Climate Risk Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

A review of methodologies applied in Australian practice to evaluate long-term coastal adaptation options

Timothy David Ramm [a,b,*], Christopher John White [a,c,d], Andrew Hin Cheong Chan [a], Christopher Stephen Watson [e]

[a] School of Engineering and ICT, University of Tasmania, Hobart, Australia
[b] Bushfire and Natural Hazards Cooperative Research Centre, Melbourne, Australia
[c] Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia
[d] JBA Consulting, Skipton, UK
[e] School of Land and Food, University of Tasmania, Hobart, Australia

ARTICLE INFO

Article history:
Received 22 December 2016
Revised 6 June 2017
Accepted 14 June 2017
Available online xxxx

Keywords:
Adaptation
Climate change
Coastal inundation
Evaluation
Sea level rise
Uncertainty

ABSTRACT

Rising sea levels have the potential to alter coastal flooding regimes around the world and local governments are beginning to consider how to manage uncertain coastal change. In doing so, there is increasing recognition that such change is deeply uncertain and unable to be reliably described with probabilities or a small number of scenarios. Characteristics of methodologies applied in Australian practice to evaluate long-term coastal adaptation options are reviewed and benchmarked against two state-of-the-art international methods suited for conditions of uncertainty (Robust Decision Making and Dynamic Adaptive Policy Pathways). Seven out of the ten Australian case studies assumed the uncertain parameters, such as sea level rise, could be described deterministically or stochastically when identifying risk and evaluating adaptation options across multi-decadal periods. This basis is not considered sophisticated enough for long-term decision-making, implying that Australian practice needs to increase the use of scenarios to explore a much larger uncertainty space when assessing the performance of adaptation options. Two Australian case studies mapped flexible adaptation pathways to manage uncertainty, and there remains an opportunity to incorporate quantitative methodologies to support the identification of risk thresholds. The contextual framing of risk, including the approach taken to identify risk (top-down or bottom-up) and treatment of uncertain parameters, were found to be fundamental characteristics that influenced the methodology selected to evaluate adaptation options. The small sample of case studies available suggests that long-term coastal adaptation in Australian is in its infancy and there is a timely opportunity to guide local government towards robust methodologies for developing long-term coastal adaptation plans.

Contents

* Corresponding author at: School of Engineering and ICT, University of Tasmania, Private Bag 65, Hobart, Tasmania 7001, Australia.
E-mail address: timothy.ramm@utas.edu.au (T.D. Ramm).

http://dx.doi.org/10.1016/j.crm.2017.06.005
2212-0963/

1. Introduction

Australia is an arid country with approximately 85% of the population settled near the coast (Australian Bureau of Statistics, 2004; McInnes et al., 2016). During the last few hundred years there has been a steady rise in the global mean sea level and the rate of sea level rise appears to have accelerated in recent decades (Church et al., 2013, p.1150; White et al., 2014). This trend is consistent in Australia, with regional sea level rise observations at many locations comparable to the global rate (CSIRO and Bureau of Meteorology, 2014, p.148). Sea level rise increases the frequency and severity of natural hazards (storm surge, coastal erosion; Hunter, 2010), whilst over multi-decadal (long-term) time scales can contribute to permanent loss of land in low-lying areas. It was estimated that a 1.1 m sea level rise across Australia would threaten over $200 billion of buildings, roads and rail, including 274,000 residential buildings (Commonwealth of Australia, 2011). Further impacts of sea level rise and changing coastal flooding regimes include more frequent impacts to the built environment, increasing threats to public safety, and disruptions to important resident lifestyle values (Graham et al., 2014).

Engineered shoreline management controls (e.g. sea walls, groynes) that mitigate the impact of coastal hazards are often designed with a serviceable life of 50–100 years (Hallegatte et al., 2012, p.5; Stafford-Smith et al., 2011, p.199), thereby carrying long-term commitments. Evaluating the effectiveness of different management controls in mitigating projected coastal impacts is difficult because of uncertainty in long-term changes to biophysical, socioeconomic, technological, institutional and built environment stressors (Smith et al., 2015). Such uncertainty is unlikely to be reduced in the short-term due to limitations in scientific knowledge, predictability and multi-decadal climate variability. For these reasons, new methods of decision support have been called for that can accommodate irreducible uncertainty (Hallegatte, 2009).

Local government plays an important role in promoting long-term climate change adaptation in response to the threat of changing coastal hazards. They are responsible for 'day-to-day' decision making in coastal planning and management, often guided by State policy and legislation (Commonwealth of Australia, 2009, p.244). Local government works with communities to raise awareness of climate change risks, manage public assets, deliver services and support local planning (Council of Australian Governments, 2012). As local government are at the forefront of community decision-making, they are the target audience of this paper.

This paper systematically reviews characteristics of the methodologies used in current practice by Australian local government to evaluate long-term adaptation options to manage risks in low-lying coastal settlements. These characteristics include the decision objectives, approach taken to identify risk, time horizon over which risks and evaluation activities are assessed, management of uncertainty, choice of decision process and the decision metrics. Case studies are drawn from across Australia, including selected literature from the 2011 to 2012 Australian Government's coastal adaptation decision pathways program (CAPPs). The characteristics of the methodologies used to evaluate adaptation options in Australia are then compared with two state-of-the-art methods for decision-making under conditions of deep uncertainty – Robust Decision Making (RDM; Lempert et al., 2003) and Dynamic Adaptive Policy Pathways (DAPP; Haasnoot et al., 2013) – to identify any opportunities for local government to improve adaptation planning and the evaluation of long-term coastal adaptation options.

Whilst previous studies have reviewed (a) the challenges and successes of Australian coastal vulnerability and adaptation studies (Kay et al., 2014); (b) general decision support methods for climate change adaptation (Watkiss and Hunt, 2013;

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

Dittrich et al., 2016); and, (c) decision support methods suited to conditions of deep uncertainty (Kalra et al., 2014; Walker et al., 2013a), there has not been a review of current decision support methodologies being applied by local government at a local scale (i.e. city or urbanised area) in Australian coastal adaptation practice. Notwithstanding the complexities and different decision contexts faced at various locations along the Australian coast, this review seeks to reduce some of the difficulties associated with long-term decision making by exploring the defining characteristics of the evaluation process and highlighting fundamental considerations for local government agencies. Benchmarking the characteristics of current practice with two state-of-the-art methods for decision-making under conditions of uncertainty allows opportunities to improve long-term decision-making in Australia to be identified. This review may direct local government towards a defensible methodological basis to invest in adaptation policies under conditions of uncertainty, so that they can make better informed decisions without the threat of maladaptation and legal liability (Baker and McKenzie, 2011; Productivity Commission, 2012).

The remainder of this paper is structured as follows. Section 2 summarises the review methodology, and a short summary of risk management and components underpinning evaluation methodologies across long-term planning horizons is provided in Section 3. Section 4 presents the results of the reviewed case studies. Section 5 summarises the key characteristics of the case studies, before benchmarking these with attributes of RDM and DAPP (two approaches that have been demonstrated quantitatively abroad) which are used to support decision-making under conditions of uncertainty. Opportunities to advance current practice are then identified and conclusions drawn in Section 6.

2. Review methodology

The literature reviewed in this study focuses on characteristics of the methodologies applied by local government to evaluate the performance of long-term coastal adaptation options ('adaptation option' is used interchangeably with 'adaptation policy'). Case studies were derived from published local government and corporate reports, and peer-reviewed publications. Given there are more than 200 local government areas in Australia sharing boundaries with coastal or estuarine water bodies (based on a count of local government areas; Australian Bureau of Statistics, 2014), this review did not explore publications from each local government agency in Australia. Therefore, although the literature reviewed in this paper represents diverse geographical coverage, it is a representative selection of studies from around the country.

The review was limited to literature published since 2010, allowing the analysis to focus on recent case studies and include relevant literature produced as part of the 2011–2012 Australian Government funded CAPPs project. Prior to the CAPPs project there were very few examples of local government case studies published that focus on the evaluation of long-term coastal adaptation options. In 2008–2010, 39 projects were completed as part of the Australian local adaptation pathways program (LAPP; Productivity Commission, 2012), however these were excluded from this review because those reports focused on risk assessment activities, rather than the evaluation of adaptation options (see Pillora, 2010 for short summary of outcomes).

3. Summary of evaluation methodology characteristics in risk management

The formal evaluation of a policy or project requires the use of decision support tools to assess the efficacy of a risk treatment (adaptation) option. This section provides a short summary of background fundamentals that characterise the methodology used in identifying risk and evaluating adaptation options. The section forms a basis from which the systematic review of case studies is undertaken in Section 4.

3.1. Risk management as an overarching framework

Risk management is a recognised framework for developing long-term climate change adaptation strategies under conditions of uncertainty (Jones and Preston, 2011; Jones et al., 2014) and is a common feature of leading climate change adaptation frameworks (European Commission and European Environmental Agency, 2013; Mediation Adaptation Platform, 2013; UKCIP, 2015). The evaluation of adaptation options is a risk treatment activity with the benefits often expressed in terms of how well the option mitigates projected impacts (AS/NZS ISO 31000, 2009; Travis and Bates, 2014). Therefore, the framing of future risk scenarios is crucial to the evaluation process.

The approach to risk identification is important as it reflects the decision-makers framing of risk (Jones and Preston, 2011). It influences the selection of climate change scenarios (risk identification), from which impacts to low-lying coastal settlements are analysed (risk analysis), risk treatment options developed (adaptation options) and the net benefit of the adaptation options evaluated. Two common ways that decision-makers frame risk have been described in the literature as being 'bottom-up' or 'top-down' (García et al., 2014; IPCC, 2012; Jones et al., 2014). Both approaches differ in the order in which the risk assessment steps are undertaken and more crucially in their treatment of uncertainty, thereby making it an important characteristic of the chosen methodology to evaluate adaptation options. In this paper, reference is made to 'impact-first' (i.e. 'top-down') and 'threshold-first' (i.e. 'bottom-up') as presented by the Intergovernmental Panel on Climate Change (IPCC, 2012) to describe the risk identification characteristics found within the Australian case studies. The 'top-down' approach follows the sequence of first projecting future emissions of greenhouse gases, then developing climate

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

Table 1
Levels of uncertainty used to describe parameters and model future impacts (adapted from Riesch, 2013; Kwakkel et al., 2010; Walker et al., 2013b). The levels of uncertainty are not mutually exclusive.

