for risk management by the councils. For the Sydney region, inundation was based upon modelling undertaken by the CSIRO of 1:100 year storm surge inundation with different magnitudes of sea-level rise (+40 cm by 2050 or +90 cm by 2100), consistent with the 2009 NSW Sea Level Rise Policy Statement.[5] Hence, these two future time horizons were assumed to represent storm surge scenarios for Sydney under the "medium-term" and "long-term" time horizons.

4.1.2.2.2 Erosion Hazard

For erosion hazard, spatial information regarding the risk of erosion and shoreline recession for all coastlines in the case study regions were not available. As such, a new methodology was developed and applied in all three case study regions (see Appendix V), which was designed to be consistent with the NSW Coastal Risk Management Guide (NSW, 2010). The Smartline Coastal Segmentation Data Product was used to identify coastlines in each case study region that were classified as sandy beaches not backed by bedrock and thus susceptible to erosion. Buffers were drawn landward of Smartline to identify zones potentially susceptible to erosion, with the landward distance determined by a simple Brunn rule calculation according to the NSW Coastal Risk Management Guidelines. Those guidelines recommend calculating a coastal recession distance from the maximum

[5] The 2009 NSW Sea Level Rise Policy Statement ceased to be NSW State Government policy in 2012.

water height above AHD[6] multiplied by a factor of 50 to 100. Initial erosion zones were based on the 100x assumption, but these were later adjusted to the 50x assumption based upon recommendations from Local Government staff. Maximum water heights (and therefore the size of the erosion hazard zones) increased over time, consistent with the aforementioned NSW Sea Level Rise Policy Statement.

Hazard classifications for properties were calculated for each time horizon and hazard using a common scale (Table 11). A net hazard classification was calculated by adding the percentage of each property exposed to inundation to the percentage of each property exposed to erosion and then using the same classification scheme identified in Table 12 (Figure 20). Hence, properties exposed to a high level of inundation or erosion alone were classified as being at very high risk, regardless of whether or not they were exposed to the other hazard. Meanwhile those properties exposed to relatively low levels of inundation and erosion were considered to be at higher risk than those exposed to low levels of a single hazard.

Weights were applied to these hazards based upon the subjective opinions of Local Government staff that emerged from the survey completed in November–December, 2011. That survey asked participants to rank the importance of different coastal hazards to Local Government (e.g., Figure 4). For sea-level rise, participants were also asked to rank the importance of sea-level rise as a hazard over time. Hence, inundation weights were time-sensitive, such that even if only a single hazard overlay was available for a case study region, the weighting caused that hazard to increase over time. Time-sensitive weights were not available for erosion, but for all case study regions, erosion hazard increased over time due to assumptions about sea-level rise. Weights had the effect of increasing or decreasing the exposure classification for a given property. For example, a property with a moderate level of net exposure (e.g., 35%) could be classified as high after weighting if hazards were given particularly high importance. In contrast, if the weight was relatively low, the hazard classification could be reduced. To capture differences in opinions among staff in different study regions, weights for a given study region were based only on survey respondents from Local Government staff in that region.

In addition to generating sea-level rise and erosion hazard overlays for the case study regions, the risk assessment was used to identify properties for which there was no erosion risk or for which there was a very high risk of exposure to coastal hazards. This information was then used as the basis for two of the performance constraints added into the Stage II BBN. Local government stakeholders who participated in the project noted that storm surge inundation and erosion do not necessarily occur together at every location. Some properties may be subject to the former but not the latter. As such, just because one might contemplate building a sea wall at a particular location doesn't mean that one would also use measures to manage erosion. Hence, an additional node was added to the BBN to make use of the hazard information to discount the performance of adaptation options designed to manage erosion for properties for which there was no erosion risk. In addition, stakeholders noted that the high costs and environmental externalities of sea walls and revetment meant that they were likely only to be used to protect properties for which there was a 'very high' risk of exposure. Similarly, allocation of properties by councils also carries a high cost, and thus would likely only be implemented for properties facing a 'very high' risk of exposure to coastal hazards. The addition of these constraints into the Stage II BBN thus acted to make the results of the model more consistent with a) general knowledge of appropriate practice and b) the place-based conditions and hazards associated with individual properties.

6 AHD= Australian height datum

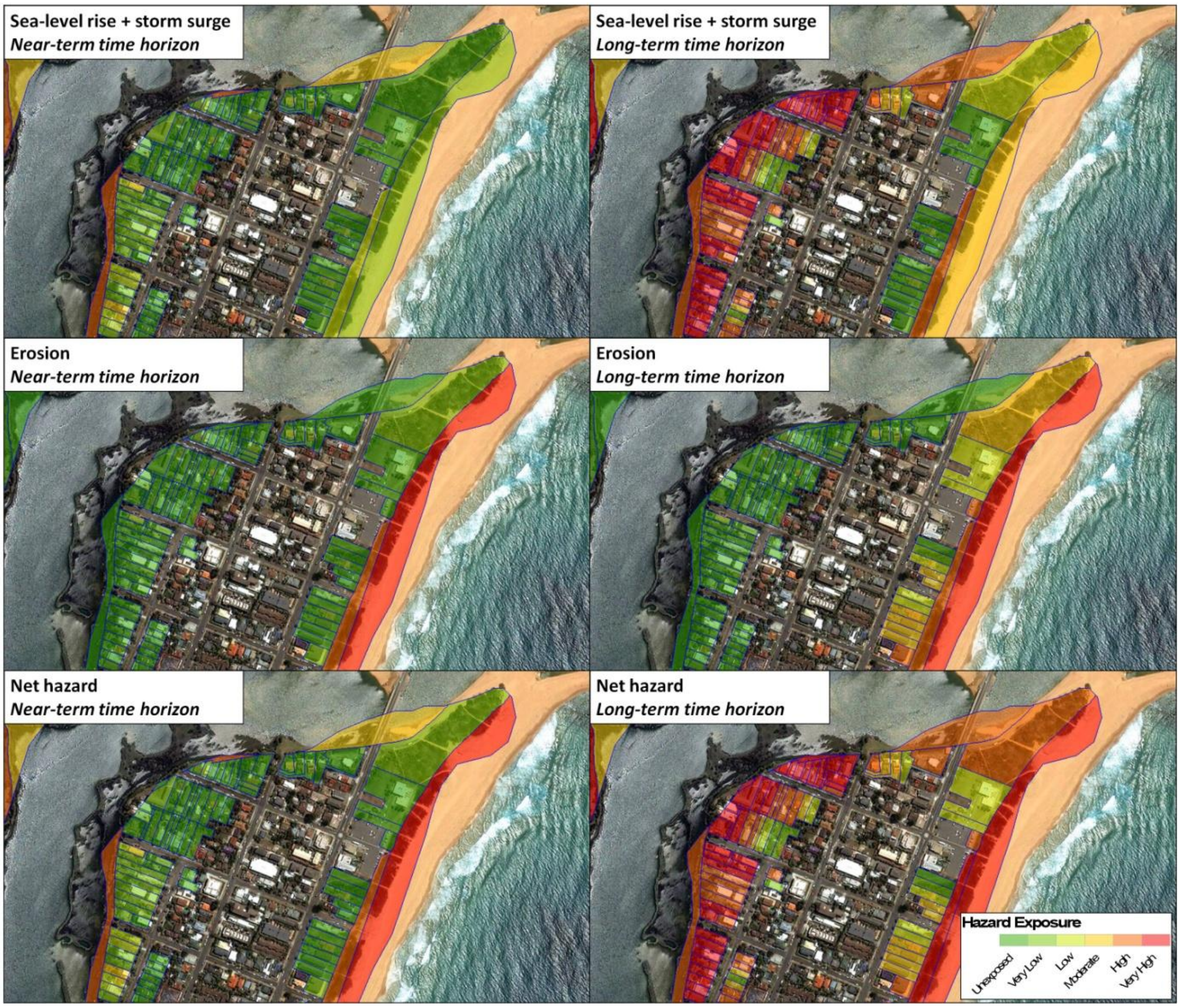


Figure 20. Illustration of coastal hazard information used in the Stage II MCA model. Figures on the left hand side represent hazard scores over the near-term time horizon for different properties based upon sea-level rise and storm surge (top), erosion (middle), or a combination of the two (bottom). The figures on the right hand side are identical except they represent the long-term time horizon. Overall, the magnitude of the hazard increases from top to bottom as the number of hazards considered increases and from left to right as sea-level rise increases both storm surge and erosion risk.

Table 12. Hazard classifications applied to inundation and erosion hazards in the case study regions.

Percentage of Property Exposed	Hazard Classification
0–1%	Unexposed
1–10%	Very Low
10–20%	Low
20–40%	Moderate
40–80%	High
80–100%	Very High

4.1.2.3 Asset Classifications

Each property in the analysis was classified based upon the relative density of financial, social, or environmental assets (Table 12), consistent with the multi-criteria framing of the project. The data used to undertake this classification varied among the case study regions, due to data availability (see Appendix V for a detailed list of data sources). For example, data for Sunshine Coast and Bega case studies were sourced directly from the councils whereas data for Sydney was largely sourced from the NSW Land and Property Management in order to obtain consistent information across the 15 councils in the Sydney Coastal Councils Group. However, as some assets are locally controlled, this meant some data were not available in the Sydney region (e.g., storm water infrastructure).

Table 13. Examples of data used to classify assets for properties in the three case study regions.

Asset Category	Examples
Financial	• Property valuations, • Density of commercial/industrial buildings • Density of transportation infrastructure • Density of water/waste water infrastructure
Social	• Density of social/community-oriented buildings (e.g.,. schools, hospitals, churches) • Recreational areas (parks, clubs, sporting grounds, recreational reserves) • Community hubs/cultural centres
Environmental	• Critical habitat areas • Density of endangered flora/fauna • Distribution of native vegetation • Distribution of natural land use • SEPP 71 areas (NSW only) • Crown lands

Asset indicators were processed for inclusion in the analysis, with different methods applied to different types of data. For polygon (i.e., area) features, polygons were compared with the underlying property layer and the percentage of that property intersecting the asset layer was calculated. For line data (e.g., roads) and point data (e.g., buildings), a line density or point density algorithm was applied to the data to generate a 5m resolution gridded density layer which was then averaged over each property. This average value was used to calculate a percentile rank for each property to convert the data to an ordinal scale. Within the Bayesian model, properties were then assigned classifications for each data layer according to the scheme in Table 14, which is identical in its scaling to that for hazard information. In addition to the qualitative classification, a numerical score was assigned which enabled aggregation of different data layers (see below). If no data were available for a particular property with which to make an accurate determination, it was assigned a classification of “No Data” and a numerical score of “3”, equivalent to a classification of “Moderate”.

Table 14. Classification scheme used for asset indicators in the Bayesian model.

Percentage of Property Area/Indicator Percentile Ranking	Asset Classification	Numerical Score
0–1%	None	0
1–10%	Very Low	1
10–20%	Low	2
20–40%	Moderate	3
40–80%	High	4
80–100%	Very High	5
No Data	No Data	3

4.1.2.4 Risk Classifications

Risk classifications for each property were calculated based upon the net hazard classifications and the aggregate asset classifications. This was undertaken by the insertion of a risk assessment matrix into the Bayesian model which generated a risk score for each property (Figure 22), which was subsequently translated into a weight that could be applied to the various asset protection criteria (Table 14).

Hazard Rankings	Asset Rankings						
	No Data	None	Very Low	Low	Moderate	High	Very High
No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Unexposed	No Data	Unexposed	Unexposed	Unexposed	Unexposed	Unexposed	Unexposed
Very low	No Data	Unexposed	Very Low	Low	Low	Moderate	Moderate
Low	No Data	Unexposed	Low	Low	Moderate	Moderate	Moderate
Moderate	No Data	Unexposed	Low	Moderate	Moderate	High	High
High	No Data	Unexposed	Moderate	Moderate	High	High	Very High
Very High	No Data	Unexposed	Moderate	Moderate	High	Very High	Very High

Figure 21. Risk assessment used in the Bayesian model to generate risk classifications and spatial weights for each property based upon property-specific hazard exposure and net asset classifications.

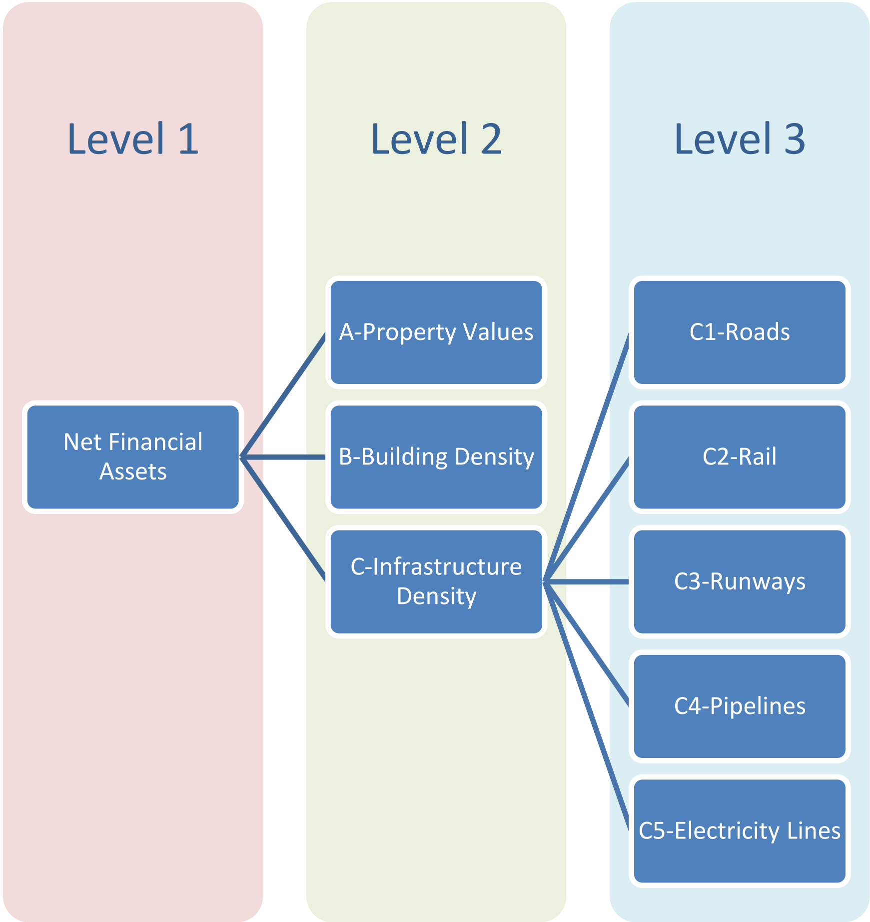


Figure 22. Example of the hierarchy for aggregation of financial asset indicators for the Sydney region.

Table 15. Scheme for translating risk classifications for individual properties into spatial weights consistent with the weighting scheme used in the Bayesian network model.

Property Risk Classification	Spatial Weight
No Data	Moderate Importance
Unexposed	Unexposed
Very Low	Very Low Importance
Low	Low Importance
Moderate	Moderate Importance
High	High Importance
Very High	Critical

4.1.3 Updating Bayesian Models with Spatial Information

Once the general structure of the Bayesian model was established (including the various data inputs, classification schemes and aggregation methods) the model was finalised by entering the prior probability distributions for each of the input variables (e.g., the relative frequency with which all of the properties in a case study region were classified into the various categories for a given data layer). In addition, given the inclusion of a range of additional decision constraints in the Stage II MCA as compared to Stage I, the CPTs for the performance nodes of the Bayesian models were expanded to include the following decision nodes (see also Figure 19 and Table 10):

- **Erodable coast** – Indicates whether or not a property is located along a coastline that is subject to erosion (based on Smartline).
- **Public land** – Indicates whether or not a property represents public/Crown land.
- **Room for setback** – Indicates whether or not a property has sufficient space to allow an additional setback as an adaptation option.
- **High hazard exposure** – Indicates where or not a property is exposed to a particular high level of exposure to coastal hazards.
- **High level of assets** – Indicates whether or not a property is associated with a particularly high level of assets of value.

The addition of these nodes enhanced the sensitivity of the BBN's evaluation of different adaptation options to different spatial inputs, particularly those associated with exposure to hazards and subsequent risk.