Uncertainty level	Attributes/knowledge about future conditions	Example of complementary evaluation methodology
Level 1 (certainty)	■ *Future scenarios:* Relatively clear scenario ■ *Parameters:* Known (deterministic) ■ *Model:* Known	Traditional CBA (single scenario with sensitivity analysis on uncertain parameters)
Level 2	■ *Future scenarios:* Multiple ■ *Parameters:* Unknown (described with multiple probabilistic scenarios or single estimate with confidence interval) ■ *Model:* Known	CBA with Monte Carlo simulation
Level 3	■ *Future scenarios:* Multiple (selection) ■ *Parameters:* Unknown (non-probabilistic; use of trends) ■ *Model:* Unknown (able to identify likely model and rank alternatives)	CBA output (point estimate) from different models and scenarios; ranked by likelihood
Level 4	■ *Future scenarios:* Multiple (many) ■ *Parameters:* Unknown (non-probabilistic; specify bounds) ■ *Model:* Unknown (recognise sources of model inadequacy and assumptions; cannot rank alternatives)	Adaptation pathways; RDM; DAPP[a]
Level 5 (total ignorance)	■ *Future scenario:* Unknown ■ *Parameters:* Unknown ■ *Model:* Unknown (recognised ignorance and inadequacies)	DAPP[a]

[a] Level 4 and 5 are referred to as 'deep uncertainty'. DAPP is considered to be suitable under level 4 uncertainty, and in some cases level 5 uncertainty (Walker et al., 2013b).

scenarios and studying the impacts and adaptation options; in contrast, a 'bottom-up' approach starts from a given system and then studies vulnerabilities and risk thresholds (i.e. the degree to which the system is susceptible to, and unable to cope with, adverse impacts of climate change) (Dessai and Hulme, 2004; Kwadijk et al., 2010; Ray and Webb, 2015; White et al., 2017).

The time horizon across which the adaptation planning occurs influences the degree of uncertainty about future impacts and adaptation benefits. The extent of knowledge about the models and parameters used to identify risks and evaluate adaptation options can be described as being certain (i.e. deterministic), quantifiable probabilistically as risk (i.e. stochastic), or non-quantifiable (Hall and Solomatine, 2008; Knight, 1921; Willows and Connell, 2003). This conceptualisation can be broadened by using a gradation of uncertainty levels ranging from certainty to total ignorance (Courtney, 2003; Riesch, 2013; Walker et al., 2013b; Table 1). Uncertain parameters used in traditional cost-benefit analysis (CBA) can include the discount rate, probability of a coastal hazard event occurring and the damage cost estimates.

Deep uncertainty is a condition where decision-makers are unable to agree on models that describe the relationships amongst key input parameters and future impacts, nor the probability distributions used to describe the uncertain parameters in these models (Lempert et al., 2003). Additionally such uncertainty requires decisions to be made in a way that responds to system change with time (Kwakkel et al., 2016). Climate change is an example of deep uncertainty. Attributes of this uncertainty are often encountered when identifying risks and evaluating adaptation options across multi-decadal time horizons (Kalra et al., 2014; Lempert and Collins, 2007; Reeder and Ranger, 2011). There is general agreement that non-probabilistic descriptions of parameters and modelled impacts are better suited to manage this uncertainty (Kunreuther et al., 2013; PROVIA, 2013).

3.2. Components of evaluating adaptation options

Deciding how to evaluate coastal adaptation options requires the analyst to (a) understand the decision needs and context, (b) select a 'decision process' and (c) identify appropriate 'decision metrics' (for more details see Hallegatte et al., 2012; Kalra et al., 2014; PROVIA, 2013; Walker et al., 2013a; Watkiss and Hunt, 2013). Once adaptation options have been evaluated, an adaptation plan can be developed, which could involve doing nothing and monitoring future changes to risk, selecting a single adaptation option, implementing a portfolio of options, or designing an adaptation pathway. An adaptation pathway is a set of sequenced adaptation options that together form a long-term plan and can be updated iteratively over time (through adaptive management) as new information on uncertain parameters becomes available, or when risk thresholds are reached (Haasnoot et al., 2012, 2013; Stafford-smith et al., 2011; Walker et al., 2013a). Thresholds are future conditions where the level of risk becomes unacceptable to the decision-maker, signifying that the adaptation option is no longer effective in managing the risk (Kwadijk et al., 2010; Reeder and Ranger, 2011).

3.2.1. Understanding the decision needs

Identifying the decision needs is addressed during the scoping and context setting activities in risk management practice (refer ISO 31000 risk management standard; AS/NZS ISO 31000, 2009; Australian Standard AS5334, 2013; Jones et al., 2014).

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

This activity includes defining the decision objectives, data availability and technical capacity for the analysis, uncertainty characteristics and the time horizon across which the risks are identified and the benefits of the adaptation option evaluated.

Decision-making objectives often seek either optimal outcomes (i.e. to maximise, or minimise, the performance of an option) or robust outcomes (i.e. identify an option that achieves a satisfactory level of performance across a wide range of future scenarios; Ben-Haim, 2012; Lempert and Collins, 2007; Walker et al., 2013b; Woodward et al., 2014). Optimal adaptation options can be beneficial when assumptions about coastal impacts can be estimated with confidence, or when the adaptation option is flexible and easily reversed. Optimal adaptation options rely on upfront assumptions about the future being correct, which becomes problematic over long-term horizons. This makes robust options superior when future impacts are difficult to model and when adaptation options, such as engineering infrastructure, provide ongoing benefits across multiple decades.

3.2.2. Selecting a decision process

A decision process is a tool used to appraise adaptation options and produce a metric. Kalra et al. (2014) categorises the decision process into 'agree-on-assumption' or 'agree-on-decision' processes, based on the analyst's assumptions and how they manage uncertainty. Traditional decision processes such as CBA and multi-criteria decision analysis (MCDA) are examples of an agree-on-assumption process, as is real options analysis (ROA). These processes generally align with optimal-seeking decision objectives and require analysts to agree on the assumptions used in the analysis before the evaluation takes place. Robust Decision Making (RDM) is an example of an agree-on-decisions process, which does not require stakeholders to agree on input parameter assumptions prior to the analysis. Such processes seek robust outcomes by evaluating policies under hundreds or thousands of non-probabilistic scenarios, to explore the performance of an adaptation option across a large uncertainty space and uncover the vulnerabilities of that option (i.e. when the options fails to adequately manage risks). Data mining algorithms, such as the patient rule induction method, are then used in a process of scenario discovery (e.g. Bryant and Lempert, 2010) to identify those uncertain parameters that have the greatest impact on achieving the desired objectives of the decisions-maker. Decision processes such as RDM rely on computational support to explore the performance of adaptation options across a much larger uncertainty space than is traditionally done using a limited set of scenarios (see Walker et al., 2013a for a review of computational support tools).

Dynamic Adaptive Policy Pathways (DAPP) is a risk management tool that incorporates transient scenarios to assess the limits of different adaptation options and define risk thresholds (Haasnoot et al., 2013). The DAPP framework builds upon the adaptation tipping point (ATP) concept (Haasnoot et al., 2013; Kwadijk et al., 2010; Watkiss and Hunt, 2013), and allows adaptation pathways to be mapped. Pathways are usually designed following the evaluation of individual adaptation options. The adaptation pathway methods align closely with the monitoring and review principals of the globally recognised risk management framework (AS/NZS ISO 31000, 2009) and are examples of adaptive management.

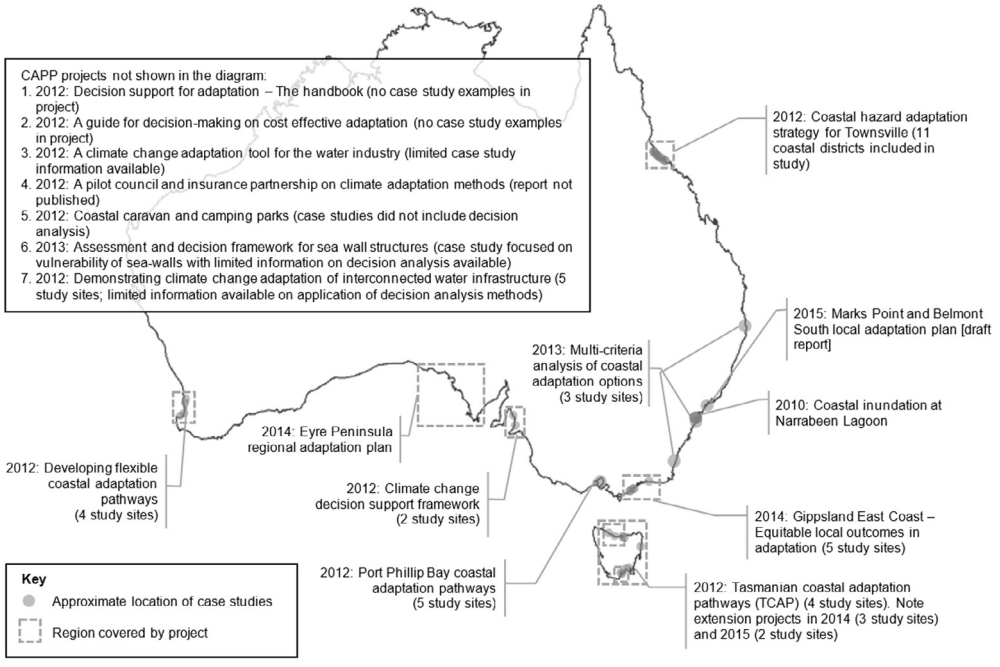

Fig. 1. Geographic location of selected coastal adaptation projects reviewed from around Australia. For the projects analysed (see Table 2), the number of case study sites are shown in parenthesis.

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

3.2.3. Selecting decision metrics

Decision metrics are used to compare the performance of different adaptation options. Metrics can be expressed in qualitative, quantitative or economic (monetary) terms. The decision process uses decision metrics to evaluate the adaptation options, for example the net present value (NPV) metric is used to evaluate options with CBA. An important advantage of the NPV metric over other metrics is that it determines whether an adaptation strategy is economically feasible and calculates the net monetary benefits. The use of an MCDA score as a metric can only rank adaptation options in order of preference, rather than explicitly indicating whether to make the investment or not. The use of a benefit-cost ratio (BCR) produces a ratio of benefits to cost, however risks favouring outcomes that may not have the highest monetary net benefit (Boardman et al., 2011, p.34). Evaluating adaptation options based on an MCDA score can be useful when there are quantitative, qualitative and economic criteria that are to be considered (Watkiss and Hunt, 2013), however reducing the evaluation of multiple criteria down to a single score is often criticised as being subjective and easily influenced by stakeholders (Deb, 2001; Dobes and Bennett, 2009). Techniques such as multi-objective optimisation have been developed to overcome the subjectivities in using a single MCDA score but require a higher level of technical resource to implement. Multi-objective optimisation methods can present decision-makers with a larger set of information about the performance of adaptation options against multiple metrics, from which they can make informed decisions using their own value judgements about the relative importance of the objectives (for further examples see Kwakkel et al., 2015; Mortazavi-Naeini et al., 2013; Woodward et al., 2014).

4. Review of long-term coastal adaptation case studies in Australia

This section systematically reviews characteristics of the methodologies applied to evaluate adaptation options in a representative sample of long-term coastal adaptation studies in Australia.

4.1. Selected case studies

The geographic location of reviewed case studies is shown in Fig. 1. Of the seventeen coastal adaptation studies identified in the review, ten of these projects contained sufficient information about the characteristics of the risk management process and evaluation methodology for use in this analysis (Table 2). The number of case studies reviewed is a small sample size, suggesting that the evaluation of long-term coastal adaptation options is a new area of practice in Australia, with limited progress being made by local government in recent years as they transition from risk assessment activities into adaptation planning, evaluation and implementation. A reference list of case study reports and supporting project documentation has been collated in Appendix A.

4.2. Characteristics of decision support in selected case studies

The reviewed decision support and risk management literature summarised in Section 3 finds that six characteristics (Fig. 2) can be used to provide insights about the basis and context of a chosen methodology to evaluate adaptation options: (1) decision objectives; (2) time horizon; (3) approach to risk identification; (4) management of uncertainty; (5) decision process, and (6) decision metrics. Section 4.2.1–4.2.6 summarises the results from Australian case studies based on these characteristics.

4.2.1. Decision objectives

Six case studies focussed on identifying adaptation options that either maximised the monetary benefits of coastal adaptation or minimised the projected monetary damage costs through adaptation (ACIL Tasman, 2012; AECOM Australia, 2012; AECOM and Commonwealth of Australia, 2010; Balston et al., 2012; GHD, 2012; SGS Economics and Planning, 2012). Two case studies aimed to maximise a weighted MCDA score based on multiple decision criteria (GHD, 2012; Preston et al., 2013). These were all studies with optimum-seeking decision objectives. Evaluating adaptation options for an optimal outcome is generally of greater use over short time horizons where uncertainty can be well characterised by probabilities (Watkiss et al., 2014). The Lake Macquarie City Council (2015) case study evaluated adaptation options using a semi-quantitative MCDA approach however the decisions were based on community deliberation, rather than a predefined optimisation rule. The cases studies that did not have optimal-seeking decision objectives tended to display attributes of robustness-seeking objectives (Barnett et al., 2014; Siebentritt et al., 2014). These studies identified limits of existing coastal risk management measures through stakeholder workshops, producing a list of adaptation responses mapped as an adaptation pathway.

4.2.2. Time horizon

The majority of case studies adopted a planning horizon up to the year 2100 to identify risks and evaluate adaptation options (ACIL Tasman, 2012; AECOM Australia, 2012; AECOM and Commonwealth of Australia, 2010; Balston et al., 2012; GHD, 2012; Lake Macquarie City Council, 2015; Preston et al., 2013; SGS Economics and Planning, 2012). This characteristic is likely to be based upon the time horizons used in climate change projections published by scientific bodies such as the IPCC and CSIRO. The case studies that mapped adaptation pathways using risk thresholds generally did not specify a

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

Table 2
Summary of case studies reviewed with selected characteristics of the methodology used to identify risks and evaluate adaptation options.

State	Project containing case study	Decision objective	Dominant risk framing	Time horizon	Highest uncertainty level	Total number of scenarios	Scenario type[a]	Decision process[b]	Decision metrics[b]	Reference
NSW	Coastal inundation at Narrabeen Lagoon	Optimal-seeking	Impact-first	2100	Level 2	1,000	Transient	CBA, ROA	NPV	AECOM and Commonwealth of Australia (2010)
NSW	A multi-criteria analysis of coastal adaptation options for local government	Optimal-seeking	Impact-first	2100[c]	Level 1[c]	2	Endpoint	MCDA, BBN	MCDA score	Preston et al. (2013)
NSW	Marks Point and Belmont South local adaptation Plan	Optimal-seeking	Impact-first	2100	Level 4[d]	Not specified	Endpoint	MCDA (semi-quantitative), CBA	BCR, Deliberative[d]	Lake Macquarie City Council (2015)
QLD	Coastal hazard adaptation strategy for Townsville City Council	Optimal-seeking	Impact-first	2100	Level 2	1,000	Transient	CBA, MCDA	NPV, BCR, MCDA score	GHD (2012)
SA	Climate change decision support framework and software for coastal councils	Optimal-seeking	Impact-first	2100	Level 2	10,000	Transient	ROA	NPV	Balston et al. (2012)
SA	Regional climate change adaptation plan for the Eyre Peninsula	Robustness-seeking	Threshold-first	2050+	Level 4	Not specified	N/A	MCDA (semi-quantitative)[e]	Deliberative[e]	Siebentritt et al. (2014)
TAS	Tasmanian coastal adaptation pathways project	Optimal-seeking	Impact-first	2100	Level 1	3	Endpoint	CBA[f]	NPV[f]	SGS Economics and Planning (2012)
VIC	Port Phillip Bay coastal adaptation pathways project report		Impact-first	2100	Level 1	1	Endpoint	CBA	NPV, BCR	AECOM Australia (2012)
VIC	Equitable local outcomes in adaptation to sea-level rise	Robustness-seeking	Threshold-first	Not defined[g]	Level 4	Options not evaluated[g]	N/A	Options not evaluated[g]	Options not evaluated[g]	Barnett et al. (2014)
WA	Developing flexible adaptation pathways for the Peron-Naturaliste coastal region of Western Australia	Optimal-seeking	Impact-first	2100	Level 2	Not specified	Transient	ROA	NPV	ACIL Tasman (2012)

[a] Transient scenarios (future described as a time-series) or endpoint scenarios (future described at a single point in time).
[b] Acronyms: BBN – Bayesian belief network; BCR – benefit-cost ratio; CBA – cost-benefit analysis; MCDA – multi-criteria; NPV – net present value; ROA – real options analysis; decision analysis;
[c] Based on the hazard scenarios generated in Stage 2 (place-based evaluation) of the case study.
[d] Evaluation of adaptation options through stakeholder workshops. Although the CBA reflected level 1 uncertainty, the development of thresholds in the adaptation plan recognises level 4 uncertainty.
[e] Siebentritt 2016, pers. Comm., 22 Jan.
[f] Evaluation of adaptation options not demonstrated explicitly in these case studies. CBA was inferred on basis that an NPV metric was used to quantify risk and the project being based on a CBA framework (SGS Economics and Planning, 2014).
[g] Actions implemented based on when risk thresholds were reached (i.e. water elevation levels).
[h] Options not evaluated quantitatively in this case study.

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

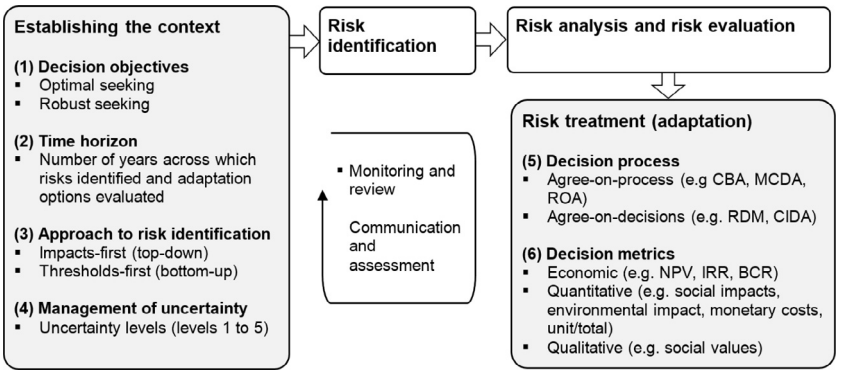

Fig. 2. Selected characteristics used to review methodologies applied in Australia to evaluate long-term coastal adaptation options. The characteristics are grouped into the corresponding steps of the AS/NZS ISO 31000 (2009) risk management process, aligning with Section 4.2.1–4.2.6.