At this point, the model could be used for inferring the utility of different adaptation options under different input assumptions (e.g., hazard exposure, asset density, indicator weighting, or option performance). Results from such inferences reflect statistical likelihoods given the prior probability distributions for all variables. In other words, what is the maximum expected utility for an adaptation option for a property selected at random from the case study region? Such inference enables one to draw generalizations at the level of the case study region with respect to the performance and utility of different adaptation options.

Table 16. Total number of properties associated with each of the case study regions and the number for which some potential exposure was identified and thus included in the MCA. Numbers in parentheses in the exposed parcels/properties column represent the percentage of total properties with some chance of exposure.

Cast Study Region	Number of Parcels/Properties	Number of Exposed Parcels/Properties
Sydney Coastal Councils Group	362,151	19,694 (5%)
Sunshine Coast Regional Council	182,220	37,775 (21%)
Bega Valley Shire Council	24,863	1,496 (6%)

The ultimate goal of the Bayesian modelling, however, was to generate property-specific evaluations of adaptation options. To accomplish this, data for individual properties had to be input into the model. For Netica, such data inputs are organised within a 'case file', which represents all of the input values for all of the variables in the model for each 'case' or, in this application, property. To accelerate the modelling process, case files were constructed just for those properties for which the available hazard information indicated there was a possibility of exposure to inundation or erosion at some point in the future (
Table 16). A 'control file' was used to specific which outputs should be generated from the model. The default outputs included:

- Property ID number
- Inundation hazard classification (most likely result)
- Erosion hazard classification (most likely result)
- Net hazard classification (most likely result)
- Financial asset classification (most likely result)
- Social asset classification (most likely result)
- Environmental asset classification (most likely result)
- Adaptation option with the highest utility (most likely result)

- Quantitative utility scores for all adaptation options included in the spatial MCA

As BBNs provide probabilistic information on variables and model outcomes, model output was reported as the most likely outcome for a given node of interest, except for utility variable which yielded a discrete quantitative estimate of the utility of different adaptation options. In addition, to facilitate the communication of the model results, quantitative utility scores were converted into qualitative rankings according to the scheme in Table 16.

Table 17. Qualitative ranking scheme used for converting quantitative Bayesian utility scores into more user-friendly categories.

Cast Study Region	Model Variants 2, 3, 4 (1 decision criterion)	Complete MCA Model Variant 1 (all 16 decision criteria)
Highly Unfavourable	<-0.75	<-2.25
Unfavourable	-0.75 – -0.25	-2.25 – -0.75
Marginally Unfavourable	-0.25 – 0.00	-2.25 – 0.00
Marginally Favourable	0.00 – +0.25	0.00 – +0.75
Favourable	+0.25 – +0.75	+0.75 – +2.25
Highly Favourable	>+0.75	>+2.25

Hence, for each property, the Bayesian network:

1) Examines the input data for that property for each variable;
2) Assesses the performance of each adaptation option given the decision criteria, stakeholder performance scores and performance constraints;
3) Generates spatial weights based upon hazard and asset classifications;
4) Applies stakeholder and spatial weights to the performance assessments for the various criteria; and
5) Assesses the utility of each adaptation option.

This analysis is repeated for property and time horizon in a given case study region. In addition, multiple variants of the Bayesian model were constructed for each case study region to examine the sensitivity of findings to underlying values. For example, a model that includes governance, financial, social and environmental criteria might yield one set of answers regarding the utility of different adaptation options, while a model that focuses simply on one dimension (e.g., environmental) or even a single criterion (e.g., protection of financial assets), might yield a different set of answers.

However, often public debates regarding appropriate policy decisions often involve conflict among stakeholders who prioritise a very limited set of values. Hence, the different model variants, therefore enable the utility of different options to be examined from different value perspectives and thus highlight the distinction in preferred adaptation options that arises from more comprehensive consideration of relevant values. It also enables one to identify robust adaptation options – meaning those that have a high utility across different value position.

The spatial MCA examined four different model variants for each case study region:

- **Variant 1** - Includes all 16 criteria (four from each dimension of financial, social and environmental; Table 2)
- **Variant 2** - Truncated to include only the protection of financial assets criterion
- **Variant 3** - Truncated to include only the protection of social assets criterion

- **Variant 4** - Truncated to include only the protection of environmental assets criterion

Each study region therefore has 12 different model outputs – four model variants for each of three different time horizons. Netica's output is comprised of a text file including all of the information specified in the control file, which can subsequently be converted to different formats (e.g., an Excel spreadsheet) and/or linked back into a GIS system for visualization.

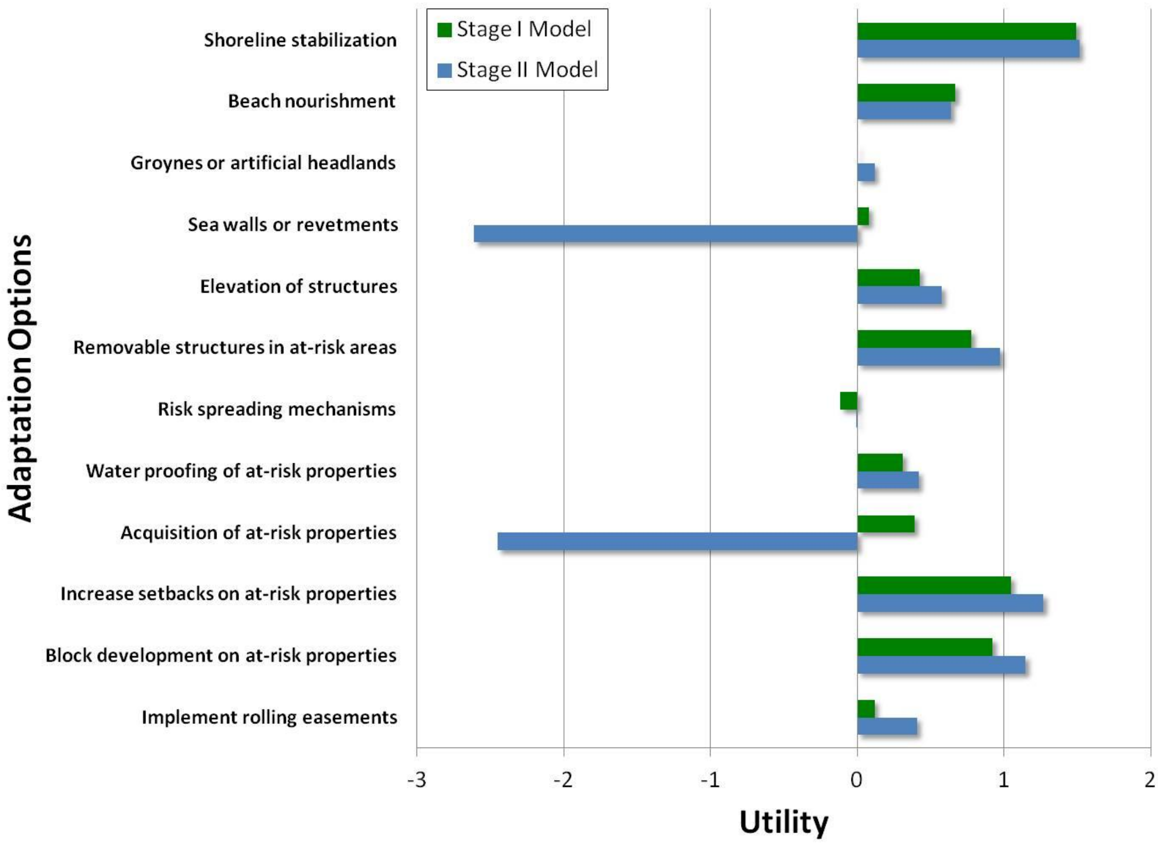


Figure 23. Comparison of utility scores derived from the Stage I and Stage II Bayesian MCA models for Sydney.

4.1.4 Visualising Spatial MCA Results

In order to visualise the outputs from the variants of the MCA Bayesian model, the output files for each variant, time horizon and region were joined back to the base property layer for each case study region using the unique property identification number. This resulted in a new GIS shapefile for each variant, time horizon and case study region that contained the existing property information used by local/state government as well as the output from the Bayesian model regarding hazards, assets and the utility of different adaptation options.

Multiple visualization options could be used to access the MCA results. The project team was working with the ArcGIS suite of software tools. For workshops conducted in early September, 2012, the project team used the ArcExplorer application, which is a freely available software package for visualising GIS information. ArcExplorer combines the mapping features of other ArcGIS software (e.g., ArcMap) with the spatially browsing and land surface visualization capabilities of other applications like Google Earth. Thus users can readily pan from one location to another and view the MCA results against high-resolution imagery from multiple perspectives. For these workshops, a common symbology was selected for each GIS shapefile containing MCA model output, and HTML labels were enabled such that the underlying information associated with the different properties could be readily accessed simply by clicking on a specific property. Each shapefile was then saved as an ArcGIS layer file to preserve the symbology and formatting. Shapefiles and layer files were placed in common directory, which could be accessed by ArcExplorer for visualization using a range of underlying imagery data.

However, as the shapefiles contain all of the output from the MCA model, those shapefiles could be readily used to generate a range of visualization outputs or data formats including .kml files for use with Google Earth.

4.2 Results

4.2.1 Comparing General and Spatially Explicit Bayesian Models

Comparison of overall utility scores for the general Bayesian model used in the Stage I MCA, which was not structured to manage spatial inputs, with those used in Stage II suggest the inclusion of spatial parameters does indeed influence the utility of adaptation options (Figure 23). For example, in the Sydney region, utility scores across all properties and time horizons were generally higher in the Stage II model than in the Stage I model, which is likely a function of changes made to the CPTs to accommodate additional constraints as well as the incorporation of spatial weights. The key exceptions were seawalls and revetments as well as acquisition of properties, which received quite low utility scores at the regional level. This is due to the limited number of properties for which these options were considered viable (i.e. having very high financial asset densities and/or very high exposure to coastal hazards). In addition, utility declined slightly for beach nourishment in the Stage II model relative to Stage I. This disparity between the Stage I and Stage II models reflects the sensitivity of the model to the introduction of additional decision constraints and the potential for the Stage II model to generate evaluations of adaptation options that are quite different than the Stage I model when spatial heterogeneity in landscape characteristics are considered.

4.2.2 Demonstration of Spatial MCA Results

As the spatial MCA tool developed for the three case study region includes information on tens of thousands of properties, summarising all the results in this report is impractical. Rather, for each case study region, we illustrate the results from the model and the visualization capabilities developed for the project for one area within the study region. For that area, we present a series of images that compare and contrast results from the MCA for different properties and/or for different model variants and time horizons to illustrate sensitivity of results to time preferences and different values frameworks. We subsequently synthesise the results for all the properties in each case study region across the different model variants, with a particular emphasis on robust adaptation options.

4.2.2.1 Sydney Coastal Councils

In the Sydney Coastal Councils region, we focus on North Narrabeen beach, which is well known for its potential vulnerability to erosion from coastal storms and, in the future, sea-level rise. In North Narrabeen, Figure 24 identifies a property near the intersection of Ocean Street and Emerald Street. Results indicated that over the near-term time horizon, this property is not anticipated to be exposed to erosion or inundation, although the fact that it was included in the analysis suggests it will be exposed over the long-term. This is true for a broad range of other properties visible in the map. In contrast, foreshore areas along Narrabeen Beach are subject to coastal hazards. Yet, existing development is largely protected from those hazards. The property in question is associated with moderate financial value, and relatively high environmental value, likely due to its location within a SEPP-71 area. As such, the best adaptation option recommended for the location is shoreline stabilization, which would help increase the resilience of the foreshore buffer, and hard protection measures in particular are judged to be inappropriate for the location.

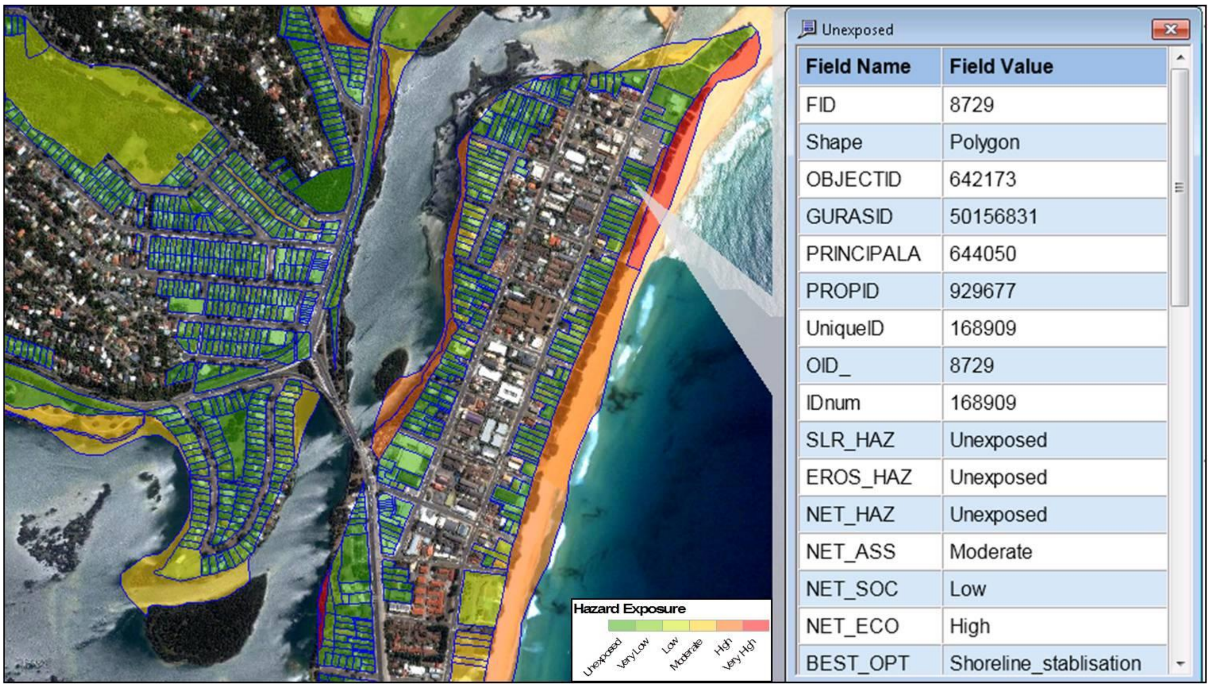


Figure 24. Results from the spatial MCA for North Narrabeen Beach north of Sydney for the model variant where all criteria are considered and a near-term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

Looking over the long-term, the risk to properties along Narrabeen Beach changes significantly. Many of the properties along Ocean Street that were unexposed over the near-term begin to show signs of exposure to erosion and inundation. However, exposure is more profound along Wakehurst Parkway and Pittwater Road, which are particularly vulnerable to sea-level rise. The property on Ocean Street discussed previously is exposed to relatively low levels of erosion (Figure 25). As a result, the best adaptation option changes from shore-line stabilisation to increasing the setback on the property. Although this wouldn't necessarily be protective of the current structures on the property, it suggests future development/redevelopment on that site should be mindful of potential erosion risk when planning over the long-term. Hence, the visualisations selected for the Sydney region highlight the sensitivity of the MCA to time – particularly the increasing risk of erosion and inundation. These results also highlight that vulnerability, and therefore appropriate adaptation options, are place-based, with significant differences from one property to another even within a relatively small geographic area.

Figure 25. Results from the spatial MCA for North Narrabeen Beach north of Sydney for the model variant where all criteria are considered and a long-term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shading were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

4.2.2.2 Sunshine Coast Council

For Sunshine Coast Council, our visualization concentrates on Noosa Beach and the canal estates behind the beach. Over the long-term, a number of the properties in this area are anticipated to be exposed to erosion and/or inundation (Figure 26). To illustrate results for Noose, we select a land parcel on Noosa Parade that is currently undeveloped, yet adjacent to a number of high value properties. Hence, the asset score for this property is very high. Social assets are also high at this site, largely due to its proximity to Noosa Beach. No significant ecological value was attached to this land. The property is anticipated to be at significant risk over the long-term due to both flooding and erosion. One of the few properties in the area with only moderate exposure was selected to illustrate results for Noosa. Therefore, the best adaptation option for this particular property over the long-term was blocking development.

An alternative model variant that incorporates only the criterion of protection of environmental assets also indicates that blocking development is the best adaptation option for this location (Figure 27). If however, when on explores a third variant focused just on protection of social assets, the best adaptation option switches to beach nourishment (Figure 28), suggesting an emphasis on protecting the land for the community. These various results therefore illustrate how preferred adaptation options emerging from the MCA model are sensitive to the criteria used to evaluate the options.

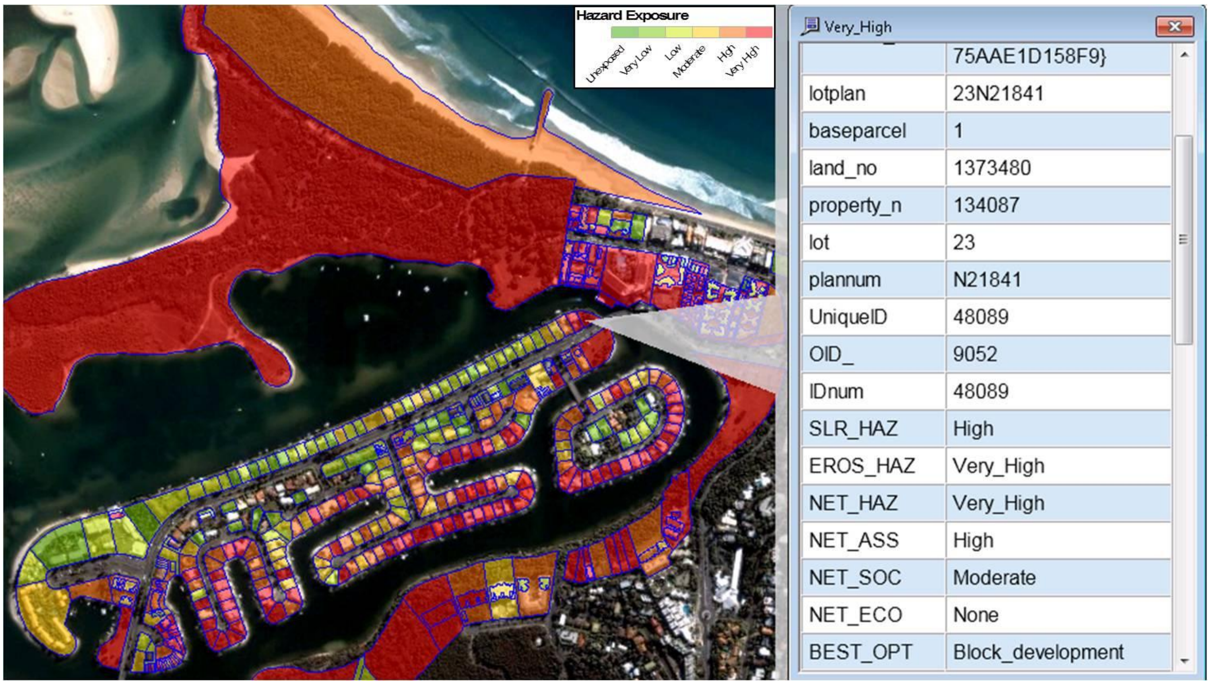


Figure 26. Results from the spatial MCA for Noosa for the model variant that incorporated all criteria and a long term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

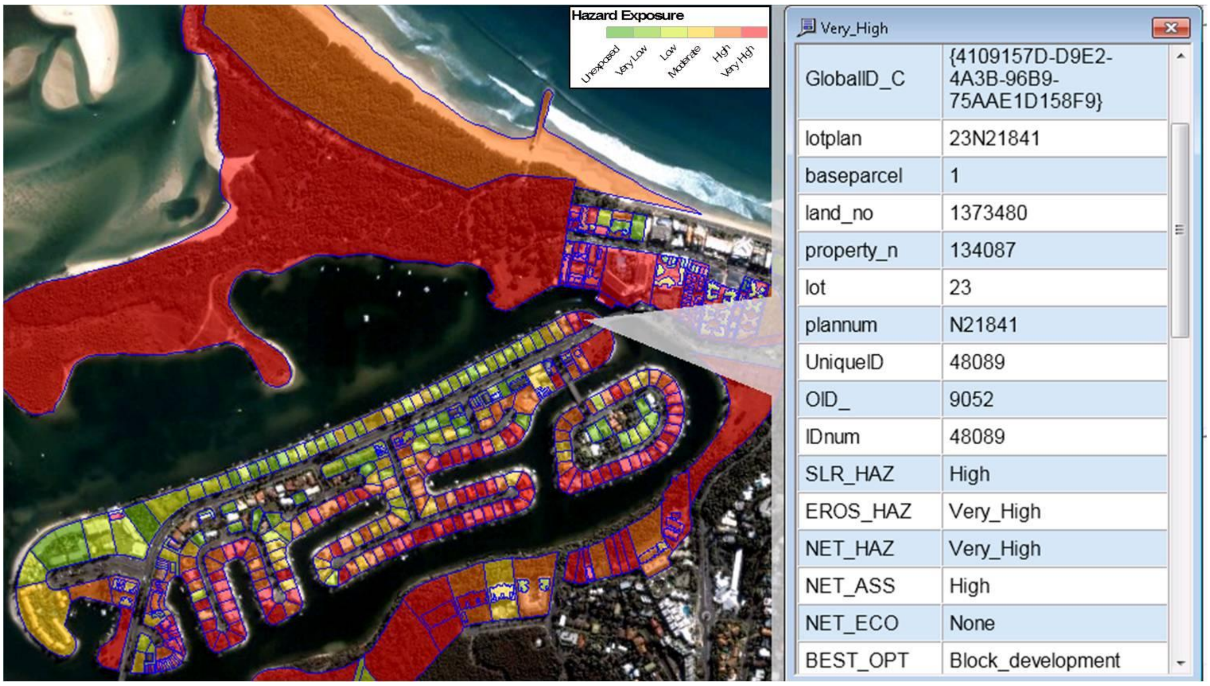


Figure 27. Results from the spatial MCA for Noosa for the model variant where only the criterion protection of environmental assets and a long-term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

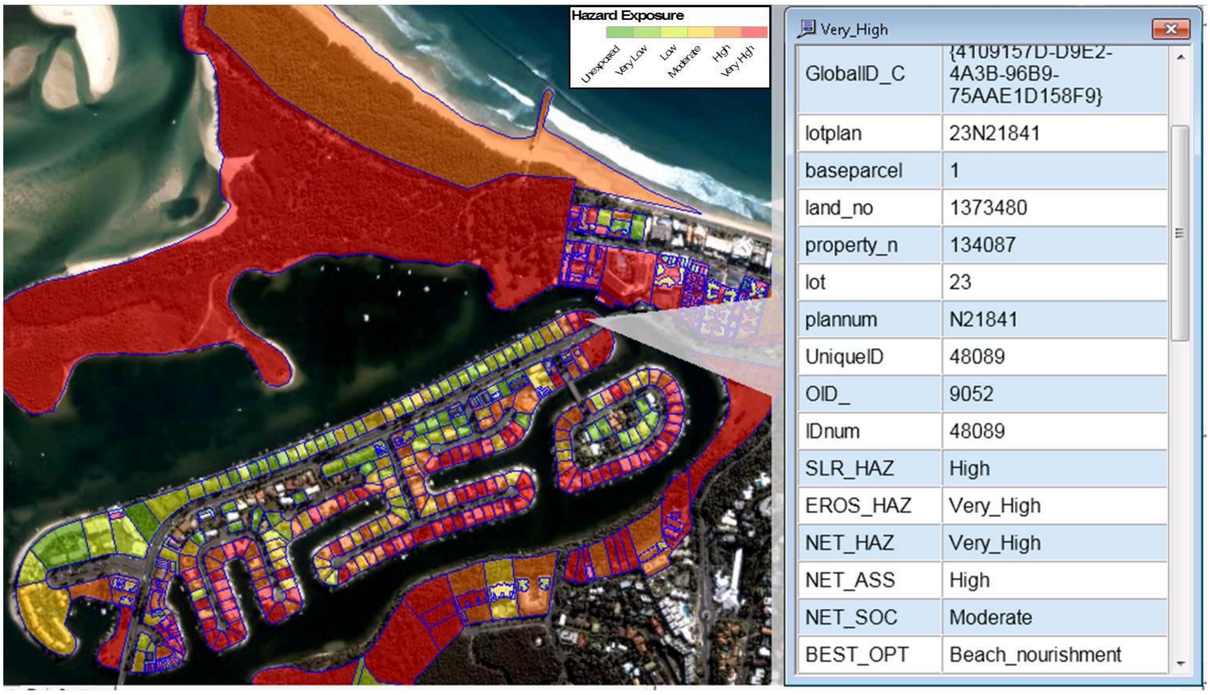


Figure 28. Results from the spatial MCA for Noosa for the model variant where only the criterion protection of social assets and a long-term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

4.2.2.3 Bega Valley Shire Council

To visualise the results from the Stage II MCA for Bega Valley Shire Council, we focus on the town of Merimbula, specifically the properties backing Merimbula Beach. The map in Figure 29 indicates a very high hazard exists for a number of properties in the area including residential properties and the Merimbula Beach reserve. The reserve ultimately acts like a buffer against coastal hazards for those properties facing the foreshore. As a consequence, many of the buildings along Ocean drive are not exposed and those that are experience relatively low levels of exposure. In contrast, the properties along Fishpen Road are at greater risk, simply due to the lack of a buffer between residential housing and the water. The map selects a single property at the corner of Fishpen Road and Calendo Court and the table lists the various output variables from the model for that location for the long term-time horizon. The results indicate a very high hazard score. Meanwhile, the property is associated with a very high financial value, high social value and moderate environmental value based on spatial data and indicators (Section 4.1.2.3). As a result of these factors, the best adaptation option for the location is removable structures, reflecting the high degree of vulnerability for that location. If one examines the same property over the same time-scale using just the criterion of environmental protection (Figure 30), however, the best adaptation option changes to blocking development, which Local Government staff considered more environmentally friendly than removable structures.

Figure 29. Results from the spatial MCA for Merimbula for the model variant where all criteria are considered and a long term time horizon. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

Figure 30. Results from the spatial MCA for Merimbula for the model variant where the only criterion considered is protection of financial assets over the long-term. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

The following figure (Figure 31) focuses on the same map extent but targets a different property with a significantly lower hazard characterisation. Meanwhile, the distribution of assets at this location are comparable to the previous location. The reduced risk associated with this site results in a change in the best adaptation option. Here, increasing setbacks is judged to still be a viable adaptation option, as only a small fraction of the property is at risk, even over the long-term.

Figure 31. Results from the spatial MCA for Merimbula for the model variant where the only criterion considered is protection of environmental assets over the near-term. Shading of each property reflects the level of exposure to coastal hazards inundation and erosion (see legend in figure). Properties without shaded were judged to not be vulnerable to coastal hazards, even over the long-term time horizon.

4.2.3 Identifying Robust Adaptation Options

The spatial MCA results provide significant detail regarding the utility of over a dozen illustrative adaptation options over thousands of different properties. However, those results also indicate that the type of adaptation option selected for a given location is sensitive to the underlying values considered in the MCA. There is no single ‘right’ set of values or value weightings. Therefore, if reconciling the appropriate values framework to use in the MCA proves problematic, it is perhaps useful to aggregate such information back to a more general level in order to extract some simple insights regarding which types of adaptation options are robust to such uncertainties over all the time horizons. By examining which options perform particularly well or particularly poorly across all four variants of the Bayesian model within (or among) each case study region, one can identify options that are insensitive to the values employed by decision-makers. Such options should in principle be supported by a cross-section of stakeholders and therefore more straightforward to implement.

To assess the robustness of different adaptation options for each case study region, information regarding the favourability of each adaptation option with respect to each exposed property was aggregated and plotted for each MCA model variant. This enabled the overall utility of each adaptation option for each study region to be evaluated and compared across the different model variants to assess the sensitivity of the performance of a particular adaptation option to underlying values. This information was subsequently compiled into an overall robustness index (R_i), defined as the fraction of properties in each study region for which a given adaptation option was evaluated to be ‘marginally favourable’, ‘favourable’ or ‘highly favourable’ across all model variants. Hence, the equation for the Robustness index was as follows:

$$R_i=[F_{v1} + F_{v2} + F_{v3} + F_{v4}]/[P_{exp} X 4]$$

where F_{v1-4} = the number of properties for which a particular adaptation option was evaluated as favourable for each of the four model variants and P_{exp} = the total number of exposed properties in the region. The resulting index ranged from 0 to 1, with a result of 0 indicating a particular adaptation option was not favourable for any property in any model variant and a value of 1 indicating an option was favourable for all properties across all model variants. This approach was applied to results from each of the study regions, as discussed further in the following subsections. However, the discussion here uses findings from the long-term time horizon to illustrate output from the Stage II MCA.

4.2.3.1 Sydney Coastal Councils Group

The evaluation of different adaptation options for exposed properties in the Sydney Coastal Councils Group region against all 16 of the MCA criteria indicated that soft protection and retreat measures are the most favourable options (i.e., they have the highest utility based upon the criteria considered) (Figure 32). This evaluation includes consideration for the long-term time horizon given the subjective preferences of Local Government staff, the distribution of hazards and assets and other decision constraints. The most obvious result is the general low utility of protection measures (hard and soft). This is a consequence of several factors including:

- many properties being poorly suited for the application of protection measures to address erosion; and
- the general bias against seawalls and revetments as well as the requirement in the model for those options to be applied only to areas with both high risk of exposure and high financial asset values.

For other options, their utility is closely linked to the criteria considered in their evaluation. When all criteria were included, accommodation measures generally evaluated quite unfavourable, with the exception of removable structures. Rather, retreat measures such as blocking development or rolling easements had high utility. Increasing setbacks and/or acquisition of properties were favourable in some circumstances, depending on the conditions at the property of interest. For example, the model discounted increasing the setback of the majority of a property was subject to coastal hazards, and acquisition of properties was reserved for those with a very high level of exposure to hazards.

This evaluation differs markedly, however, if one considers just a single criterion as opposed to all criteria. For example, in the model variant that considered only whether or not an adaptation option provided protection for financial assets, the various retreat options evaluated less favourably due to the implications of such options for property damage and loss. When only the protection of social assets was used as a criterion, only a few accommodation options routinely perform well across the region. Interestingly, the model variant that considered only the protection of environmental assets yielded results similar to the model variant with all 16 decision criteria. As mentioned previously in the Stage I analysis (Section 3.2.1), this suggests that when a long-term planning horizon is used, those options that protect environmental assets also tend to be protective of other values, at least from the perspective of Local Government.

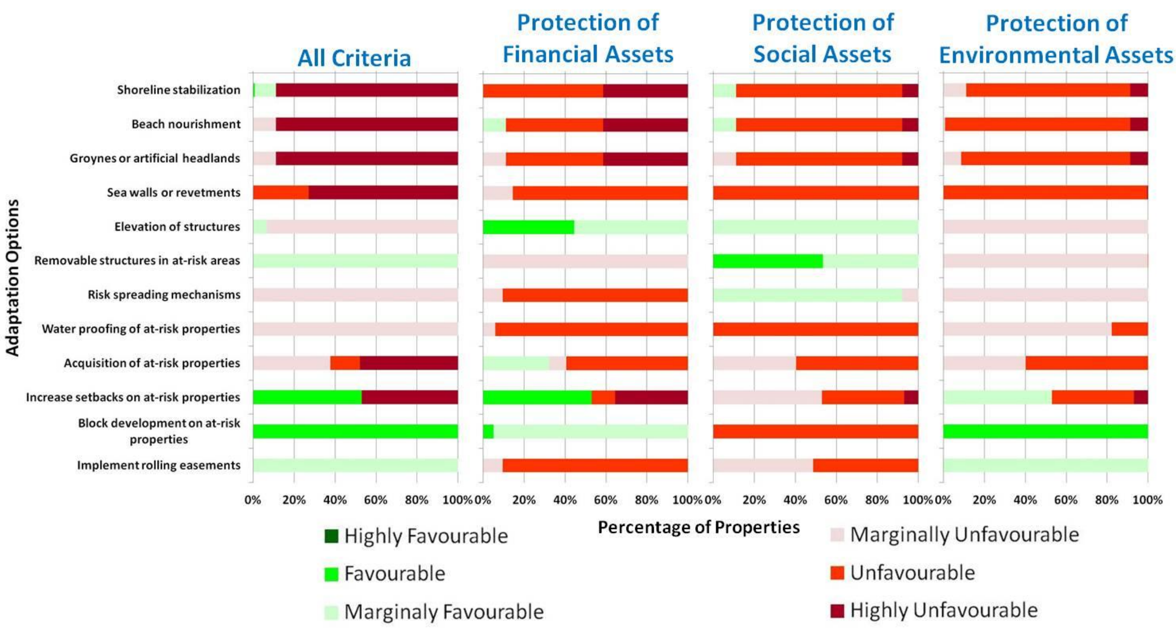


Figure 32. Evaluation of different adaptation options for exposed properties in the Sydney Coastal Councils Group region. The evaluation was conducted with each of the four variants of the Bayesian model using a long-term time horizon. The bars associated with each adaptation option reflect the relative frequency with which a given favourability rating was assigned to properties in the region.