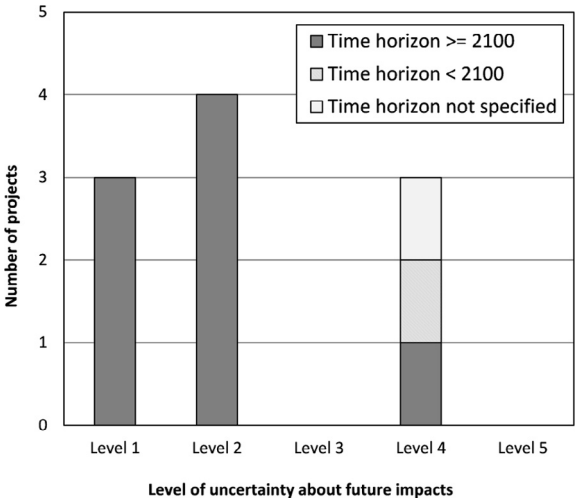

Fig. 3. Levels of uncertainty used to describe input parameters and model future impact scenarios (see Table 1), against the time horizon over which the analysis was undertaken (number of projects = 10).

planning time horizon, rather focusing on the development of triggers to implement risk mitigation actions and avoid unacceptable risk thresholds being reached (Barnett et al., 2014; Siebentritt et al., 2014).

4.2.3. Approaches to risk identification

A simple classification of the risk identification approach into impact-first or threshold-first was not definitive for many of the case studies, however a dominant approach was identifiable. The use of impact-first approaches to identify climate risks (scenarios) was dominant in ACIL Tasman (2012), AECOM Australia (2012), AECOM and Commonwealth of Australia (2010), Balston et al. (2012), GHD (2012) and SGS Economics and Planning (2012). Lake Macquarie City Council (2015) adopted an impact-first perspective for their economic evaluation, while Preston et al. (2013) used an impact-first approach in their place-based risk assessment. Fewer case studies displayed traits of a threshold-first approach to risk identification (Barnett et al., 2014; Siebentritt et al., 2014). A clear example was provided by Barnett et al. (2014) who engaged with the community to identify measurable risk thresholds based on observable changes to future coastal flooding regimes. These thresholds reflected the risk tolerance of the community and allowed action plans to be developed should those risk thresholds be reached.

4.2.4. Management of uncertainty

It was difficult to describe a single level of uncertainty in case studies that definitively reflected how uncertain parameters were managed in the analysis (Table 1). To illustrate this point, some studies described the sea level rise parameter deterministically (level 1) and the likelihood of an extreme coastal hazard event stochastically (level 2). In such instances, the higher uncertainty level was chosen for this analysis (i.e. level 2 in this example). The Lake Macquarie City Council (2015) case study made deterministic assumptions about the future for their CBA evaluation, however identified triggers for future action which is indicative of recognising level 4 parameter uncertainty. Seven out of ten case studies described

future hazards with either level 1 or level 2 uncertainty (Table 2; Fig. 3). Notably the studies that made these assumptions also evaluated the costs and benefits of adaptation options up to the year 2100, a timeframe that is highly uncertain. Assuming that parameters can be described with level 1 or 2 uncertainty does allow analysts to use familiar appraisal methods (such as CBA) to quantify the risks and benefits of adaptation. Barnett et al. (2014) and Siebentritt et al. (2014) recognised limitations in their ability to define the likelihood of future hazards (an attribute of level 4 uncertainty) and adopted a flexible adaptation pathway to support their long-term coastal adaptation plans.

Sensitivity analysis, or use of a small set of scenarios to evaluate adaptation options, was used in some case studies that managed uncertain parameters deterministically, such as an assuming a sea level rise amount by 2100 (e.g. AECOM Australia, 2012; SGS Economics and Planning, 2012). Monte Carlo simulation was used in some case studies to stochastically simulate the probability of future coastal hazards such as extreme inundation events (ACIL Tasman, 2012; AECOM and Commonwealth of Australia, 2010; Balston et al., 2012; GHD, 2012). Based on the assumed stochastic parameters in the Monte Carlo simulation, the costs and benefits of an adaptation option could be propagated into CBA (or ROA) and an expected value calculated (e.g. NPV metric).

There were different conceptualisations of the term 'pathways' that emerged in this review. Some studies (e.g. AECOM Australia, 2012) grouped individual adaptation options into discrete pathway sets (e.g. an accommodate or protection pathway); others (e.g. GHD, 2012) analysed adaptation options individually and identified an optimal investment time for the options (reflecting a future trigger for action contingent on underlying assumptions being correct); and some (e.g. Barnett et al., 2014) focussed on developing risk triggers for adaptation through deliberation with stakeholders. Barnett et al. (2014) and Siebentritt et al. (2014) where the only two case studies that mapped an adaptation pathway to manage long-term uncertainty. Neither study utilised a quantitative method or any modelling to identify the risk thresholds in the adaptation pathway. The Lake Macquarie City Council (2015) study developed a draft ten year action plan to manage risk in their community with the plan being reviewed at regular intervals as more information becomes available. They established triggers to implement adaptive actions which included the use of governance mechanisms (e.g. local government applications for asset maintenance), human processes (e.g. re-development applications) and observable increases to flood risk from sea level rise.

4.2.5. Decision process

The decision process and decision metrics applied in the reviewed case studies are summarised in Fig. 4.

An agree-on-assumption decision process was used in the majority of case studies with CBA being the most common decision process, used in half of the case studies (Table 2). ROA extends traditional CBA to handle uncertainty and was used in three case studies (ACIL Tasman, 2012; AECOM and Commonwealth of Australia, 2010; Balston et al., 2012), whilst MCDA was applied in two of the case studies (GHD, 2012; Preston et al., 2013). MCDA is useful in addressing the challenge of decision-making with stakeholders whom have multiple, conflicting objectives. GHD (2012) applied MCDA as a screening tool to reduce the number of adaptation options down to a smaller shortlist, which were then evaluated in further detail with CBA. Preston et al. (2013) obtained local government stakeholder preferences through a survey and expressed these as multiple criteria in stage 1 of their analysis, which were then used with MCDA to evaluate adaptation options. They extended their analysis with a Bayesian Belief Network (BBN) to understand the variability in individual preferences within, and between local government stakeholders. Lake Macquarie City Council (2015) and Siebentritt et al. (2014) used MCDA in a deliberative manner, the former identifying four critical criteria (one of which was to pass a CBA test) that had to be addressed for the option to be progressed into the adaptation plan.

Barnett et al. (2014) did not formally evaluate adaptation options in their pathway approach. They identified a shortlist of adaptation options with community participants that could be explored once risk thresholds are reached. The first trigger level set by the community was designed to represent a change to the frequency of the inundation hazard and prompted the next level of adaptation planning activities to be implemented.

4.2.6. Decision metrics

The NPV metric was most commonly used in the case studies (refer Table 2; Fig. 4), which complements the use of CBA and ROA as a decision-process. Siebentritt et al. (2014) did not specify a decision metric to evaluate the different adaptation options in their study, choosing to undertake the evaluation with stakeholder participation and discussion. Lake Macquarie City Council (2015) used a semi-quantitative analysis (MCDA) to evaluate adaptation options, but did not reduce the assessment against four criteria into a single MCDA score leaving it open for deliberation.

5. Discussion

5.1. Towards better informed long-term decisions

The small number of case studies available for review suggests that the planning and evaluation of coastal adaptation options is a relatively new area of practice in Australia. Although there is guidance material available to local government on risk management and the selection of suitable evaluation methodologies (Dittrich et al., 2016; Mediation Adaptation Platform, 2013), there is no nationally recognised standard in Australia. The different methodological approaches taken in Australia to identify risk and evaluate adaptation options suggest that further guidance is needed to provide a consistent basis in local governments. Current research being undertaken by the National Climate Change Adaptation Research Facility

Please cite this article in press as: Ramm, T.D., et al.. Climate Risk Management (2017), http://dx.doi.org/10.1016/j.crm.2017.06.005

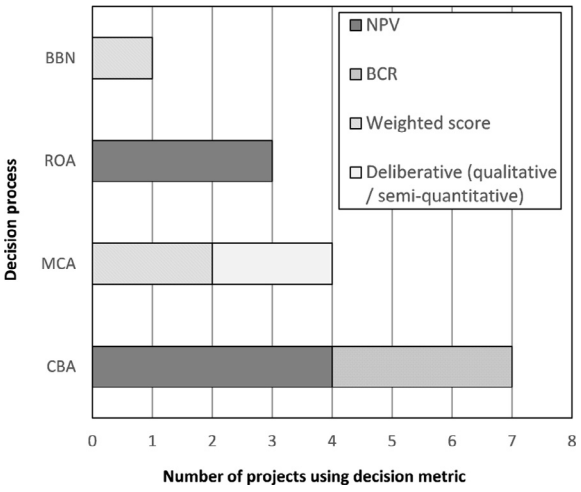

Fig. 4. Grouping of the decision process with the decision metrics used in the case studies (number of projects = 9; Barnett et al. (2014) excluded). All metrics used in each case study have been counted, therefore the sum of the metrics (15) exceeds the number of projects (9) as multiple metrics were used in some case studies. (Acronyms: NPV – net present value; BCR – benefit-cost ratio).

(NCCARF) is contributing to this knowledge base, aiming to provide risk management information and a decision support platform through an online portal called CoastAdapt (https://coastadapt.com.au/).

The diversity of methodological approaches used in the Australian case studies made it difficult in some instances to categorise the approach to risk identification (i.e. impact-first or threshold-first) and identify what level best describes the treatment of uncertain parameters. Armstrong et al. (2015) experienced similar difficulties classifying adaptation projects into theoretical frameworks, suggesting that the strengths of different approaches sometimes compensate for methodological weaknesses in others, in order to meet decision-maker needs. This conclusion can also be drawn in current Australian practice.