In looking across the results for different model variants, the robustness index calculations for Sydney Coastal Councils Group suggest that the retreat options of blocking development and rolling easements have the greatest overall utility (Figure 33). This was followed by the accommodation options of elevation of structures or the use of removable structures. In contrast, none of the other accommodation options consistently had robustness index values above 0.5, indicating they evaluated unfavourably more often than favourably for properties in the region.

The robustness index also indicated that, for any given adaptation option, the robustness of the option tended to be greater over the mid-term time horizon than either the near-term or long-term. This likely represents a transition point, as some options perform well against certain criteria over the near-term by poorly over the long-term. Other options behave in the opposite manner. Hence, the mid-term time horizon is where these strengths and weaknesses are somewhat in balance.

4.2.3.2 Sunshine Coast Council

The evaluation of adaptation options for exposed properties in Sunshine Coast Council against all 16 of the MCA criteria yielded results that were somewhat similar to those for Sydney, particular with respect to the various protection measures (Figure 34). However, both accommodation options and retreat options tended to evaluate better for Sunshine Coast Council than for Sydney. Model variant which considered only the protection of financial assets as a criterion yielded similar results as the model variant that considered all criteria, with the exception of rolling easements which evaluated quite poorly in this regard. Meanwhile, the other two model variants that focused purely on the protection of social or environmental assets yielded quite similar results. They differed from the first two model variants with respect to the use of risk spreading mechanisms and water proofing, which evaluated slightly unfavourably. This is likely due to the perception that these options create 'moral hazard' over the long-term by reducing disincentives for development in at-risk areas.

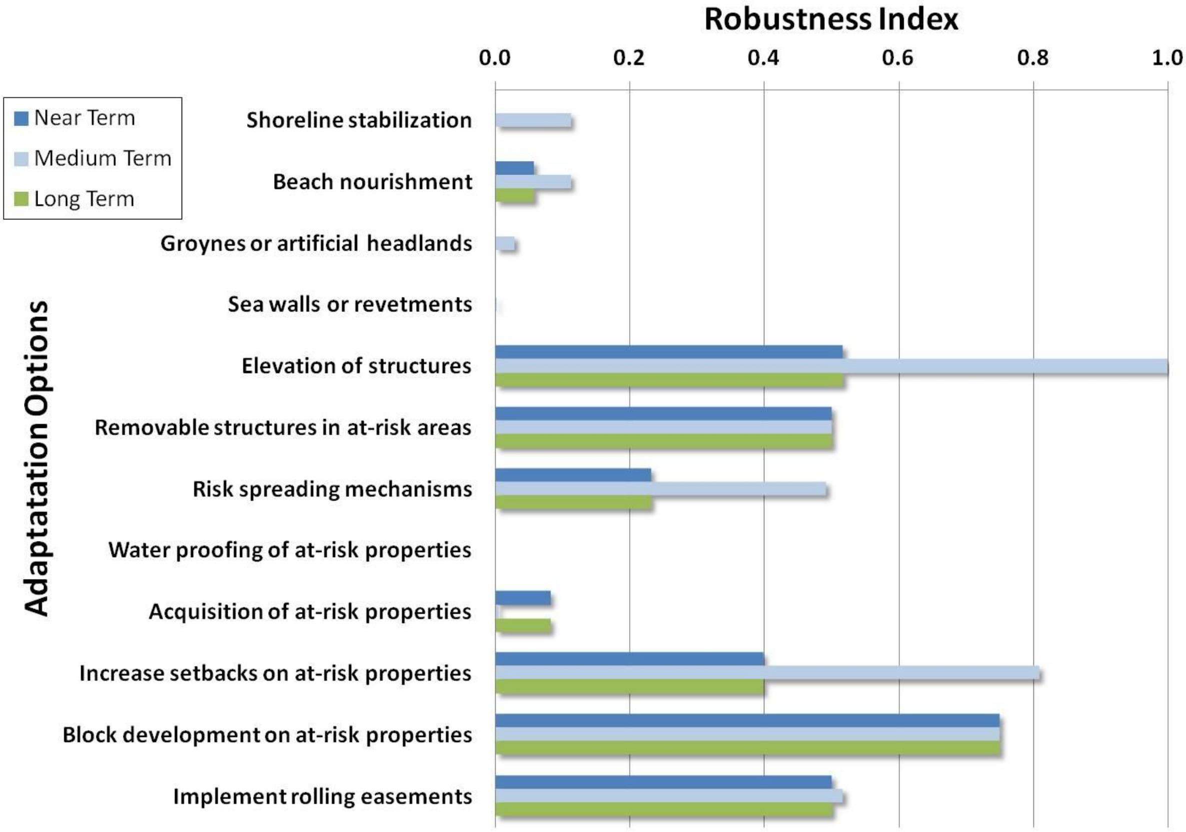


Figure 33. Assessment of the robustness of different coastal adaptation options in the Sydney Coastal Councils Group region. A result of 0 indicates a particular adaptation option is not favourable for any property in any model variant and a value of 1 indicates an option is favourable for all properties across all model variants.

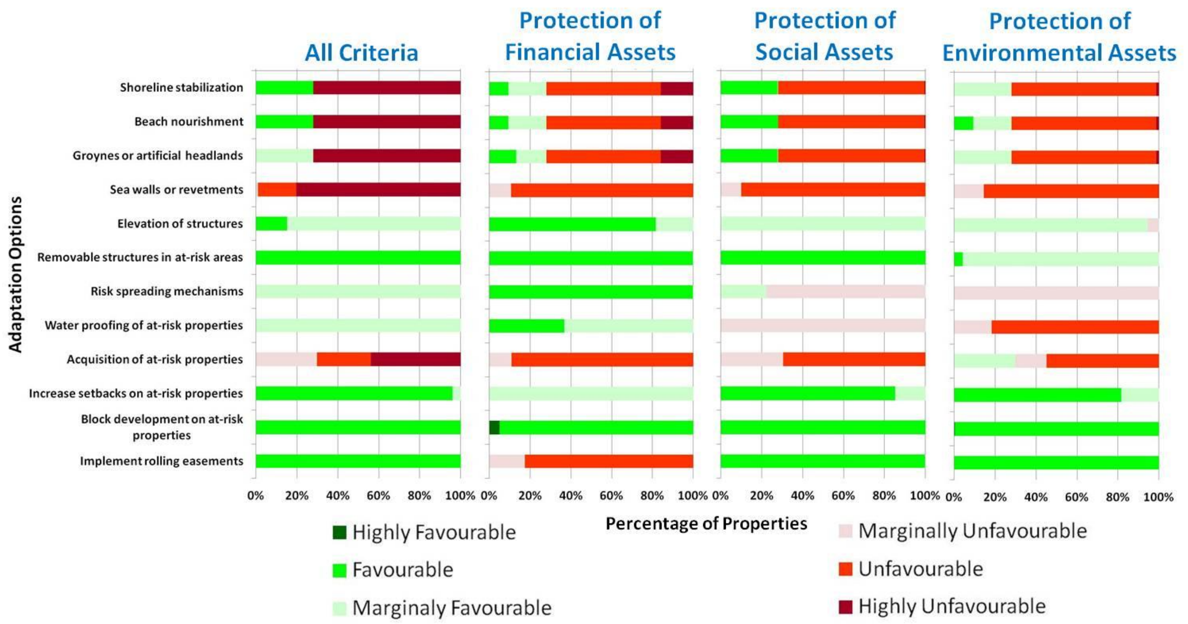


Figure 34. Evaluation of different adaptation options for exposed properties in the Sunshine Coast Council. The evaluation was conducted with each of the four variants of the Bayesian model using a long-term time horizon. The bars associated with each adaptation option reflect the relative frequency with which a given favourability rating was assigned to properties in the region.

The robustness indices for coastal adaptation options for Sunshine Coast Council (Figure 35) mirror the results for Sydney, which is indicative of some shared understanding with respect to the implications of different adaptation options for Local Government. Specifically, two accommodation options and two retreat options evaluated favourably for all properties in all model variants. On the other hand, sea walls and revetments evaluated poorly for all properties in all model variants, and acquisition of at-risk properties was also only seen as having positive utility in a small fraction of properties. In contrast with Sydney, little variation in robustness was observed for different adaptation options over different time horizons.

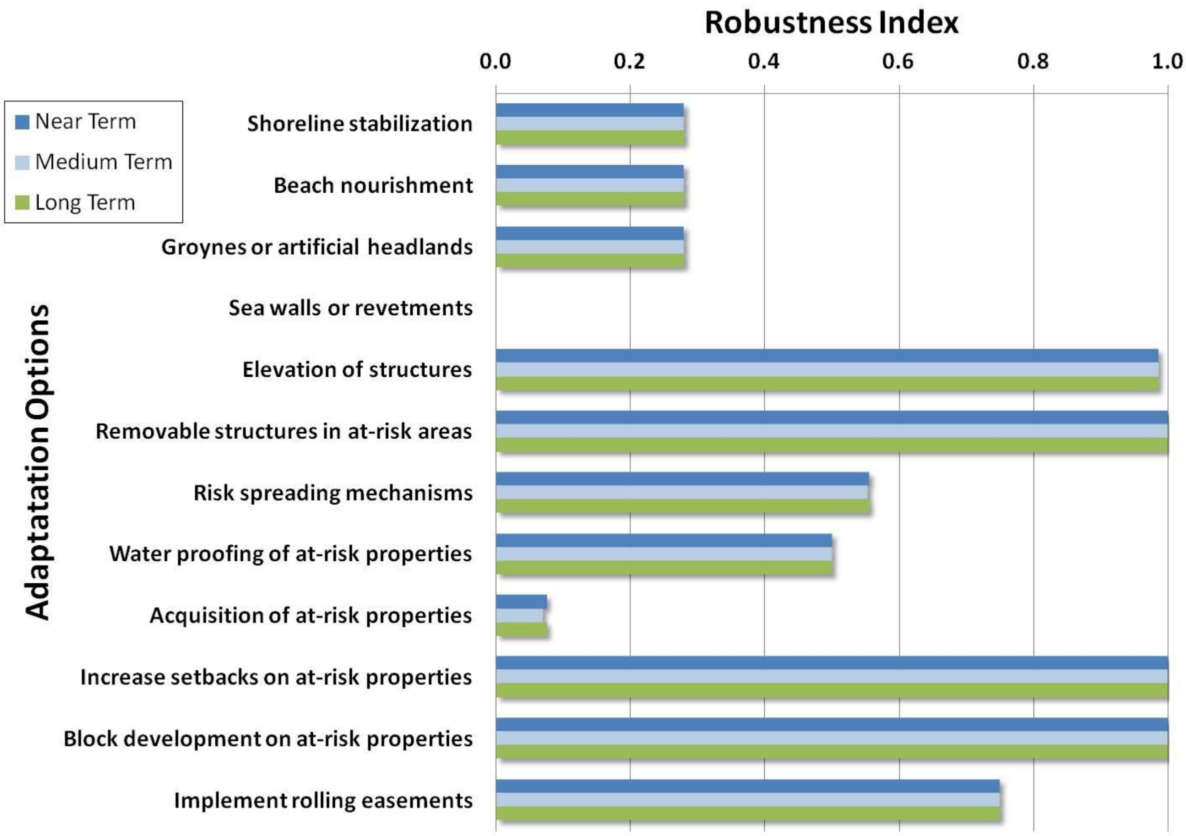


Figure 35. Assessment of the robustness of different coastal adaptation options in Sunshine Coast Council over different time horizons. A result of 0 indicates a particular adaptation option is not favourable for any property in any model variant and a value of 1 indicates an option is favourable for all properties across all model variants.

4.2.3.3 Bega Valley Shire Council

The evaluation of adaptation options for exposed properties in Bega Shire Council was analogous to the other two case study regions with respect to the use of protection measures, with such measures being judged favourably for only a small fraction or properties (Figure 36). The robustness index also indicated that only one adaptation option (removable structures) was associated with a robustness index close to 1 for Bega Valley Shire Council (Figure 36). Options such as the elevation of structures, increasing setbacks, blocking development and rolling easements tended to evaluate favourably more often than not among the model variants. As with Sydney, the robustness index was often sensitive to the time horizon, again reflecting temporal trade-offs with respect to how different options perform.

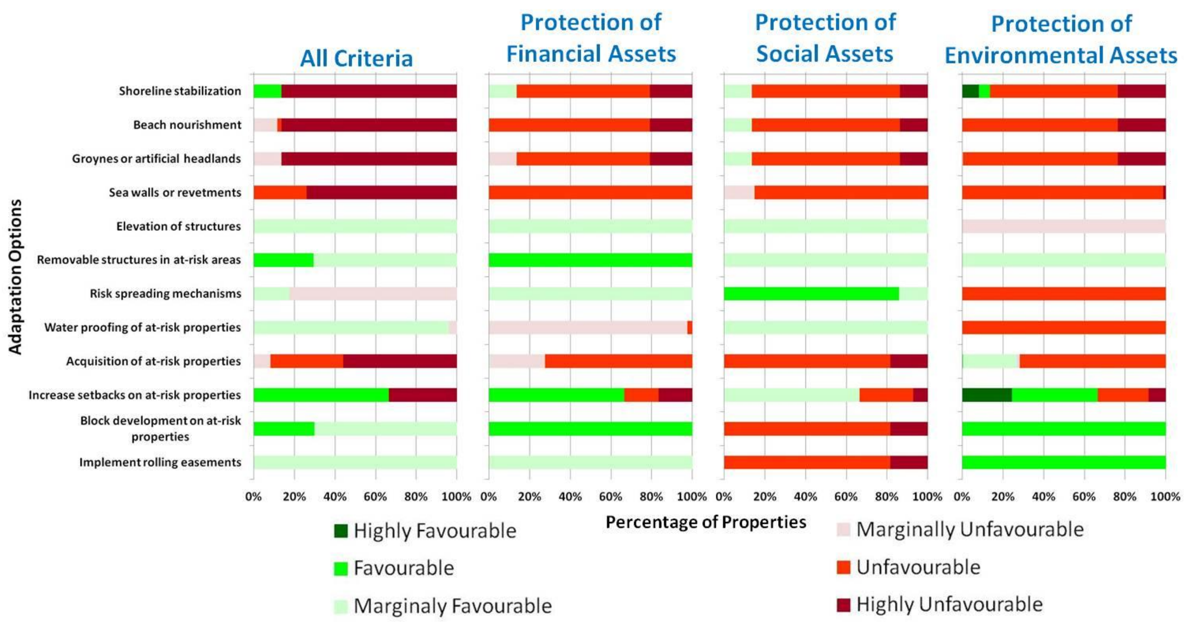


Figure 36. Evaluation of different adaptation options for exposed properties in Bega Valley Shire Council. The evaluation was conducted with each of the four variants of the Bayesian model using a long-term time horizon. The bars associated with each adaptation option reflect the relative frequency with which a given favourability rating was assigned to properties in the region.

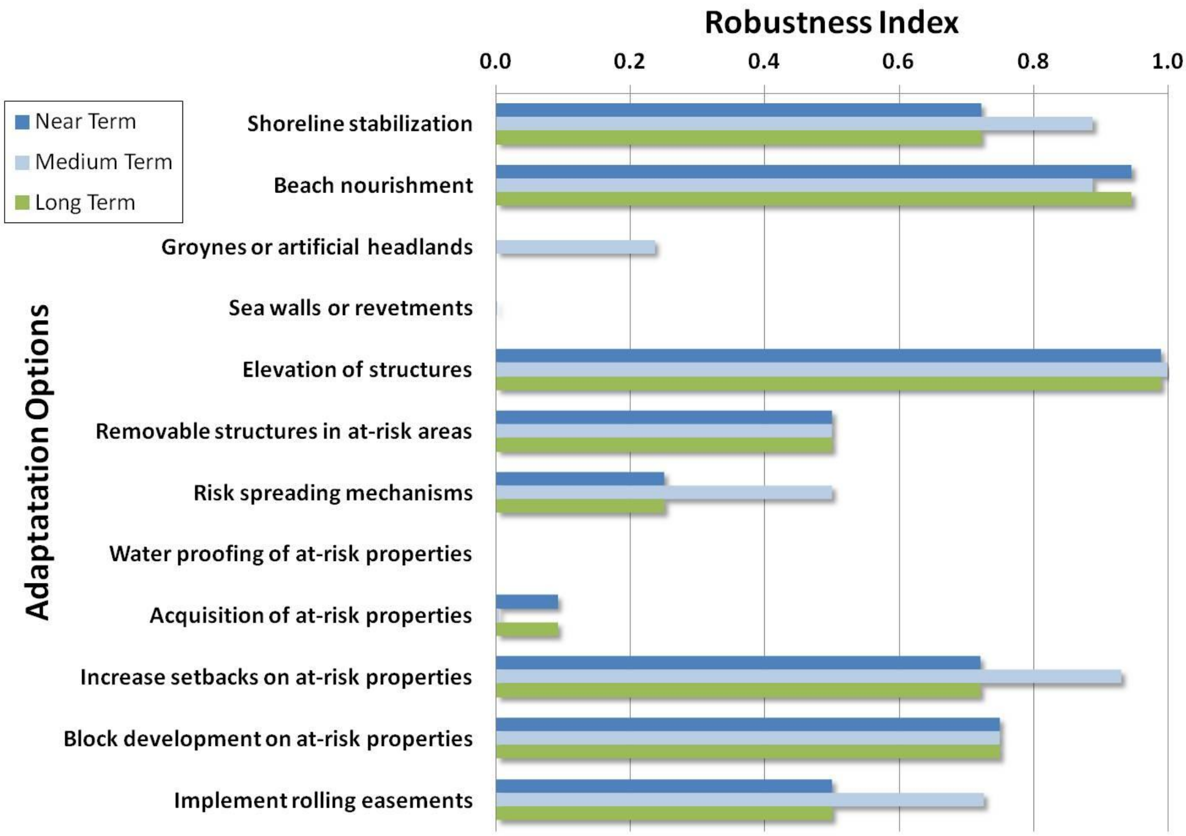


Figure 37. Assessment of the robustness of different coastal adaptation options in Bega Valley Shire Council over different time horizons. A result of 0 indicates a particular adaptation option is not favourable for any property in any model variant and a value of 1 indicates an option is favourable for all properties across all model variants.

This analysis or the robustness of different adaptation options revealed that at times each study region had a somewhat different perspective on the performance of specific options. Yet, overall, the best performing and worst performing options were largely consistent among different regions. Protection measures, while appropriate for particular applications, are generally not appropriate for widespread deployment. Meanwhile, accommodation measures such as risk spreading mechanisms were the least popular along with waterproofing and hard protection measures. Overall, these results indicate a preference to maintain the natural amenity of the coastline, even if artificial means (e.g., beach nourishment) are required, as opposed to more structural fixes.

5 Flexible Decision Pathways for Coastal Adaptation Planning

- ***The preference of Local Government staff and therefore the Stage II MCA was to move toward anticipatory adaptive planning and development that avoided decisions that create the potential for an escalation of future risk.***
- **Strategic planning for adaptation may be aided by the consideration of 'risk-weighted decision pathways', where different portfolios of adaptation options are planned and implemented over time, depending on the perceived risk.**
- **Although one can use formal planning tools such as MCA to identify priority adaptation options, *ultimately effort must also be invested in the monitoring and evaluation of adaptation implementation to ensure priority options achieve desired outcomes.***

Traditional adaptation planning focuses on identifying discrete adaptation options that address discrete risks or vulnerabilities to systems of interest. As such, this planning tends to be fairly static, which creates challenges for designing adaptation strategies that are flexible to the inherent uncertainties associated with climate change and community preferences regarding appropriate policy responses.

Adaptation planning largely assumes the key vulnerability and/or risks are known. As such, adaptation options are identified based upon a very simple dichotomy of acting if this risk is sufficiently high, else no additional action is necessary. However, this approach to adaptation planning overlooks the fact that risk is not simply an either/or proposition – rather there are gradients of risk, which suggest the need for more nuanced responses. In addition, understanding of risk may change as new information is acquired and/or as stakeholder risk tolerances shift. Meanwhile, adaptation planning often neglects the issue of how to integrate and coordinate portfolios of adaptation options. For example, there is unlikely to be a single adaptation 'silver bullet' that effectively addresses a particular risk. One might need to implement multiple policy changes to facilitate a desired adaptation objective, and the preferred options might change over time. For example, the MCA results presented previously illustrate strong time preferences among Local Government staff with respect to adaptation solutions. While it is possible to identify a single option as being the 'best', the MCA also indicates that multiple adaptation options may be considered appropriate for a particular location. Ensuring coordination and harmonization among portfolios of options increases their efficiency and reduces the costs of implementation. As such, while the identification of plausible adaptation options to respond to particular risks is fundamental to adaptation planning, that planning should also develop methods for the integrated implementation of those options over time.

One approach to achieving such integration is to frame long-term adaptation strategies 'risk-weighted decision pathways', where different portfolios of adaptation options are planned and implemented over time, depending on the perceived risk (Table 17). For example, when future risk to property and assets is perceived to be negligible or low, risk managers may opt to continue to rely upon existing management strategies and measures. Meanwhile, if the perceived risk is high, the response of decision-makers will vary depending on the time-scales over which that risk will unfold. If the risk is immediate, such as a coastal storm event that places houses at immediate threat of inundation or erosion, decision-makers may be forced to act in reactive mode with emergency management measures. Such a response offers little time for consultation and deliberation and the response options may be quite limited giving decision-makers little flexibility. In contrast, if a significant risk is likely to emerge over a longer period of time, decision-makers have greater flexibility to act in anticipation of a future risk and phase in policies and measures over time. Greater investments can also be made in deliberation among stakeholders to identify novel solutions that meet multiple societal objectives.

Table 18. Simple framework illustrating different approaches to adaptation decision-making. Each cell of the figure suggests a different adaptation pathway should be employed depending upon the level of risk that is anticipated (hence the label, 'risk-weighted decision pathways').

<table>
<tr><th colspan="2"></th><th colspan="2">Time Horizon</th></tr>
<tr><th colspan="2"></th><th>Near Term</th><th>Long Term</th></tr>
<tr><th rowspan="2">Perceived Risk</th><th>Low</th><td colspan="2">Managers can continue to rely upon existing management strategies while monitoring for potential changes in risk and/or changing community preferences</td></tr>
<tr><th>High</th><td>Need for reactive emergency management to address immediate threats to established community values</td><td>Need for anticipatory strategic planning to avoid or mitigate future risk</td></tr>
</table>

The results of the MCA conducted in the current project tend to reflect this concept of risk-weighted pathways. For example, the Stage II MCA indicated that only a fraction of properties within the case study regions were likely to be exposed to inundation or erosion in the decades ahead. Hence, not all coastal locations are vulnerable to climate change, and therefore discriminating between properties at risk and those that are out of harm's way is an important first-step in prioritising adaptation. Hence, the high priority placed by Local Government staff on vulnerability assessment as a cross-cutting adaptation option. At the same time, Local Government staff clearly reflected a general preference for shifting coastal adaptation away from protection measures toward a greater reliance upon retreat options over the long-term. While there was an acknowledgement that such measures have a role, particularly in protecting high value assets and/or in addressing immediate vulnerabilities, over long time scales, the preference of Local Government staff was to move toward anticipatory adaptive planning and development that avoided such vulnerabilities.

The value of MCA methods and the prototype tools developed for this project is to elucidate the potential risks to different locations over different time scales and screen a portfolio of adaptation options to determine which can contribute to managing risk over those time scales. However, the MCA examines adaptation options independently and while it can screen such options for utility, subsequent decision-making and deliberation is needed to determine how to construct portfolios of options as well as the additional actions that may be needed to lay the groundwater for their implementation. Furthermore, while tools such as MCA can assist in prioritising adaptation options for Local Government, ultimately effort must also be invested in the monitoring and evaluation of adaptation implementation. To that end, *Prioritising Coastal Adaptation and Development Options for Local Government* included an M&E component which involved the development of a framework for undertaking such M&E in a Local Government context. This provides a mechanism for testing whether selected adaptation options are in fact performing as anticipated, thereby providing an evidence base for the continuation or revision of adaptation efforts.

6 Discussion

- **Multi-criteria analysis offers a number of advantages for supporting adaptation planning: scalability for use in different contexts, inclusion of monetary and non-monetary values, and identification of potential trade-offs.**
- **The current study also reflects potential challenges in using MCA: high sensitivity to subjective judgments of stakeholders, potential for endless debated regarding appropriate criteria and weights.**
- **The tendency for the prioritization of options to change over time given the dynamics of communities, natural environments, and the policy arena emphasizes the need to consider flexible options that avoid 'lock in' as well the potential benefits of planning for the staged implementation of different options.**
- **Overall, financial and environmental criteria tended to be the key factors influencing which options were evaluated highly versus poorly. Given that options that performed well against financial criteria also performed well against environmental criteria, there may be greater opportunities to identify options that make sense from both perspectives than is often appreciated.**

The approach presented here for undertaking an MCA for coastal adaptation options illustrates both the potential strengths and challenges of MCA for supporting decision-making. The current study, for example, illustrates how a diverse set of criteria can be used to prioritise different adaptation options, without the need for translating those criteria into common monetary units as is often the case with traditional cost/benefit analysis. In so doing, MCA also allows one to explore the potential trade-offs implied by the selection of a particular adaptation option. For example, as evident in the results reported here, an adaptation option such as beach nourishment may perform well from a social values perspective as it helps to maintain shorelines and ensure the continued accessibility of beaches for public use and recreation. Nevertheless, the analyses reported here also indicate that implementing beach nourishment has negative consequences due to its high cost and concerns about environmental consequences. Furthermore, by eliciting stakeholder knowledge in the parameterization of an MCA, the analysis may be tailored to mirror actual decision-making criteria and processes of decision-makers and stakeholders. This enhances the likelihood that the analysis will be relevant to potential end users.

Despite these advantages of MCA, its implementation and the subsequent interpretation of results is not without challenges. The approach used here relied heavily upon subjective judgments of both the research team that structured the analysis and the Local Government staff that provided input. While decision-making on adaptation in practice cannot avoid subjective judgments, relying solely upon such information can pose problems. One example that emerged from the current study was the relatively small number of questionnaire respondents from Sunshine Coast Council, which reduced confidence that the weights used for that case study region in the Bayesian MCA were a robust reflection of that council's values. Nevertheless, a fairly high degree of consistency was observed when results were stratified by case study region. Similarly, results were quite similar between the initial performance assessment and the Bayesian analysis. Hence, the results appear to be relatively robust, at least with respect to the data collected from the sample of Local Government staff in the three study regions.

The results of the MCA revealed that the financial and environmental dimensions were significant drivers of the analysis and the apparent utility of different adaptation options. For example, the relatively low utility of protection measures and the high utility of retreat and cross-cutting measures reflected Local Government perceptions of the high financial burden of the former, particularly when compared to the latter. At the same time, however, the scores of different adaptation options against these financial criteria were generally highly correlated with those of the environmental criteria. Hence, those adaptations options that scored well on financial criteria also tended to score well on environmental criteria. This suggests that, at least from the perspective of Local Government, assumptions regarding the inherent trade-offs between the protection of financial assets and the protection of environmental assets may be overstated.

Rather, the more apparent trade-off appeared to be between one of the governance criterion and criteria associated with the other three dimensions. Specifically, scores of adaptation options for the G4 governance criterion pertaining to the infringement of adaptation options on property rights of individuals, tended to be inversely correlated with those of other criteria. This suggests that many of the traditional coastal adaptation options available to Local Government, while making sense from a Local Government perspective, may have implications for other decision-makers (such as private property-owners or businesses) that have different priorities and management objectives. This highlights the importance of considering the opportunities and constraints associated with governance (and different scales of governance) in selecting appropriate adaptation options.

The other very clear consideration that emerged from the analyses reported here is the sensitivity of the utility of different adaptation options to the time horizon under consideration. Stakeholders who participated in the evaluation of coastal adaptation options clearly anticipate the risks of climate change and sea-level rise to increase over time. This results in some adaptation options declining in utility when longer time horizons are considered due to concerns about their effectiveness in the face of that growing risk. This is best demonstrated with the soft protection measure of shoreline stabilization. This option, while performing well across many criteria over the near-term, loses effectiveness beyond a couple of decades, due to stakeholder assumptions about the rate and magnitude of sea-level rise and beach erosion largely exceeding the capacity of this option to manage risks to coastlines. Other considerations also reduced the utility of different options over time. These included rising costs associated with options that must be maintained indefinitely into the future (e.g., beach nourishment); proliferation of incentives for risk-seeking behaviour (e.g., waterproofing, risk spreading mechanisms); and concerns regarding 'moral hazard' should Local Government be perceived as the insurer of last resort (e.g., property acquisition). In addition, simply the fact that the future is uncertain reduced the confidence in the utility of different adaptation options beyond the near-term. Changes in the political atmosphere, technology, or community values could all influence the fate of adaptation efforts, yet all of these factors are quite difficult to predict. Overall, this time sensitivity suggests there is potential value in Local Government thinking more strategically about methods for staging adaptation options over time in order to maximise the overall utility of coastal adaptation, with different options being phased in or out as appropriate. This could include monitoring the environment for the emergence of trigger points that suggest hazards or risk have reached the point where a fundamental shift in management response is necessary.

While all of these insights provide new context to understand how Local Government view coastal adaptation, the true novelty of the project arose from its generation of property-specific evaluations of adaptation options. As the methods developed in the Stage II MCA were new and previously untested, the results of the Stage II MCA are best interpreted as a 'proof-of-concept'. The 12 adaptation options included in the analysis do not represent the full range of possible responses and the data sources used to understand the distribution of financial, social and environmental assets on coastal landscapes provided a coarse level of discrimination, but more detail would be needed to support real world decision-making regarding adaptation for a specific adaptation. Nevertheless, the Stage II MCA illustrated how geospatial data could be integrated with subjective value preferences of stakeholders to evaluate adaptation options in a manner that reflects the heterogeneity of coastal landscapes. In particular, the results presented in this report highlight how adaptation options that are likely to yield the most benefit to the greatest number of properties can be identified. Specifically, the elevation of structures and/or the use of structures that can be readily moved or abandoned consistently satisfied the MCA criteria in each study region, even when viewed from narrow values perspectives. In addition, some retreat options also evaluated favourably, particularly increasing of coastal setbacks, which is also a common risk management option currently in use in the Australian coastal zone.

By using a Bayesian Belief Network to facilitate the analysis, uncertainty in both geospatial information and Local Government values could be incorporated into the analysis. Meanwhile, by using a GIS environment to visualise the MCA results, the project developed a mechanism to facilitate communication of results and highlighted the potential of using GIS as a platform for the convenient delivery of a broad range of information about coastal hazards, assets and plausible management responses. Hence, in addition to the execution of an MCA for Local Government, the project also suggests there may be future opportunities for the development of geospatial adaptation information systems to advance decision support for adaptation planning efforts.

7 Next Steps and Future Applications

- ***There are a range of additional activities and tool development that could provide additional utility to the MCA approaches developed as part of this project: enhancing the availability of spatial data for assets of interest; developing location-specific MCA tools; streamlining the integration of data into analysis tools; and the developing of information systems that provide details regarding hazards, risks, and adaptation options to Local Government staff.***

Prioritising Coastal Adaptation and Development Options for Local Government was initiated to develop and test new approaches to evaluating adaptation options for Australia's coastal communities. The outcomes of the project, particularly with respect to the MCA (both Stages I and II) indicate there is potential utility in MCA methods for identifying potential trade-offs in different adaptation options. Furthermore, the project introduced conceptual and methodological approaches for placed-based evaluation of the utility of different adaptation options and the visualisation of those options within a GIS environment.