An emerging theme in the Australian case studies was a reliance on key upfront assumptions to explore future impact scenarios and to evaluate adaptation options across multi-decadal periods (to the year 2100). This framing was driven by optimal-seeking decision objectives with common assumptions including the extent of sea level rise, probability of extreme events, discount rates and damage costs. Studies that sought to optimise the benefits of adaptation took an impact-first perspective to identify risk, assuming a risk scenario, from which the value of the adaptation response could be assessed. Impact-first perspectives are subject to the 'cascade of uncertainty' (Wilby and Dessai, 2010), whereby assumptions made about future (e.g. emissions) feed into downscaled climate projections (e.g. sea level rise), which then are carried through to impact assessments (e.g. monetary impacts) and propagate into the evaluation of adaptation options. Although impact-first approaches are useful to local government faced with budget, time and technical resource constraints, they can make it challenging to formulate a defensible basis for adaptation investment. Furthermore, there is general acknowledgement in the literature that impact-first approaches are useful when uncertainty can be well characterised, however under conditions of uncertainty – which occurs in long-term evaluations – threshold-first approaches are more suitable (Jones et al., 2014). Many of the Australian case studies overlooked this important principle for identifying risk and evaluating adaptation benefits over the coming decades. Additionally, impact-first approaches can overlook social and community-based objectives in adaptation planning, which are increasingly becoming recognised (Downing, 2012; Hinkel and Bisaro, 2015; Wise et al., 2014) and essential to local government decision-making.

The management of uncertainty was another important characteristic of the evaluation methodology, reflecting assumptions made by analysts in their ability to describe future impacts and knowledge of input parameters. The majority of Australian case studies characterised uncertain parameters as being deterministic (level 1 uncertainty) or stochastic (level 2 uncertainty). This could be due to the relatively infancy of robust methods being used in policy analysis (Dittrich et al., 2016) or because such assumptions simplify the quantitative analysis of adaptation options and make it more accessible to resource constrained local governments. Case studies that characterised uncertainty in this way generally tested their assumptions with a sensitivity analysis; however, there is no guarantee that this explores the full range of uncertainty (Bonzanigo and Kalra, 2014). A few case studies generated many scenarios using Monte Carlo simulation which allowed a much greater set of assumptions about parameter values to be explored. These approaches relied on a probabilistic description of uncertain parameters and the result of the analysis infers a likelihood of attaining the calculated metric (Bonzanigo and Kalra, 2014). The assumption that parameters can be described probabilistically is often argued to be inadequate for long-term decision-making (Kunreuther et al., 2013; PROVIA, 2013), therefore the basis for managing uncertainty in the analysis of risks and adaptation options in Australian practice requires rethinking to avoid a reliance on overly simplistic assumptions. The reliance on upfront assumptions in Australian practice to evaluate adaptation options (notably underpinning the risk identification and management of uncertainty) provides empirical evidence to support the conclusions made by Jones and Preston (2011) that the framing of risk in the scoping phase is fundamental to the subsequent risk management activities.

The use of CBA to assess the efficacy of capital expenditures is common in practice (Department of Prime Minister and Cabinet, 2016; Dobes and Bennett, 2009; HM Treasury, 2003; IPCC, 2012; Metroeconomica, 2004) and was a theme evident in the case studies. Case studies that recognised the shortcomings of using CBA across longer planning horizons used ROA to undertake an economic analysis, but ROA requires the direction of change in the uncertain parameters to be monotonic and adaptation options to be flexible (Stafford-Smith et al., 2011). ROA can also be challenged by political barriers, for example having uncertain timeframes for capital investment is less desirable to governments than committing to inflexible 'one-off' investments (Linquiti and Vonortas, 2012). ROA also assumes that uncertainty is reduced over time (Hallegatte et al., 2012) and like CBA, relies on probabilistic projections for climate related parameters which in not always appropriate for long-term evaluations.

The complexities of the adaptation challenge faced by local government was evident across all of the case studies. Whilst it is too early to understand how effective the appraisal of adaptation options were in the Australian case studies (i.e. the analysis was done *ex ante*), two general observations are made about the resultant conclusions. Firstly, most case studies followed a risk management process (adaptive management) in the face of uncertainty and concluded that adaptation investments were necessary at a future time. However, at such points in the future a decision will need to be made whether to invest and the robustness of such decisions will depend on characteristics such as the objectives, management of uncertainty and decision process. If investments are to have multi-decadal consequences, then traditional appraisal methods like CBA can risk maladaptive outcomes should the future depart from the assumptions. Secondly, what is identified as being at risk shaped the selection of adaptation options (Hinkel and Bisaro, 2015). For example, many of the case studies focused on mitigating physical impacts (i.e. losses to assets) which could be monetised for use in CBA or ROA. This directed adaptation responses towards engineered defences (levees and seawalls) to manage changing coastal hazards. These plans overlook non-measurable social impacts from changing coastal hazards and resultant policy recommendations could underestimate the need for adaptive action.

5.2. Benchmarking Australia practice with international methodologies

Two state-of-the-art evaluation methodologies used internationally to support decision-making under conditions of uncertainty include RDM and DAPP (Kalra et al., 2014; Kwakkel et al., 2016; see Section 3.2.2). These methods are most useful when the future is uncertain, complex and unable to be characterised probabilistically, which was a decision context shared by most of the Australian cases studies as planning and evaluation activities occurred across multi-decadal time horizons. In contrast with many of the case studies reviewed which targeted optimal outcomes using an impact-first approach (e.g. ACIL Tasman (2012), AECOM Australia (2012), AECOM and Commonwealth of Australia (2010), Balston et al. (2012), GHD (2012) and SGS Economics and Planning (2012)), RDM and DAPP seek robust outcomes and take a threshold-first approach to identify risk. They do not require an evaluation timeframe to be specified, focusing on observable changes to key parameters. The conclusions drawn in many of the optimal-seeking case studies rely entirely on initial assumptions being realised decades from today, which can be contentious amongst stakeholders and impede the adaptation planning process. RDM and DAPP can also utilise conventional metrics such as NPV, which is important for decision-makers who rely on economic measures as was seen in many of the Australian case studies (e.g. ACIL Tasman, 2012; AECOM Australia, 2012; AECOM and Commonwealth of Australia, 2010; Balston et al., 2012; Lake Macquarie City Council, 2015; GHD, 2012; SGS Economics and Planning, 2012).

The use of non-probabilistic scenarios to manage uncertainty across multi-decadal time horizons was a key differentiating factor between those Australian case studies that used many scenarios and RDM/DAPP methods. Methods such as RDM and DAPP specify non-probabilistic bounds for uncertain variables and explore how well an adaptation option performs under many scenarios, which is better suited to managing level 4 or 5 parameter uncertainty. It also allows thresholds for critical variables to be established. In complex coastal applications where there are many uncertain variables and interactions amongst stressors, this allows decision-makers to focus on a reduced set of critical variables that matter most to their risk management objectives. Furthermore, the use of many scenarios to evaluate adaptation options allows a greater suite of uncertain parameters to be explored, such as population growth or damage costs, not limited exclusively to climate related variables like sea level rise which was the case in many of the Australian case studies. In contrast, some case studies only used a small number of scenarios to explore a very limited set of future conditions. Those studies that used many probabilistic scenarios inferred a likelihood of attaining measured outcomes. The assumption that probability distributions for input parameters can be used to describe scenarios extending decades into the future is challenged by factors such as non-stationarity (e.g. Milly et al., 2008) and the legitimacy of such plans is likely to reduce as the planning timeframe increases. Some Australian case studies incorporated basic ideas from the DAPP method (Barnett et al., 2014; Lake Macquarie City Council, 2015; Siebentritt et al., 2014). Barnett et al. (2014) acknowledged the limitations of technical resource in local government to apply quantitative evaluation methods, and focussed on a non-intensive methodology for constructing their local adaptation pathway. This approach identified thresholds based on community participation and resident experience with historic floods, instead of through computationally intensive scenario modelling. Notwithstanding the constraints faced by local government, inclusion of a quantitative basis for identifying thresholds would be valuable information to supplement adaptation planning in Australian communities.

5.3. Opportunities to advance current adaptation practice in Australia

Local government are faced with many challenges that need to be addressed to advance current adaptation practice. Financial and technical constraints play an important role in the ability of authorities to undertake planning and eval-

uation activities. Additionally, local government are operating in an environment where there is no mandate from higher-order government for adaptation planning, unclear responsibilities amongst government authorities (Nalau et al., 2015) and the threat of legal liability for maladaptive decisions. Providing opportunities to increase the uptake of new methods such as RDM and DAPP for planning and evaluating adaptation options requires the creation of interest and awareness in local government (Lawrence and Haasnoot, 2017), availability of relevant data (Bhave et al., 2016), leadership from within governments, buy-in from senior management and a coordination mechanism (Lawrence and Haasnoot, 2017).

Notwithstanding current challenges, the ten representative Australian case studies reviewed suggest that the approach to identifying risk and managing uncertainty in evaluation activities can be improved by recognising the time scales across which the appraisal is occurring and the diminishing ability to predict the future. This is because uncertainty increasingly propagates as time horizons extend and multiple futures become possible (Maier et al., 2016). Recognising such uncertainty in evaluation activities requires a shift towards robust rather than optimal-seeking decision objectives. Exploring the performance of adaptation options across many scenarios (as used in RDM and DAPP) can provide an opportunity for local governments to make better informed decisions in the face of uncertainty, however, the accessibility of these methods to local government needs to be addressed by future research given the challenges mentioned earlier. Scenario-based methods can also provide quantitative information to support the identification of risk thresholds in coastal communities, which can then inform stakeholder discussions and the design of flexible adaptation pathways. Given the severity of coastal impacts is projected to increase in the coming decades along with uncertain change to built and environmental stressors, it is prudent that alternate evaluation methodologies to those currently used in Australian practice are considered when long-term coastal adaptation options are being appraised. This can improve the legitimacy of adaptation planning and avoid maladaptive outcomes that only consider a narrow range of uncertainties.