Nevertheless, while presenting a proof-of-concept for future spatial MCA of climate adaptation options, a range of additional activities and tool development could provide additional utility to the MCA approaches developed as part of this project. These include the following:

1) **Enhanced Data Acquisition** – While a broad range of data sets were incorporated into the analysis, such data change regularly. For example, different model estimates of sea-level rise and/or storm surge have emerged within Australia in recent years. Similarly, land use classifications, development, and property values also change over time. In addition, the current study likely made use of only a fraction of the data sets that could have been incorporated if challenges of access, licensing, and internal consistency were overcome.
2) **Streamlined Data Work Flow** – Spatial MCA methods require significant data inputs. While a range of existing software tools exist for spatial optimisation methods (including Community Viz[7], LUMASS[8], and analysis tools in ArcGIS) that could be readily deployed to support spatial adaptation planning. However, the current study also accounted for non-spatial decision criteria that are important to evaluating adaptation options. Enhancing the useability of the NETICA tools developed as part of this project could be achieved by developed more robust data management tools to automate the processing of various data sources into case files that can used with NETICA. This would allow for streamlined 'plug-and-play' of different data sets and reduce the time required to process data layers.
3) **Site-Specific MCA Tools** – The current project specifically developed an approach to spatial MCA that could be applied to an entire region, including thousands of properties, at a time. While efforts were made to identify data sets that enabled the discrimination of different properties based upon their exposure to coastal hazards and associated financial, social, and environmental assets, some generalizations were necessary. While such a region-wide analysis can function as a screening tool, decision-making on adaptation will ultimately be made on a site-by-site basis. As such, developing MCA tools that are designed to evaluate

[7] http://placeways.com/communityviz/
[8] http://www.alex-herzig.de/lumass/lumass.htm

adaptation options at individual locations may be a useful next step to support Local Government adaptation planning. Such tools could be more streamlined as users would need to input information only for a particularly location. Furthermore, that information could be obtained through site inspection and survey and thus would be optimised for the location in question. Place-based tools could be developed relatively easily as a Microsoft Excel application. With greater investment in software engineering, more specialised applications could be developed for mobile platforms.

4) **Adaptation Information Systems –** The GIS-based visualisations developed for this project provide not only information on the utility of different adaptation options, but also a range of details regarding exposure to different hazards and assets at-risk. Adaptation planning will ultimately depend upon having easy access to multiple forms of information relevant to decision-making. As such, adaptation decision-support must ultimately move beyond the risk/vulnerability assessment and the development of potential adaptation options to more integrated assessment of options and the delivery of information to end users, such as Local Government staff. The current study therefore represents a template for such an adaptation information system that could be developed to achieve these goals.

References

Department for Communities and Local Government (2009) Multi-criteria analysis: a manual. Department for Communities and Local Government, London.

Greiner, R., Herr, A., Brodie, J., Haynes, D. (2005) A multi-criteria approach to Great Barrier Reef catchment (Queensland, Australia) diffuse-source pollution problem. Marine Pollution Bulletin 51(1-4): 128-137.

Hallegatte, S. (2011) Uncertainties in the cost-benefit analysis of adaptation measures, and consequences for decision making. In *Climate: Global Change and Local Adaptation*, I. Linkov and T.S. Bridges (eds.), NATO Science for Peace and Security Series C: Environmental Security, pgs. 169-192, DOI 10.1007/978-94-007-1770-1_10.

Huang, I.B., Keisler, J., Linkov, I. (2011) Multi-criteria decision analysis in environmental sciences:Ten years of applications and trends. Science of the Total Environment 409:3578-3594.

Intergovernmental Panel on Climate Change (1990) Strategies for Adaptation to Sea-Level Rise. Report of the CZMS, Response Strategies Working Group of the IPCC. Ministry of Transport, Public Works and Water Management,The Hague, Netherlands, 127 p.

Johnson, S. Low-Choy, S., Mengersen, K. (2011) Integrating Bayesian networks and geographic information systems: good practice examples. Integrated Environmental Science and Management, DOI: 10.1002/ieam.262.

Lempert, R.J. (2002) A new decision sciences for complex systems. Proceedings of the National Academy of Sciences 99:7309-7313.

Kandlikar, M., Risbey, J., and Dessai, S. (2005) Representing and communicating deep uncertainty in climate change assessments. Comptes Rendus Geoscience 337(4):443-455.

Mangoyana, R.B., Thomsen, D.C., Smith, T.F., Preston, B.L., Maloney, M., Armstrong, I., Withycombe, G. (2012) Literature review of adaptation to climate change in the coastal zone. Prioritising Coastal Adaptation and Development Options for Local Government Coastal Adaptation Decision Pathways Project– Ref. 002144, University of the Sunshine Coast, Sippy Downs, Queensland.

Marinoni, O., Higgins, A., Hajkowicz, S., and Collins, K. (2009) The multi-criteria analysis tool (MCAT): A new software tool to support environmental investment decision-making. Environmental Modeling and Software 24(2):153-164.

McCann, R.K., Marcot, B.G., and Ellis, R. (2006) Bayesian belief networks: applications in ecology and natural resource management. Canadian Journal of Forest Research 36: 3053-3062.

Morgan, M.G., Kandlikar, M., Risbey, J., Dowlatabadi, H. (1999) Why conventional tools for policy analysis are often inadequate for problems of global change. Climatic Change 41: 1573-1580.

Mosadeghi, R., Tomlinson, R., Mirfenderesk, H., and Warnken, J. (2009) Coastal management issues in Queensland and application of a multi-criteria decision-making techniques, 1252-1256 Lisbon, Portugal, ISSN 0749-0258.

New South Wales Department of Planning, 2006, *The CCA Integrated Decision Framework: A guide for sustainable land use planning*, prepared for the Comprehensive Coastal Assessment (Department of Planning), Sydney.

Nyberg, J.B., Marcot, B.G., Sulyma, R. (2006) Using Bayesian belief networks in adaptive management. Canadian Journal of Forest Research 36:3104-3116.

Peel, J. and Godden, L. (2009) Planning for Adaptation to Climate Change: Landmark Cases from Australia." Sustainable Development Law & Planning 9(2): 37-41, 71-72.

Pollino, C.A., Woodberry, O., Nicholson, A., Korb, K., and Hart, B.T. (2007) Paramterisation and evaluation of a Bayesian network for use in ecological risk assessment. Environmental Modelling and Software 22:1140-1152.

Preston, B.L., Westaway, R.M., Yuen, E.J. (2011) Climate adaptation planning in practice: an evaluation of adaptation plans from three developed nations. *Mitigation and Adaptation Strategies for Global Change* 16(4):407–438.

Straton, A.T., Jackson, S., Marinoni, O., Proctor, W., and Wood, E. (2011) Exploring and evaluating scenarios for a river catchment in northern Australia using scenario development, multi-criteria analysis, and a deliberative process as a tool for water planning. Water Resources Management 25(1):141-164.

Ticehurst, J.L., Newham, L.T.H., Rissik, D., Letcher, R.A., and Jakeman, A.J. (2007) A Bayesian network approach for assessing the sustainability of coastal lakes in New South Wales, Australia. Environmental Modelling and Software 22: 1129-1139.

Watthayu, W. and Peng, Y. (2004) A Bayesian network based framework for multi-criteria decision-making. MCDM 2004, Whistler, B. C., Canada August 6-11.
Yohe, G.W. (2003) More trouble for cost-benefit analysis. Climatic Change 56(3): 235-244.

Appendix I. Questionnaire regarding values used in Local Government decision-making

Information for Survey Participants

Purpose of this survey
You are being asked to participate in a survey as part of a project investigating different approaches for managing the risks to coastal assets in your region due to climate change and sea-level rise. In this survey, you will be asked your opinions regarding the importance of different factors that may influence Local Government decision making. Your response to the questions within this survey will be integrated with other sources of information collected over the course of this project.

Please remember that:
Your participation in this survey is entirely voluntary. You are not required to answer the questions. The survey should take approximately 20 – 30 minutes to complete. You may discontinue your participation in the survey at any time. You will not receive any compensation for your participation.

Benefits
Your contribution will help ensure the perspectives of your local government area are represented in the project and subsequent analyses. Information emerging from this survey will be made available to participants in order to share learning among local government staff. This survey is one component of a larger project, which aims to build the capacity of local government to evaluate different management approaches to address the challenges of climate variability, climate change, and coastal hazards.

Confidentiality
We will keep the information you give us private and confidential. Your name will not be used in the final report. No answer you make will be linked to you by name. Only members of the research staff will be allowed to look at the records. When we present this study or publish its results, your name or other facts that point to you will not show or be used.

Persons to Contact
If you have questions about this survey, or taking part in it, you may contact:

Dr Dana Thomsen
Sustainability Research Centre
University of the Sunshine Coast
Tel. 5456 5043
Email: dthomsen@usc.edu.au

Section 1. Background Information

1. Background Information
Council: [Drop-down list]: **Department:** [Drop-down list]: **Job Role:** [Drop-down list]:

2. How would you describe your level of knowledge regarding the potential risks of climate change to your council?
☐Very Knowledgeable ☐Somewhat Knowledgeable ☐ Not at All Knowledgeable

3. How would you describe your level of knowledge regarding adaptation as a strategy for reducing the risks of climate change to your council?
☐Very Knowledgeable ☐Somewhat Knowledgeable ☐Not at All Knowledgeable

Section 2. Factors Affecting Council Decision-Making

Notes for Participants: The questions in this section seek your opinion on the relative importance of different factors or values in influencing current decision-making by council. In considering your response, you may consider a single policy or practice with which you are particularly familiar or you may think more generally about what drives decision-making across council.

4. How important are the following factors in the design and implementation of council policies or practices?

4.1. Factors Associated with Planning, Management and Governance

A policy or practice is consistent with local planning policy or other local guidelines

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice is consistent with State planning policy or other State guidelines

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice has been successfully tested in other locations

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice is consistent with best practice

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice creates opportunities for building new relationships or partnerships

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

Are there any other factors pertaining to planning, management, or governance that you consider important?

4.2. Financial/Economic Factors

The cost to council of implementing a policy or practice over its entire life cycle

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

The capacity of council to manage the costs associated with implementing a policy or practice within the constraints of council budget

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

The availability of opportunities to share the costs of implementing a policy or practice (e.g., with State government, private businesses, or local residents)

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

The cost to the community (e.g., residents or businesses) of implementing a policy or practice over its entire life cycle

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

A policy or practice preserves or enhances existing property rights and values

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

The potential for financial/economic benefits for council and/or community to arise from implementation of a policy or practice

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Confidence that the benefits of implementing a policy or practice will outweigh the costs

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Are there any other economic or financial factors that you consider important?

4.3. Environmental Factors

A policy or practice is consistent with local environmental planning

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

The potential for environmental benefits for the community and its natural resources to arise from implementation of a policy or practice

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

The potential for the implementation of a policy or practice to have adverse impacts on public/scenic amenity

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

The potential for the implementation of a policy or practice to have adverse impacts on ecological assets and resources

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Are there any other environmental factors that you consider important?

4.4. Social Factors

A policy or practice is consistent with local social/community planning

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

A policy or practice is supported by the community

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

A policy or practice will preserve or improve social cohesiveness and/or social networks within the community

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

A policy or practice will preserve or improve social equity

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Are there any other social factors that you consider important?

4.5. Human/Cultural Factors

Council has the necessary expertise and training or access to the necessary expertise or training (e.g., via expert consultancies) to effectively design and implement a policy or practice

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice improves education and understanding within council or the broader community

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice will preserve or improve health and safety

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

The potential for cultural benefits for the community to arise from implementation of a policy or practice (e.g., protection of cultural icons or community identity)

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

Are there any other human/cultural factors that you consider important?

4.6. Physical/Infrastructure Factors

A policy or practice is consistent with council asset/infrastructure management plans

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice provides benefits to council physical infrastructure and built environment (e.g., provides protection of existing infrastructure or facilitates development of new infrastructure)

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice provides benefits to other public physical infrastructure and built environment (e.g., provides protection of existing infrastructure or facilitates development of new infrastructure)

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

A policy or practice provides benefits to private physical infrastructure and built environment (e.g., provides protection of existing infrastructure or facilitates development of new infrastructure)

☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

Are there any other factors pertaining to physical infrastructure that you consider important?

Section 3. Decision-Making Regarding Management of Coastal Hazards

Notes for Participants: The questions in this section seek your opinion regarding the relative importance of different factors or values specifically associated with the management of coastal hazards.

5. How important are the following coastal hazards to the design and implementation of coastal management policies and practices in your council?
Beach/coastal erosion (movement of sand offshore due to storm wave attack) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Shoreline recession (progressive landward shift of the average long term position of the coastline) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Short-term coastal inundation (temporary flooding of coastal lands by ocean waters due to above normal high tides and/or storm events) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Long-term coastal inundation (permanent flooding of coastal lands due to sea-level rise and/or subsidence) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Coastal entrance (migration or changes to coastal entrances due to flooding and/or storm events) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Sand drift (windborne sediment transport) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Stormwater erosion (erosion of the beach berm and the nearshore area associated with semi-perennial creeks) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Slope and cliff instability (structural incompetence of coastal slopes and cliffs) ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Interactions among two or more of the above hazards ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

6. Thinking specifically about sea-level rise, how important are the potential risks associated with sea-level rise to your council over the following time horizons?
Near-term (1 to 10 years)? ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Mid-term (10 to 25 years)? ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know
Long-term (25 years and beyond)? ☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

7. How important is certainty about future sea-level rise and/or changes in other coastal hazards to the design and implementation of coastal management policies and measures in your council?
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical ☐Don't Know

8. How important is certainty about future social, demographic and/or economic changes to the design and implementation of coastal management policies and measures in your council?
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical

☐Don't Know

9. How effective are coastal management policies from the following levels of government for guiding and supporting the management of coastal hazards in your council?

Federal coastal management policies and practices
☐Completely ineffective ☐Somewhat effective ☐Highly effective ☐Don't Know

State coastal management policies and practices
☐Completely ineffective ☐Somewhat effective ☐Highly effective ☐Don't Know

Local coastal management policies and practices
☐Completely ineffective ☐Somewhat effective ☐Highly effective ☐Don't Know

10. How important are the following organizations and actors to the successful management of risks to council and the community associated with coastal hazards?

Councilors
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Council staff
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

State government agencies
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Federal government agencies
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Regional bodies and organizations
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

University academics and other researchers
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Private corporations and businesses
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Media organisations
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Non –governmental organizations
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Community organizations
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Individual residents
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

11. How important are the following tools or processes for informing council decision-making regarding the design or implementation of a policy or practice to manage the risks associated with coastal hazards?

Scientific and technical analyses by experts
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Economic/financial tools such as cost/benefit analysis
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Adherence to existing statutes and guidelines
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Adherence to best practice
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Learning from other councils
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Public consultation and participation
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Application of the 'precautionary principle'
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Application of 'adaptive management'
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Application of 'risk management'
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Monitoring and evaluation of council policies and practices
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

12. How important are the following factors in motivating changes in council coastal management policies and practices or driving the implementation of new policies and practices?

Information regarding coastal hazards and/or the risks such hazards pose to community welfare (e.g., economic/financial impacts, public health and safety)
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Evidence of failure of existing policies and practices that are used to manage the risks associated with coastal hazards
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Changes in State policies or legislation for which local government is the implementing authority
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Changes in elected representatives
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Concerns regarding legal liability of council for impacts associated with coastal hazards
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Routine, periodic updates/revisions to council coastal management policies or practices
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Community pressure (e.g., lobbying by residents, businesses, or non-governmental organizations)
☐ Not Important at All ☐ Low Importance ☐ Moderate Importance ☐ High Importance ☐ Critical
☐ Don't Know

Section 4. Monitoring and Evaluation

13. Please list below any monitoring and evaluation activities that you are involved with?

14. Who conducts monitoring and evaluation within your council?

15. How does monitoring and evaluation influence your council?

Reporting and communication
☐Not at All ☐Low Influence ☐Moderate Influence ☐High Influence ☐Critical Influence
☐Don't Know

Budgeting
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Cultural change within council
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Evaluating effectiveness of coastal management strategies
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Provide a basis for improved management, including adjustments and amendments of policies, strategies, procedures and individual projects
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Accountability for resource use efficiency
☐Not Important at All ☐Low Importance ☐Moderate Importance ☐High Importance ☐Critical
☐Don't Know

Others

16. What do you see as being the major constraints to monitoring and evaluation in relation to climate change adaptation in council?

Section 5. Contact information

17. Would you be interested in receiving future communications regarding the outcomes of this survey and the *Multi-Criteria Approaches to Adaptive Coastal Development Project?*

☐Yes ☐No
If Yes, please provide an email address to receive future communications

Email:

Appendix II. Illustration of calculation of raw performance scores for adaptation options

To calculate raw performance scores for the 15 coastal adaptation options considered in the current study, the performance scores of workshops participants were multiplied by the number of times that score was assigned for a given criterion, resulting in a frequency-weighted total score. This analysis was undertaken for each individual criterion, but, as shown in the hypothetical example below for an unnamed adaptation option, calculations could also be conducted at a higher level of aggregation, in this case on the four different criteria dimensions. Below, for the governance criteria, n represents the total number of times a score was reported by participants across all of the four governance criteria. This value is then multiplied by the corresponding score to generate a frequency-weighted total. A dimension score is then calculated by dividing the sum of weighted scores by the total number of responses (in this case +8/12), resulting in a dimension score of +0.67. In contrast, this same adaptation option performs neutral to moderately unfavorably against the financial criteria. Following this approach, responses can be pooled across all criteria, resulting in an aggregate score of +0.61. Hence, despite performing poorly on financial criteria, this option has an overall favorable rating due to high performance against environmental criteria. Adaptation options were evaluated in this way for all three study regions, for all criteria, and for all three time horizons.

Governance Criteria	n	Score	Weighted Total	Dimension Score
Strongly Agree	2	+2	+4	
Agree	5	+1	+5	
Neither Agree Nor Disagree	4	0	0	
Disagree	1	-1	-1	
Strongly Disagree	0	-2	0	
Dimension Subtotal	**12**		**+8**	**+0.67**

Social Criteria	n	Score	Weighted Total	Dimension Score
Strongly Agree	1	+2	+2	
Agree	2	+1	+2	
Neither Agree Nor Disagree	3	0	0	
Disagree	2	-1	-2	
Strongly Disagree	1	-2	-2	
Dimension Subtotal	**9**		**0**	**0**

Financial Criteria	n	Score	Total	Dimension Score
Strongly Agree	1	+2	+2	
Agree	1	+1	+1	
Neither Agree Nor Disagree	2	0	0	
Disagree	4	-1	-4	
Strongly Disagree	3	-2	-6	
Dimension Subtotal	**11**		**-8**	**-0.63**

Environmental Criteria	n	Score	Weighted Total	Dimension Score
Strongly Agree	5	+2	+10	
Agree	4	+1	+4	
Neither Agree Nor Disagree	3	0	0	
Disagree	0	-1	0	
Strongly Disagree	0	-2	0	
Dimension Subtotal	**12**		**14**	**+1.17**

Total	n	Score	Total	Aggregate Score
Strongly Agree	9	+2	18	
Agree	12	+1	12	
Neither Agree Nor Disagree	12	0	12	
Disagree	7	-1	-7	
Strongly Disagree	4	-2	-8	
Grand Total	**44**		**14**	**+0.61**

Appendix III. Questionnaire queries used in the development of criteria weights

MCA Criterion	Survey Questions Used to Generate Criterion Weight	
G1	*A policy or practice is consistent with local planning policy or other local guidelines*	*A policy or practice is consistent with State planning policy or other State guidelines*
G2	*A policy or practice creates opportunities for building new relationships or partnerships*	*The availability of opportunities to share the costs of implementing a policy or practice (e.g., with State government, private businesses, or local residents)*
G3	*Concerns regarding legal liability of council for impacts associated with coastal hazards*	
G4	*A policy or practice preserves or enhances existing property rights and values*	
F1	*A policy or practice preserves or enhances existing property rights and values*	*The potential for financial/economic benefits for council and/or community to arise from implementation of a policy or practice*
F2	*The cost to council of implementing a policy or practice over its entire life cycle*	*The capacity of council to manage the costs associated with implementing a policy or practice within the constraints of council budget*
F3	*The cost to the community (e.g., residents or businesses) of implementing a policy or practice over its entire life cycle*	
F4	*The cost to council of implementing a policy or practice over its entire life cycle*	*The capacity of council to manage the costs associated with implementing a policy or practice within the constraints of council budget*
	The availability of opportunities to share the costs of implementing a policy or practice (e.g., with State government, private businesses, or local residents)	*The cost to the community (e.g., residents or businesses) of implementing a policy or practice over its entire life cycle*
	A policy or practice preserves or enhances existing property rights and values	*The potential for financial/economic benefits for council and/or community to arise from implementation of a policy or practice*
	Confidence that the benefits of implementing a policy or practice will outweigh the costs	
S1	*A policy or practice will preserve or improve social cohesiveness and/or social networks within the community*	
S2	*A policy or practice will preserve or improve health and safety*	
S3	*A policy or practice will preserve or improve health and safety*	
S4	*A policy or practice will preserve or improve social equity*	
E1	*The potential for environmental benefits for the community and its natural resources to arise from implementation of a policy or practice*	
E2	*The potential for environmental benefits for the community and its natural resources to arise from implementation of a policy or practice*	
E3	*The potential for the implementation of a policy or practice to have adverse impacts on ecological assets and resources*	
E4	*The potential for environmental benefits for the community and its natural resources to arise from implementation of a policy or practice*	

Appendix IV. Methods for estimation of areas subject to erosion

Using the Bruun Rule, recession due to sea level rise can be estimated simply as the product of the sea level rise (over the planning timeframe of interest) multiplied by the inverse of the active profile slope. According to the *NSW Coastal Risk Management Guidelines*,[9] it has been common practice along the NSW coastline to assume active profile slopes in the range of 1:50 to 1:100. Hence, estimating shorelines recession can be performed by multiplying the Still Water Level (SWL) by the inverse of the preferred assumption about the active profile slope. While a value of 1:100 was originally selected for the current study, this was later revised downward to the more conservative estimate of 1:50, due to significant uncertainties in the robustness of the Bruun Rule.

Using the benchmarks in the *NSW Coastal Risk Management Guidelines*, a continuous estimate of 1:100 year SWL was generated by applying the projected sea-level rise in 2050 and 2100 (+40 and +90 cm, respectively) to the baseline SWL of 1.44 metres. A best-fit curve was fit to these three points, resulting in a model of future SWL relative to time of $SWL = 2E\text{-}05(year)^2 + 0.0078x + 1.4322$. This allowed the SWL to be estimated for any future year out to 2100, and therefore an estimate of shoreline recession (calculated simply as the projected SWL times 50).

As the Bayesian MCA model was based upon three time horizons, benchmarks of sea-level rise and shoreline recession had to be developed for these time horizons. To do this, we selected 2010 as the baseline year, which meant the end of the near-term time horizon (1-10 years) corresponded with the year 2020 (the year 2010 + 10 years). Subsequently, the end of the mid-term time horizon (10-25 years) corresponded with the year 2035 (the year 2010 + 25 years) and the end of the long-term time horizon corresponded with the year 2060 (the year 2010 + 50 years). Estimates of future SWLs for these time horizons were generated by applying the aforementioned equation. As a result of this approach, the estimates of shoreline recession for the three time horizons represented in the Bayesian MCA model are presented in the table below.

Table. Current and projected 1:100 Year Still Water Levels

Time Horizon	Estimated Still Water Level (metres AHD)	Estimated Shoreline Recession (metres)
Present (Near-term)	1.51	76
2050 (Medium-term)	1.64	82
2100 (Long-term)	1.87	94

To apply these shoreline recession estimates to the three case study regions, the Smartline coastal segmentation produce was used as a benchmark estimate of the coastline at mean sea level. Beaches identified by Smartline as potentially susceptible to significant erosion (i.e., soft sediments not backed by bedrock) were selected as coastline segments subject to erosion. Polygon buffers were drawn landward from Smartline in GIS for these segments according to the distances in the table above. This resulted in three buffers, corresponding with each time horizon. All area within those buffers was assumed to be lost to shoreline recession, and thus the percentage of properties lost to erosion could be estimated in GIS through the application of simple spatial overlay methods.

[9] http://www.environment.nsw.gov.au/resources/water/coasts/10760CoastRiskManGde.pdf

Appendix V. Data sources for hazards and assets for the three case study regions

Sydney Coastal Councils Group

Data Layer	Description	Data Origins	Network Hierarchy
Hazard			
Net coastal hazard	Indicator of joint exposure of land areas to storm surge/sea-level rise based upon adding the percentage of a given property's area subject to inundation to the percentage of that property's area subject to erosion.	This study	Level 1
Storm surge/sea-level rise	Indicator of the geographic distribution of 1:100 year storm surge inundation areas with different sea-level rise scenarios (+0, +40, and +90 cm with lidar uncertainty). Sea-level rise scenarios were used in the MCA to represent near-term, medium-term, and long-term risk, respectively.	CSIRO/SCCG	Level 2A
Coastal erosion/ recession	Indicator or erosion based upon a Brunn Rule-like calculation assuming coastal recession due to erosion of 50 times the vertical rise in sea level based upon sea-level rise and storm surge scenarios (as suggested b y NSW guidance). Areas subject to erosion were identified by using the Smartline coastal segmentation data and isolating sandy beaches not backed by bedrock and generating landward spatial buffers equivalent to the estimated coastal recession.	Geoscience Australia and this study	Level 2B
Financial Assets			
Net financial assets	Aggregate indicator of financial asset density, which was derived by averaging among the Level 2 indicators.	This study	Level 1
Property value	Property values were based on a property value index derived from 2006 census data at the census collective district (CCD) level. The index was a weighted average of household rents reported in the census for each CCD. This value was subsequently normalised to a scale from 0 to 100. All properties falling within a CCD were assigned the same property value index value.	Australian Bureau of Statistics	Level 2A
Commercial building density	A point density algorithm was applied to building complex points within the NSW Land and Property Information database with the class "Industrial Facility" or "Utility Facility". This resulted in a 5 metre resolution gridded building density layer. All grid cells falling with the boundaries of a property were then averaged to estimate building density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 2B
Infrastructure	Indicator of infrastructure density, which was derived by averaging among all of the Level 3C layers.	This study	Level 2C
Road density	A line density algorithm was applied to the road network within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded road density layer . All grid cells falling with the boundaries of a property were then averaged to	NSW Land and Property Information	Level 3C-1

	estimate road density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.		
Rail density	A line density algorithm was applied to the rail network within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded road density layer. All grid cells falling with the boundaries of a property were then averaged to estimate rail density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-2
Runway density	A line density algorithm was applied to runways within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded runway density layer. All grid cells falling with the boundaries of a property were then averaged to estimate runway density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-3
Pipeline density	A line density algorithm was applied to natural gas pipelines within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded pipeline density layer. All grid cells falling with the boundaries of a property were then averaged to estimate runway density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-4
Electricity line density	A line density algorithm was applied to natural gas pipelines within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded pipeline density layer. All grid cells falling with the boundaries of a property were then averaged to estimate runway density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-5
Social Assets			
Net social assets	Indicator of properties with significant social value, which was derived by averaging among all of the Level 2 layers.	This Study	Level 1
Social	Indicator of socially significant locations, which was derived by averaging among the Level 3A-B layers.	This study	Level 2A
Recreational areas	Indicator of recreationally significant locations, which was derived by averaging among the Level 3A-B layers.	This study	Level 2B
Community building density	A point density algorithm was applied to building complex points within the NSW Land and Property Information database with the class "Community Facility" or "Recreation Facility" "Education Facility" and "Hospital Facility". This resulted in a 5 metre resolution gridded building density layer. All grid cells falling with the boundaries of a property were then averaged to estimate building density at that location. Areas for which no data were available (i.e., properties falling outside the gridded	NSW Land and Property Information	Level 3A-1

	layer) were assigned a value of -9999 indicating 'no data' were available.		
Social points of interest density	A point density algorithm was applied to social points of interest within the NSW Land and Property Information database corresponding with hospitals, places of worship, ambulance stations, schools, clubs, community facilities, parks and recreation facilities, sport fields, and shopping centres. This resulted in a 5 metre resolution gridded social location density layer. All grid cells falling with the boundaries of a property were then averaged to estimate social location density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3A-1
Recreational areas	Indicator of land areas associated with recreational areas based upon the GEODATA TOPO 250K Series 3 topographic data set. The percentage of land associated with recreational areas was calculated for each property.	Geoscience Australia	Level 3B-1
Native vegetation areas	Indicator of land areas associated with native vegetation areas based upon the GEODATA TOPO 250K Series 3 topographic data set. The percentage of land associated with native vegetation areas was calculated for each property.	Geoscience Australia	Level 3B-1
Natural land areas	Indicator of natural lands based upon the Catchment Scale Land Use Mapping for Australia (March 2010). The percentage of property associated with land use identified as either "Conservation and Natural Environments" and/or "Production from Relatively Natural Environments" was calculated and used as an indicator of the geographic distribution of natural land assets.	Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences	Level 3B-1
Crown land areas	Indicator of land designated as Crown Land according to the GEODATA TOPO 250K Series 3 topographic data set. The percentage of each assessed property falling within the boundaries of crown land polygons was calculated as an indicator of properties associated with significant crown land area.	Geoscience Australia	Level 3B-1
Reserve areas	Indicator of land designated as parks and reserve areas.	NSW Land and Property Information	Level 3B-1
Environmental Assets			
Net ecological assets	Indicator of properties associated with significant ecological values, which was by averaging among all of the Level 2 layers.	This study	Level 1
Biodiversity areas	Indicator of areas associated with significant biodiversity values, which was derived by averaging among the Level 3a-c layers.	This study	Level 2A
Crown land areas	Indicator of the percentage area of a given property that falls within the Crown Lands (regardless of whether or not they are maintained by Local Government).	Geoscience Australia	Level 2B
SEPP 71 areas	Indicator of the percentage area of a given property that falls within the State Environmental Planning Policy (SEPP) 71 guideline.	NSW Department of Environment and Heritage	Level 2C
Native vegetation areas	Indicator of the percentage area of a given property that is associated with native vegetation according to the	Geoscience Australia	Level 3A-1

	GEODATA TOPO 250K Series 3 topographic data set. The percentage of each assessed property falling within the boundaries of native vegetation polygons was calculated as an indicator of properties associated with significant native vegetation areas.		
Natural land areas	Indicator of natural lands based upon the Catchment Scale Land Use Mapping for Australia (March 2010). The percentage of property associated with land use identified as either "Conservation and Natural Environments" and/or "Production from Relatively Natural Environments" was calculated and used as an indicator of the geographic distribution of natural land assets.	Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences	Level 3A-1
Reserve areas	Indicator of land areas associated with national parks and reserves. Indicator was derived from the "npwsreserve" data layer of NSW Land and Property Information. The percentage of each assessed property falling within the boundaries of reserve polygons were calculated as an indicator of properties associated with significant reserve area.	NSW Land and Property Information	Level 3A-1
Decision Constraints			
Land subject to erosion	Indicator derived from the erosion hazard layer, with properties for which there is some exposure to erosion assigned a numerical value of 1 (Yes, land is subject to erosion) and properties for which no exposure is anticipated assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1A
Room for setback on land	Indicator derived from the net coastal hazard layer, with properties for which less than 50% of the property area is exposed to coastal hazards assigned a numerical value of 1 (Yes, there is benefit to increasing the setback on the property) and properties for which greater than 50% of the property are is exposed assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1B
Public land	Indicator derived from data layers generally associated with public lands, particularly crown land, properties reserved for environmental protection, and properties upon which public buildings are located (e.g., council buildings). Properties that were identified as public land are assigned a numerical value of 1 while properties not on public land were assigned a value of 0.	This study	Level 1C
Land with 'very high' financial assets	Indicator derived from net hazard data layers Properties associated with financial asset categorisations of "very high" were assigned a numerical value of 1 while properties with other financial asset categories were assigned a value of 0.	This study	Level 1D
Land with 'very high' exposure to coastal hazards	Indicator derived from net hazard data layers Properties associated with net hazard categorizations of "very high" were assigned a numerical value of 1 while properties with other hazard categories were assigned a value of 0.	This study	Level 1E