6. Conclusions

The selection of a methodology to evaluate long-term coastal adaptation options can be influenced by the decision objectives, time horizon of analysis, approach to risk identification, management of uncertainty, decision process, and decision metrics. The majority of Australian case studies described uncertainty across multi-decadal timeframes as being deterministic or stochastic, which is not considered sophisticated enough for long-term risk assessment, evaluation activities and decision-making.

Comparing Australian case studies with two state-of-the-art methods from abroad reveals that a key difference lies in the use of scenarios to manage uncertainty and seek adaptation options that are robust to many future scenarios. A greater focus on the use of scenario-based evaluations is needed in Australia to account for interactions amongst multiple variables, especially given the potentially high consequences from poor local government decisions in coastal settlements. The identification of risk thresholds when formulating adaptation pathways in Australian practice can also benefit from quantitative scenario-based evaluations to better inform community decision-making.

The reviewed case studies were generally consistent with the overarching ISO 31000 risk management standard but differed in the detailed methods used at each stage of the process. The framing of risk (i.e. establishing the context) – which includes the risk identification perceptive and management of uncertainty characteristics – was found to be a fundamental consideration for local governments involved in adaptation activities as this ultimately influenced the approach taken to evaluate adaptation options. There is an opportunity for decision-makers in Australia faced with changing coastal hazards to consider adopting a threshold-first approach to identify risk and seek robust outcomes in recognition of the uncertainties associated with evaluations across multi-decadal time frames.

The small number of case studies available for this review suggests that evaluation activities associated with long-term coastal adaptation in Australia is in its infancy, and the characteristics discussed in this paper provide a timely opportunity to guide local government towards better informed decision-making, which can reduce the threat of maladaptation and legal liability in the coming decades.

Acknowledgements

The authors are grateful for the financial support of the Commonwealth of Australia through the Bushfire and Natural Hazards Cooperative Research Centre program and the Australian Postgraduate Award. The authors also wish to acknowledge Stewart Franks for the useful comments and suggestions in the early stages of this paper.

Appendix A. List of documentation used in the analysis

See Table A.1.

Table A.1
List of selected coastal adaptation projects in Australia grouped by Australian State. There were no reports used in this analysis from the Northern Territory. The Australian Capital Territory was excluded, as this is not a coastal area.

State	Date	Project Title	Reference(s)
NSW	2010	Coastal inundation at Narrabeen Lagoon	AECOM and Commonwealth of Australia, 2010. Coastal inundation at Narrabeen Lagoon. Optimising adaptation investment. https://www.environment.gov.au/system/files/resources/52d-f63be-426d-4da4-979f-de586e4c478c/files/narrabeen-lagoon.pdf (accessed 25.01.16).
NSW	2011, 2012	Decision support for coastal adaptation: The handbook	Arnold, N., Fitzgibbons, A., Kinrade, P., Prickett, K., Whiteoak, K., 2011. Literature review and consultation paper. http://www.hccrems.com.au/wp-content/uploads/2016/07/literature-review-consultation-paper.pdf (accessed 20.06.17). Kinrade, P., Arnold, N., Fitzgibbons, A., Kulkarni, K., Prickett, K., Whiteoak, K., Wilson, S., 2012a. Decision support for coastal adaptation: The handbook. Hunter and Central Coastal Regional Environmental Management Strategy, Thornton, NSW. Kinrade, P., Arnold, N., Davies, S., Whiteoak, K., Fitzgibbons, A., 2011. Discussion paper. http://www.hccrems.com.au/wp-content/uploads/2016/07/background-discussion-paper.pdf (accessed 20.06.17).
NSW	2012		ARUP, 2012a. Demonstrating climate change adaptation of interconnected water infrastructure. Synthesis Report. Synthesis Report. http://www.sydneycoastalcouncils.com.au/sites/default/files/Synthesis%20Report%20Cover%20and%20Executive%20summary.pdf (accessed 25.01.16). ARUP, 2012b. Demonstrating climate change adaptation of interconnected water infrastructure. Synthesis Report. Part 1 – Overview. http://www.sydneycoastalcouncils.com.au/sites/default/files/Part%201%20Overview.pdf (accessed 25.01.16). ARUP, 2012c. Demonstrating climate change adaptation of interconnected water infrastructure. Synthesis Report. Part 2 – User Guide. http://www.sydneycoastalcouncils.com.au/sites/default/files/Part%202%20User%20Guide.pdf (accessed 25.01.16). ARUP, 2012d. Demonstrating climate change adaptation of interconnected water infrastructure. Synthesis Report. Adaptation Resource Centre (interactive pdf). http://www.sydneycoastalcouncils.com.au/sites/default/files/Part%203%20Adaptation%20Resource%20Centre.pdf (accessed 25.01.16).
NSW	2012, 2013	AdaptWater	Allen, G., Cini, E., Cox, D., Mallon, K., Quinn, N., Nelson, N., Sullivan, J., 2013. AdaptWater™: incorporating climate change adaptation into utility asset management decision-making, fifth Leading-Edge Strategic Asset Management conference, International Water Association, Sydney, NSW. Mallon, K., Cini, E., Sullivan, J., Kristevic, O., Brown, S., Quinn, N., de Lacy, C., 2012. AdaptWater™: climate change adaptation quantification tool for the water industry. Ozwater'13 Conference and Exhibition, Perth, WA.
NSW	2013	Assessment and decision frameworks for seawall structures	Coastal Environment Pty Ltd, 2013a. Assessment and decision frameworks for seawall structures. Part A – Synthesis Report. http://www.sydneycoastalcouncils.com.au/sites/default/files/Seawalls%20Final%20report%20consolidated%20290413%20Part%20A.pdf (accessed 25.01.16). Coastal Environment Pty Ltd, 2013b. Assessment and decision frameworks for seawall structures. Part B – Appendix C – Economic Considerations. http://www.sydneycoastalcouncils.com.au/sites/default/files/appendix_c_economic_considerations.pdf (accessed 25.01.16).
NSW	2013, 2014	A multi-criteria analysis of coastal adaptation options for local government	Mangoyana, R.B., Thomsen, D.C., Smith, T.F., Preston, B.L., Heinz, S., Maloney, M., Withycombe, G., Armstong, I., 2013. Literature review of adaptation to climate change in the coastal zone. http://www.sydneycoastalcouncils.com.au/sites/default/files/litreview.pdf (accessed 25.01.16). 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. http://www.sydneycoastalcouncils.com.au/sites/default/files/MCA_of_Coastal_Adaptation_Options_for_Local_Government.pdf (accessed 25.01.16). Thomsen, D.C., Smith, T.F., Jacobson, C., Mangoyana, R.B., Preston, B.L., Maloney, M., Withycombe, G., Armstrong, I., Norrie, E., 2014. A guide to monitoring and evaluating coastal adaptation. Second edition. http://www.sydneycoastalcouncils.com.au/sites/default/files/A-Guide-to-Monitoring-and-Evaluating-Coastal-Adaptation.pdf (accessed 25.01.16).
NSW	2014	Improving adaptation of coastal communities through bottom-up approaches: a case study of the Conjola District, Shoalhaven	Serrao-Neumann, S., Schuch, G., Koschade, O., Low Choy, D., 2014. Improving adaptation of coastal communities through bottom-up approaches: a case study of the Conjola District, Shoalhaven, NSW. 23rd NSW Coastal Conference, Shoalhaven, NSW.
NSW	2015	A plan for Marks Point and Belmont South to adapt to changing lake and flood levels	Lake Macquarie City Council, 2015. A plan for Marks Point and Belmont South to adapt to changing lake and flood levels. Volume 1: Summary. http://www.lakemac.com.au/downloads/B2D11DC1207DBE89ACDD4F7D3D83C7330561928D.PDF (accessed 25.01.16).
QLD	2012	Pilot council and insurance partnership on adaptation methods	Climate Risk Pty Ltd, 2012a. Pilot Council and Insurance Partnership on Adaptation Methods. Module 1 Report. Final Draft. Sunshine Coast Regional Council, Sunshine Coast, Queensland. Climate Risk Pty Ltd, 2012b. Pilot Council and Insurance Partnership on Adaptation Methods. Module 2 Report. Sunshine Coast Regional Council, Sunshine Coast, Queensland. Climate Risk Pty Ltd, 2012c. Pilot Council and Insurance Partnership on Adaptation Methods. Module 3 Report. Sunshine Coast Regional Council, Sunshine Coast, Queensland. Climate Risk Pty Ltd, 2012d. Pilot Council and Insurance Partnership on Adaptation Methods. Module 4 Report. Sunshine Coast Regional Council, Sunshine Coast, Queensland.