Sunshine Coast Council

Data Layer	Description Data Origins	Data Provider	Asset Group
Hazard			
Net coastal hazard	Indicator of joint exposure of land areas to storm surge/sea-level rise based upon adding the percentage of a given property's area subject to inundation to the percentage of that property's area subject to erosion.	This study	Level 1
Storm surge/sea-level rise	Indicator of the geographic distribution of 1:100 year flood levels for coastal and inland waterways. No data were available for sea-level rise scenarios. The percentage of each property falling within the boundaries of essential habitat polygons were calculated as an indicator of properties associated with particularly significant ecological value.	Sunshine Coast Council	Level 2A
Coastal erosion/ recession	Indicator or erosion based upon a Brunn Rule-like calculation assuming coastal recession due to erosion of 50 times the vertical rise in sea level based upon sea-level rise and storm surge scenarios (as suggested by NSW guidance). Areas subject to erosion were identified by using the Smartline coastal segmentation data and isolating sandy beaches not backed by bedrock and generating landward spatial buffers equivalent to the estimated coastal recession.	Geoscience Australia and this study	Level 2B
Financial Assets			
Net financial assets	Aggregate indicator of financial asset density, which was derived by averaging among the Level 2 indicators.	This study	Level 1
Property value	Property values were based on a property value index derived from 2006 census data at the census collective district (CCD) level. The index was a weighted average of household rents reported in the census for each CCD. This value was subsequently normalised to a scale from 0 to 100. All properties falling within a CCD were assigned the same property value index value.	Australian Bureau of Statistics and This Study	Level 2A
Transportation infrastructure	Indicator of areas associated with significant transportation infrastructure, which was derived by averaging among the Level 3a-c layers.	This study	Level 2B
Water/waste infrastructure	Indicator of areas associated with significant water, storm water, and waste management infrastructure, which was derived by averaging among the Level 3d-f layers.	This study	Level 2C
Road density	A line density algorithm was applied to the road network provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded road density layer. All grid cells falling with the boundaries of a property were then averaged to estimate road density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-1

Airport transport density	A point density algorithm was applied to air transport points provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded air transport density layer. All grid cells falling with the boundaries of a property were then averaged to estimate air transport density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-2
Air and bus facility density	A point density algorithm was applied to air and bus facility points provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded air and bus facility density layer. All grid cells falling with the boundaries of a property were then averaged to estimate air and bus facility density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-3
Storm drain pipe density	A line density algorithm was applied to the storm drain network provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded storm drain density layer. All grid cells falling with the boundaries of a property were then averaged to estimate storm drain density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-4
Open drain density	A line density algorithm was applied to the open drain network provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded open drain density layer. All grid cells falling with the boundaries of a property were then averaged to estimate open drain density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-5
Waste management facility density	A line density algorithm was applied to the open drain network provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded open drain density layer. All grid cells falling with the boundaries of a property were then averaged to estimate open drain density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-6
Social Assets			
Net financial assets	Aggregate indicator of social asset density, which was derived by averaging among the Level 2 indicators.	This study	Level 1
Community areas	Indicator of areas associated with community facilities, which was derived by averaging among the Level 3a-c layers.	This study	Level 2A
Recreation areas	Indicator of areas associated with significant recreational areas/facilities, which was derived by averaging among the Level 3d-f layers.	This study	Level 2B

Open space	Indicator derived from the 'current open space' data layer provided by Sunshine Coast Council. The percentage of each property falling within the boundaries of open space polygons were calculated as an indicator of properties associated with significant open space area.	Sunshine Coast Council	Level 3A-1
Community hub	Indicator derived from the 'community hub' data layer provided by Sunshine Coast Council. The percentage of each property falling within the boundaries of community hubs were calculated as an indicator of properties associated with particularly significant social significance.	Sunshine Coast Council	Level 3A-2
Childcare facility density	A point density algorithm was applied to childcare points provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded childcare density layer. All grid cells falling with the boundaries of a property were then averaged to estimate childcare density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3A-3
Caravan park	A point density algorithm was applied to caravan park points provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded caravan park density layer. All grid cells falling with the boundaries of a property were then averaged to estimate caravan park density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3A-4
Recreational facility density	A point density algorithm was applied to recreational facility points provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded recreational facility density layer. All grid cells falling with the boundaries of a property were then averaged to estimate recreational facility density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-1
Recreational trail density	A line density algorithm was applied to the recreational trail network provided by Sunshine Coast Council. This resulted in a 5 metre resolution gridded recreational trail density layer. All grid cells falling with the boundaries of a property were then averaged to estimate recreational trail density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Sunshine Coast Council	Level 3B-2
Environmental Assets			
Critical habitat	Indicator derived from the 'essential habitat' data layer provided by Sunshine Coast Council. Essential habitat areas were identified by Queensland Department of Environment and Resources Management (DERM). The percentage of each	Sunshine Coast Council	Level 1

	property falling within the boundaries of essential habitat polygons were calculated as an indicator of properties associated with particularly significant ecological value.		
Decision Constraints			
Land subject to erosion	Indicator derived from the erosion hazard layer, with properties for which there is some exposure to erosion assigned a numerical value of 1 (Yes, land is subject to erosion) and properties for which no exposure is anticipated assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1A
Room for setback on land	Indicator derived from the net coastal hazard layer, with properties for which less than 50% of the property area is exposed to coastal hazards assigned a numerical value of 1 (Yes, there is benefit to increasing the setback on the property) and properties for which greater than 50% of the property are is exposed assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1B
Public land	Indicator derived from data layers generally associated with public lands, particularly crown land, properties reserved for environmental protection, and properties upon which public buildings are located (e.g., council buildings). Properties that were identified as public land are assigned a numerical value of 1 while properties not on public land were assigned a value of 0.	This study	Level 1C
Land with 'very high' financial assets	Indicator derived from net hazard data layers Properties associated with financial asset categorisations of "very high" were assigned a numerical value of 1 while properties with other financial asset categories were assigned a value of 0.	This study	Level 1D
Land with 'very high' exposure to coastal hazards	Indicator derived from net hazard data layers Properties associated with net hazard categorizations of "very high" were assigned a numerical value of 1 while properties with other hazard categories were assigned a value of 0.	This study	Level 1E

Bega Valley Shire Council

Data Layer	Description Data Origins	Data Provider	Asset Group
Hazard			
Net coastal hazard	Indicator of joint exposure of land areas to storm surge/sea-level rise based upon adding the percentage of a given property's area subject to inundation to the percentage of that property's area subject to erosion.	This study	Level 1
Storm surge/sea-level rise	1:100 year flood levels for coastal and inland waterways. No data were available for sea-level rise.	Sunshine Coast Regional Council	Level 2A
Coastal erosion/	Indicator or erosion based upon a Brunn Rule-like calculation assuming coastal recession due to	Geoscience Australia and this study	Level 2B

recession	erosion of 50 times the vertical rise in sea level based upon sea-level rise and storm surge scenarios (as suggested b y NSW guidance). Areas subject to erosion were identified by using the Smartline coastal segmentation data and isolating sandy beaches not backed by bedrock and generating landward spatial buffers equivalent to the estimated coastal recession.		
Financial Assets			
Net financial assets	Aggregate indicator of financial asset density, which was derived by averaging among all of the Level 3 indicators.	This study	Level 1
Property value	Property values were based upon assessments of unimproved property values provided by Bega Valley Shire Council.	Bega Valley Shire Council	Level 2A
Commercial building density	A point density algorithm was applied to building complex points within the NSW Land and Property Information database with the class "Industrial Facility" or "Utility Facility". This resulted in a 5 metre resolution gridded building density layer. All grid cells falling with the boundaries of a property were then averaged to estimate building density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 2B
Infrastructure	Indicator of infrastructure density derived by averaging among all of the Level 3 (a-e) layers.	This study	Level 2C
Road density	A line density algorithm was applied to the road network within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded road density layer. All grid cells falling with the boundaries of a property were then averaged to estimate road density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-1
Water line density	A line density algorithm was applied to the water network data layer provided by Bega Valley Shire Council. This resulted in a 5 metre resolution gridded water line density layer. All grid cells falling with the boundaries of a property were then averaged to estimate water line density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Bega Valley Shire Council	Level 3C-2
Storm water drain density	A line density algorithm was applied to the storm water drain data layer provided by Bega Valley Shire Council. This resulted in a 5 metre resolution gridded storm water drain density layer. All grid cells falling with the boundaries of a property were then averaged to estimate storm water drain density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data'	Bega Valley Shire Council	Level 3C-3

	were available.		
Water/sewer facilities	A point density algorithm was applied to the water/sewer facility point layer provided by Bega Valley Shire Council. This resulted in a 5 metre resolution gridded water/sewer density layer. All grid cells falling with the boundaries of a property were then averaged to estimate water/sewer density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Bega Valley Shire Council	Level 3C-4
Electricity line density	A line density algorithm was applied to natural gas pipelines within the NSW Land and Property Information database. This resulted in a 5 metre resolution gridded pipeline density layer. All grid cells falling with the boundaries of a property were then averaged to estimate runway density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 3C-5
Social Assets			
Net social assets	Indicator of properties associated with significant recreational or amenity value, which was derived by averaging among all of the Level 2 layers.	This study	Level 1
Community building density	A point density algorithm was applied to building complex points within the NSW Land and Property Information database with the class "Community Facility" or "Recreation Facility" "Education Facility" and "Hospital Facility". This resulted in a 5 metre resolution gridded building density layer. All grid cells falling with the boundaries of a property were then averaged to estimate building density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	NSW Land and Property Information	Level 2A
Recreational open space areas	Indicator of recreationally significant locations derived by averaging among the Level 3a-b layers.	This study	Level 2B
Natural land areas	Indicator of recreationally significant locations derived by averaging among the Level 3c-e layers.	This study	Level 2C
Open space	Indicator of land areas associated with open space. Indicator was developed from the council zoning overlay. Land parcels described as "existing open space" or "private open space" were selected and the percentage of assessed properties associated with these features calculated for each property.	Bega Valley Shire Council	Level 3A-1
Recreational areas	Indicator of land parcels used for recreational activities/facilities. Indicator was developed from the shire properties data layer provided by Bega Valley Shire Council. Properties identified as "park" or "sportsground" were selected and the percentage of assessed properties associated with these features calculated for each property.	Bega Valley Shire Council	Level 3A-2
Environmental	Indicator of land areas associated with	Bega Valley Shire	Level 3C-1

protection areas	environmental protection overlays. Indicator was developed from the council zoning overlay. Land parcels described as "coastal lands acquisition", "coastal lands protection", "environment protection (foreshore)", "environment protection (scenic)", "environment protection (wildlife refuge)" or "national parks & nature reserves" were selected and the percentage of assessed properties associated with these features calculated for each property.	Council	
Natural land areas	Indicator of land parcels identified as natural lands. Indicator was developed from the shire properties data layer provided by Bega Valley Shire Council. Properties identified as "natural area" (foreshore, bushland, watercourse or wetland) were selected and the percentage of assessed properties associated with these features calculated for each property.	Bega Valley Shire Council	Level 3C-2
Crown land areas	Indicator of the percentage area of a given property that falls within the Crown Lands (regardless of whether or not they are maintained by Local Government).	Bega Valley Shire Council	Level 3C-3
Environmental Assets			
Net ecological assets	Indicator of properties associated with significant ecological values derived by averaging among all of the Level 2 layers.	This study	Level 1
Biodiversity areas	Indicator of areas associated with significant biodiversity values, which was derived by averaging among the Level 3a-c layers.	This study	Level 2A
Natural areas	Indicator of areas associated with natural landscapes, which was derived by averaging among the Level 3d-f layers.	This study	Level 2B
SEPP areas	Indicator of areas associated with SEPP areas, which was derived by averaging among the Level 3g-h layers.	NSW Department of Environment and Heritage	Level 2C
Flora	Indicator of the location of ecologically significant flora. Indicator was developed by applying a point density algorithm to locations of significant flora identified by the Bega Valley Shire Council flora data layer. This resulted in a 5 metre resolution gridded flora density layer. All grid cells falling with the boundaries of a property were then averaged to estimate flora density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were available.	Bega Valley Shire Council	Level 3A-1
Fauna	Indicator of the location of ecologically significant fauna. Indicator was developed by applying a point density algorithm to locations of significant fauna identified by the Bega Valley Shire Council fauna data layer. This resulted in a 5 metre resolution gridded fauna density layer. All grid cells falling with the boundaries of a property were then averaged to estimate fauna density at that location. Areas for which no data were available (i.e., properties falling outside the gridded layer) were assigned a value of -9999 indicating 'no data' were	Bega Valley Shire Council	Level 3A-2

	available.		
Endangered ecological community areas	Indicator of the areas associated with endangered ecological communities. Indicator was developed by calculating the percentage of assessed properties associated with these features.	Bega Valley Shire Council	Level 3A-3
Crown land areas	Indicator of the percentage area of a given property that falls within the Crown Lands (regardless of whether or not they are maintained by Local Government).	Bega Valley Shire Council	Level 3B-1
Environmental protection areas	Indicator of land areas associated with environmental protection overlays. Indicator was developed from the council zoning overlay. Land parcels described as “coastal lands acquisition”, “coastal lands protection”, “environment protection (foreshore)”, “environment protection (scenic)”, “environment protection (wildlife refuge)” or “national parks & nature reserves” were selected and the percentage of assessed properties associated with these features calculated for each property.	Bega Valley Shire Council	Level 3B-2
Natural land areas	Indicator of land parcels identified as natural lands. Indicator was developed from the shire properties data layer provided by Bega Valley Shire Council. Properties identified as “natural area” (foreshore, bushland, watercourse or wetland) were selected and the percentage of assessed properties associated with these features calculated for each property.	Bega Valley Shire Council	Level3B-3
SEPP 14 areas	Indicator of the percentage area of a given property that falls within the State Environmental Planning Policy (SEPP) 14 guideline.	NSW Department of Environment and Heritage	Level 3C-1
SEPP 71 areas	Indicator of the percentage area of a given property that falls within the State Environmental Planning Policy (SEPP) 71 guideline.	NSW Department of Environment and Heritage	Level 3C-2
Decision Constraints			
Land subject to erosion	Indicator derived from the erosion hazard layer, with properties for which there is some exposure to erosion assigned a numerical value of 1 (Yes, land is subject to erosion) and properties for which no exposure is anticipated assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1A
Room for setback on land	Indicator derived from the net coastal hazard layer, with properties for which less than 50% of the property area is exposed to coastal hazards assigned a numerical value of 1 (Yes, there is benefit to increasing the setback on the property) and properties for which greater than 50% of the property are is exposed assigned a valued of 0 (No, land is not subject to erosion). These values vary with time due to increasing risk of erosion over time.	This study	Level 1B
Public land	Indicator derived from data layers generally associated with public lands, particularly crown land, properties reserved for environmental protection, and properties upon which public buildings are located (e.g., council buildings). Properties that were identified as public land are assigned a numerical	This study	Level 1C

	value of 1 while properties not on public land were assigned a value of 0.		
Land with 'very high' financial assets	Indicator derived from net hazard data layers. Properties associated with financial asset categorisations of "very high" were assigned a numerical value of 1 while properties with other financial asset categories were assigned a value of 0.	This study	Level 1D
Land with 'very high' exposure to coastal hazards	Indicator derived from net hazard data layers. Properties associated with net hazard categorizations of "very high" were assigned a numerical value of 1 while properties with other hazard categories were assigned a value of 0.	This study	Level 1E

SYDNEY COASTAL COUNCILS GROUP

Sydney Coastal Councils Group Inc.
councils **caring for the coastal environment**
Level 20, Town Hall House, 456 Kent Street
GPO Box 1591, SYDNEY NSW 2001
t: +61 2 9246 7702 **|** **f**: +61 2 9265 9660
e: info@sydneycoastalcouncils.com.au
w: www.sydneycoastalcouncils.com.au.com.au

Australian Government
Department of Climate Change and Energy Efficiency

Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

University of the Sunshine Coast
Sustainability Research Centre

SYDNEY COASTAL COUNCILS GROUP