(*continued on next page*)

Table A.1 (*continued*)

State	Date	Project Title	Reference(s)
QLD	2012	Coastal hazard adaptation strategy for Townsville City Council.	GHD, 2012. Coastal hazard adaptation strategy for Townsville City Council. Pilot Project. Townsville City Council, Townsville, Queensland.
SA	2012	Climate change decision support framework and software for coastal councils.	Balston, J.M., Kellet, J., Wells, G., Li, S., Fray, A., Western, M., 2012. Climate change decision support framework and software for coastal Councils. http://www.lga.sa.gov.au/webdata/resources/files/FINAL%20CADSP%20Report%20Published%2013%20May%202013-1.pdf (accessed 25.01.16).
SA	2014	Regional climate change adaptation plan for the Eyre Peninsula.	Siebentritt, M., Halsey, N., Stafford-Smith, M., 2014. Regional climate change adaptation plan for the Eyre Peninsula. Eyre Peninsula Integrated Climate Change Agreement, South Australia.
TAS	2012, 2014, 2015	Tasmanian coastal adaptation pathways project	Department of Premier and Cabinet, 2016. Tasmanian Coastal Adaptation Pathways project. http://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/climate_risks_and_opportunities/coastal (accessed 13.05.16). SGS Economics and Planning, 2012a. Tasmanian Coastal Adaptation Pathways Project. Kingston Beach – Final Report. http://www.kingborough.tas.gov.au/webdata/resources/files/TCAP%20Kingston%20Beach%20Final%20Report-1.pdf (accessed 25.01.16). SGS Economics and Planning, 2012b. Tasmanian Coastal Adaptation Pathways Project. Port Sorell – Report. http://www.latrobe.tas.gov.au/webdata/resources/files/TCAP%20Port%20Sorell%20Report_final.pdf (accessed 25.01.16). SGS Economics and Planning, 2012c. Tasmanian Coastal Adaptation Pathways Project. Lauderdale recommended actions. http://www.ccc.tas.gov.au/webdata/resources/files/01-Harkin%20J%20-%20TCAP%20Lauderdale%20Adaptation%20Pathway%20Recommendations%20120712,%20Final%20-%2013July2012.pdf (accessed 25.01.16). SGS Economics and Planning, 2012d. Tasmanian Coastal Adaptation Pathways Project. Georges Bay. http://www.bodc.tas.gov.au/sites/all/files/breakoday/documents/reSources/final_tcap_georges_bay_report.pdf (accessed 25.01.16). SGS Economics and Planning, 2014a. Turners Beach – Leith Coastal Adaptation Pathways. Final Report. http://www.dpac.tas.gov.au/__data/assets/pdf_file/0017/238004/TCAP_2_SGS_Final_Report_Turners_Beach_Leith_-_27_June_2014.pdf (accessed 25.01.16). SGS Economics and Planning, 2014b. Somerset Coastal Adaptation Pathways. Final Report. http://www.dpac.tas.gov.au/__data/assets/pdf_file/0004/238009/TCAP_2_SGS_Final_Report_-_Somerset.pdf (accessed 25.01.16). SGS Economics and Planning, 2014c. Kelso Coastal Adaptation Pathways. Final Report. http://www.dpac.tas.gov.au/__data/assets/pdf_file/0018/238014/TCAP_2_SGS_Final_Report_-_Kelso.pdf (accessed 25.01.16). SGS Economics and Planning, 2015. Nutgrove – Long Beach Coastal Adaptation Pathways. Status Report. City of Hobart and Tasmanian Climate Change Office, Hobart, Tasmania.
VIC	2012	Adapting to inundation in urbanised areas: supporting decision makers in a changing climate. Port Phillip Bay coastal adaptation pathways project report	AECOM Australia, 2012. Adapting to inundation in urbanised areas: supporting decision makers in a changing climate. Port Phillip Bay Coastal Adaptation Pathways Project Report. http://www.mornpen.vic.gov.au/files/3c362e99-d23b-475f-8c86-a2f801016659/Attachment_4_-_Port_Phillip_Bay_Coastal_Adaptation_Pathways_Project_-_Final_Report_2012.pdf (accessed 20.06.17).
VIC	2012	Deciding for the coast: A guide for decision-making on cost effective adaptation.	Kinrade, P., Arnold, N., Fitzgibbons, A., Kulkarni, K., Prickett, K., Whiteoak, K., 2012b. Deciding for the coast: A guide for decision-making on cost effective adaptation. http://www.seccca.org.au/wp-content/uploads/2015/09/deciding-for-the-coast-guide.pdf (accessed 25.01.16).
VIC	2012	Climate adaptation in coastal caravan parks.	Walker, C., Blackwell, B., Rolf, J., 2012a. Climate adaptation in coastal caravan parks. Economic value and equity literature review. Report 1. http://www.wcb.vic.gov.au/caravanparks/CCPs%20Literature%20Review%20-%20high%20quality%20for%20web.pdf (accessed 25.01.16). Walker, C., Blackwell, B., Rolf, J., 2012b. Climate adaptation in coastal caravan parks. Economic value and equity research report. Report 2. http://www.wcb.vic.gov.au/caravanparks/CCPs%20Research%20Report%20Final%20-%20low%20quality%20for%20web.pdf (accessed 25.01.16). Walker, C., Blackwell, B., Rolf, J., 2012c. Climate adaptation in coastal caravan parks. Economic value and equity decision support framework. Report 3. http://www.wcb.vic.gov.au/caravanparks/CCPs%20Decision%20Support%20Framework%20-%20high%20quality%20for%20web.pdf (accessed 25.01.16).
VIC	2014	Equitable local outcomes in adaptation to sea-level rise.	Barnett, J., Fincher, B.R., Hurlimann, A., Graham, S., Colette, M., 2014a. Incorporating community vales into climate change planning: a guide for government. https://minerva-access.unimelb.edu.au/bitstream/handle/11343/39610/ARCL%20Guide%20for%20government%20-%20final.pdf?sequence=3 (accessed 20.01.16). Barnett, J., Fincher, B.R., Hurlimann, A., Graham, S., Colette, M., 2014b. Equitable local outcomes in adaptation to sea-level rise. Final Project Report. https://minerva-access.unimelb.edu.au/bitstream/handle/11343/39609/ARCL%20Gippsland%20Final%20Report%20.pdf?sequence=3 (accessed 20.01.16).
WA	2012	Developing flexible adaptation pathways for the Peron-Naturaliste coastal region of Western Australia	ACIL Tasman, 2012a. Climate change adaptation – Executive Summary. Developing flexible adaptation pathways for the Peron-Naturaliste Coastal Region of Western Australia. http://www.bunbury.wa.gov.au/pdf/Planning%20and%20Building/PNPExecutiveSummary.pdf (accessed 25.01.16). ACIL Tasman, 2012b. Climate change adaptation options assessment. Developing flexible adaptation pathways for the Peron-Naturaliste Coastal Region of Western Australia. http://www.bunbury.wa.gov.au/pdf/Planning%20and%20Building/PNPAssessmentReport.pdf (accessed 25.01.16).

References

ACIL Tasman, 2012. Climate change adaptation options assessment. Developing flexible adaptation pathways for the Peron-Naturaliste Coastal Region of Western Australia. <http://www.bunbury.wa.gov.au/pdf/Planning%20and%20Building/PNPAssessmentReport.pdf> (accessed 25.01.16).

AECOM and Commonwealth of Australia, 2010. Coastal inundation at Narrabeen Lagoon. Optimising adaptation investment. <https://www.environment.gov.au/system/files/resources/52df63be-426d-4da4-979f-de586e4c478c/files/narrabeen-lagoon.pdf> (accessed 25.01.16).

AECOM Australia, 2012. Adapting to inundation in urbanised areas: supporting decision makers in a changing climate. Port Phillip Bay Coastal Adaptation Pathways Project Report. <http://www.mornpen.vic.gov.au/files/3c362e99-d23b-475f-8c86-a2f801016659/Attachment_4_-_Port_Phillip_Bay_Coastal_Adaptation_Pathways_Project_-_Final_Report_2012.pdf> (accessed 20.06.17).

Armstrong, J., Wilby, R., Nicholls, R.J., 2015. Climate change adaptation frameworks: an evaluation of plans for coastal Suffolk, UK. Nat. Hazard Earth Syst. 15 (11), 2511–2524. http://dx.doi.org/10.5194/nhess-15-2511-2015.

AS/NZS ISO 31000:2009. Risk Management – Principles and Guidelines. SAI Global, Sydney, NSW.

Australian Bureau of Statistics, 2004. Year Book Australia, 2004, cat. no. 1301.0. <http://www.abs.gov.au/Ausstats/abs@.nsf/Previousproducts/1301.0Feature%20Article32004> (accessed 04.05.15).

Australian Bureau of Statistics, 2014. Data by Region http://stat.abs.gov.au/itt/r.jsp?databyregion#/ (accessed 06.04.16).

Australian Standard AS5334, 2013. Climate Change Adaptation for Settlements and Infrastructure – A Risk based Approach. SAI Global, Sydney, NSW.

Baker and McKenzie, 2011. Local Council Risk of Liability in the Face of Climate Change – Resolving Uncertainties. A report for the Australian Local Government Association. <http://www.environment.gov.au/system/files/resources/d9b2f9cf-d7ab-4fa0-ab0e-483036079dc7/files/alga-report.pdf> (accessed 07.04.16).

Balston, J.M., Kellet, J., Wells, G., Li, S., Fray, A., Western, M., 2012. Climate Change Decision Support Framework and Software for Coastal Councils. <http://www.lga.sa.gov.au/webdata/resources/files/FINAL%20CADSP%20Report%20Published%2013%20May%202013-1.pdf> (accessed 25.01.16).

Barnett, J., Graham, S., Mortreux, C., Fincher, R., Waters, E., Hurlimann, A., 2014. A local coastal adaptation pathway. Nat. Clim. Change 4, 1103–1108. http://dx.doi.org/10.1038/nclimate2383.

Ben-Haim, Y., 2012. Doing our best: optimization and the management of risk. Risk Anal. 32 (8), 1326–1332. http://dx.doi.org/10.1111/j.1539-6924.2012.01818.x.

Bhave, A.G., Conway, D., Dessai, S., Stainforth, D.A., 2016. Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. Clim. Risk Manage. 14, 1–10. http://dx.doi.org/10.1016/j.crm.2016.09.004.

Boardman, A.E., Greenberg, D.H., Vining, A.R., Weimer, D.L., 2011. Cost-Benefit Analysis. Concepts and Practice. Pearson Education, New Jersey.

Bonzanigo, L., Kalra, N., 2014. Making Informed Investment Decisions in an Uncertain World. A short Demonstration. Policy Research Working Paper 6765. <http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2014/02/03/000158349_20140203130155/Rendered/PDF/WPS6765.pdf> (accessed 30.12.15).

Bryant, B.P., Lempert, R.J., 2010. Thinking inside the box: a participatory, computer-assisted approach to scenario discovery. Technol. Forecast. Soc. 77, 34–49. http://dx.doi.org/10.1016/j.techfore.2009.08.002.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D., Unnikrishnan, A.S., 2013. Sea level change, in: Stocker, T.F. et al. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1137–1216.

Commonwealth of Australia, 2009. Managing our coastal zone in a changing climate: the time to act is now Commonwealth of Australia. Inquiry into climate change and environmental impacts on coastal communities. <http://www.aph.gov.au/parliamentary_business/committees/house_of_representatives_committees?url=ccwea/coastalzone/report.htm> (accessed 14.04.16).

Commonwealth of Australia, 2011. Climate Change Risks to Coastal Buildings and Infrastructure – A Supplement to the First Pass National Assessment http://www.environment.gov.au/system/files/resources/0f56e5e6-e25e-4183-bbef-ca61e56777ef/files/risks-coastal-buildings.pdf (accessed 15.07.15).

Council of Australian Governments, 2012. Roles and Responsibilities for Climate Change Adaptation in Australia https://www.nccarf.edu.au/sites/default/files/18-dccee-2012.pdf (accessed 20.06.17).

Courtney, H., 2003. Decision-driven scenarios for assessing four levels of uncertainty. Strategy Leadership 31, 14–22. http://dx.doi.org/10.1108/10878570310455015.

CSIRO and Bureau of Meteorology, 2014. State of the Climate 2014. <http://www.bom.gov.au/state-of-the-climate/documents/state-of-the-climate-2014_low-res.pdf?ref=button> (accessed 07.04.16).

Deb, K., 2001. Multi-Objective Optimization Using Evolutionary Algorithms. John Wiley and Sons Ltd, West Sussex.

Department of Prime Minister and Cabinet, 2016. Guidance Note: Cost-Benefit Analysis https://www.pmc.gov.au/sites/default/files/publications/006-Cost-benefit-analysis.pdf (accessed 20.06.17).

Dessai, S., Hulme, M., 2004. Does climate adaptation policy need probabilities? Clim. Policy 4, 107–128.

Dittrich, R., Wreford, A., Moran, D., 2016. A survey of decision-making approaches for climate change adaptation: are robust methods the way forward? Ecol. Econom. 122, 79–89. http://dx.doi.org/10.1016/j.ecolecon.2015.12.006.

Dobes, L., Bennett, J., 2009. Multi-criteria analysis: "Good enough" for government work? Agenda 16, 7–29. DOI http://dx.doi.org/hdl.handle.net/10440/1065.

Downing, T.E., 2012. Views of the frontiers in climate change adaptation economics. WIREs Clim. Change 3 (2), 161–170. http://dx.doi.org/10.1002/wcc.157.

European Commission and European Environmental Agency, 2013. Climate-ADAPT – The Adaptation Support Tool http://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool (accessed 20.06.17).

García, L.E., Matthews, J.H., Rodriguez, D.J., Wijnen, M., DiFrancesco, K.N., Ray, P., 2014. Beyond Downscaling: A Bottom-up Approach to Climate Adaptation for Water Resources Management. AGWA Report 01. World Bank Group, Washington.

GHD, 2012. Coastal Hazard Adaptation Strategy for Townsville City Council. Pilot Project. Townsville City Council, Townsville, Queensland.

Graham, S., Barnett, J., Fincher, R., Hurlimann, A., Mortreux, C., 2014. Local values for fairer adaptation to sea-level rise: a typology of residents and their lived values in Lakes Entrance, Australia. Global Environ. Change 29, 41–52. http://dx.doi.org/10.1016/j.gloenvcha.2014.07.013.

Haasnoot, M., Middelkoop, H., Offermans, A., van Beek, E., van Duersen, W., 2012. Exploring pathways for sustainable water management in river deltas in a changing environment. Clim. Change 115 (3), 795–819. http://dx.doi.org/10.1007/s10584-012-0444-2.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., ter Maat, J., 2013. Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. Global Environ. Change 23, 485–498. http://dx.doi.org/10.1016/j.gloenvcha.2012.12.006.

Hall, J., Solomatine, D., 2008. A framework for uncertainty analysis in flood risk management decisions. Int. J. River Basin Manage. 6 (2), 85–98. http://dx.doi.org/10.1080/15715124.2008.9635339.

Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Global Environ. Change 19 (2), 240–247. http://dx.doi.org/10.1016/j.gloenvcha.2008.12.003.

Hallegatte, S., Shah, A., Lempert, R., Brown, C., Gill, S., 2012. Investment Decision Making Under Deep Uncertainty – Application to climate change. Policy Research Working Paper 6193. The World Bank, Washington.

Hinkel, J., Bisaro, A., 2015. A review and classification of analytical methods for climate change adaptation. WIREs Clim. Change 6, 171–188. http://dx.doi.org/10.1002/wcc.322.

Hunter, J., 2010. Estimating sea-level extremes under conditions of uncertain sea-level rise. Clim. Change 99, 331–350. http://dx.doi.org/10.1007/s10584-009-9671-6.

IPCC, 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report to working groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B., et al. (Eds.), IPCC, Cambridge University Press, Cambridge and New York.
Jones, R.N., Preston, B.L., 2011. Adaptation and risk management. WIREs Clim. Change 2 (2), 296–308. http://dx.doi.org/10.1002/wcc.97.
Jones, R.N., Patwardhan, A., Cohen, S.J., Dessai, S., Lammel, A., Lempert, R.J., Mirza, M.M.Q., von Storch, H., 2014. Foundations for decision making. In: Field, C. B. (Ed.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp. 195–228.
Kalra, N., Hallegatte, S., Lempert, R., Brown, C., Fozzard, A., Gill, S., Shah, A., 2014. Agreeing on robust decisions. New processes for decision making under deep uncertainty. Policy Research Working Paper 6906. <http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/06/04/000158349_20140604102709/Rendered/PDF/WPS6906.pdf> (accessed 29.12.15).
Kay, R., Travers, A., Dalton, L., 2014. The evolution of coastal vulnerability assessments to support adaptive decision-making in Australia: a review. In: Glavovic, B.C., Kelly, P.M., Kay, R., Travers, A. (Eds.), Climate Change and the Coast: Building Resilient Communities. CRC Press, London, United Kingdom, pp. 249–268.
Knight, F.H., 1921. Risk, Uncertainty, and Profit. Boston, MA, Hart, Schaffner & Marx, Houghton Mifflin Company.
Kunreuther, H., Heal, G., Allen, M., Edenhofer, O., Field, C.B., Yohe, G., 2013. Risk management and climate change. Nat. Clim. Change 3, 447–450. http://dx.doi.org/10.1038/nclimate1740.
Kwadijk, J., Haasnoot, M., Mulder, J., Hoogvliet, M., Jeuken, A., van der Krogt, R., van Oostrom, N., Schelfhout, H., van Velzen, E., van Waveren, H., de Wit, M., 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. WIREs Clim. Change 1 (5), 729–740. http://dx.doi.org/10.1002/wcc.64.
Kwakkel, J.H., Walker, W.E., Marchau, V.A.W.J., 2010. Classifying and communicating uncertainties in model-based policy analysis. Int. J. Technol. Policy Manage. 10, 299–315. http://dx.doi.org/10.1504/IJTPM.2010.036918.
Kwakkel, J.H., Haasnoot, M., Walker, W.E., 2015. Developing dynamic adaptive policy pathways: a computer-assisted approach for developing adaptive strategies for a deeply uncertain world. Clim. Change 132, 373–386. http://dx.doi.org/10.1007/s10584-014-1210-4.
Kwakkel, J.H., Walker, W.E., Haasnoot, M., 2016. Coping with the Wickedness of Public Policy Problems: Approaches for Decision Making under Deep Uncertainty, J. Water Res. Pl. – ASCE. 01816001. http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000626.
Lake Macquarie City Council, 2015. A plan for Marks Point and Belmont South to adapt to changing lake and flood levels. Volume 1: Summary. <http://www.lakemac.com.au/downloads/B2D11DC1207DBE89ACDD4F7D3D83C7330561928D.PDF> (accessed 25.01.16).
Lawrence, J., Haasnoot, M., 2017. What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty. Environ. Sci. Policy 68, 47–57. http://dx.doi.org/10.1016/j.envsci.2016.12.003.
Lempert, R.J., Collins, M.T., 2007. Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches. Risk Anal. 27 (4), 1009–1026. http://dx.doi.org/10.1111/j.1539-6924.2007.00940.x.
Lempert, R.J., Popper, S.W., Bankes, S.C., 2003. Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis. RAND Corporation, Santa Monica, CA.
Linquiti, P., Vonortas, N., 2012. The value of flexibility in adaptating to climate change: a real options analysis of investments in coastal defense. Clim. Change Econ. 3 (2), 1250008.
Maier, H.R., Guillaume, J.H.A., van Delden, H., Riddell, G.A., Haasnoot, M., Kwakkel, J.H., 2016. An uncertain future, deep uncertainty, scenarios, robustness and adaptation: how do they fit together? Environ. Modell. Software 81, 154–164. http://dx.doi.org/10.1016/j.envsoft.2016.03.014.
McInnes, K.L., White, C.J., Haigh, I.D., Hemer, M.A., Hoeke, R.K., Holbrook, N.J., Kiem, A.S., Oliver, E.C.J., Ranasinghe, R., Walsh, K.J.E., Westra, S., Cox, R., 2016. Natural hazards in Australia: sea level and coastal extremes. Clim. Change. http://dx.doi.org/10.1007/s10584-016-1647-8.
Mediation Adaptation Platform, 2013. The PROVIA/MEDIATION Adaptation Platform, Mediation – funded by the European Commission's seventh framework program http://www.mediation-project.eu/platform/home.html (accessed 17.09.14).
Metroeconomica, 2004. Costing the Impacts of Climate Change in the UK: Overview of Guidelines. UKCIP Technical Report, UKCIP, Oxford.
Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., 2008. Stationarity is dead: whither water management? Science 319, 573–574. http://dx.doi.org/10.1126/science.1151915.
Mortazavi-Naeini, M., Kuczera, G., Kiem, A.S., Henley, B., Berghout, B., Turner, E., 2013. Robust optimisation of urban drought security for an uncertain climate. <https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Mortazavi-Naeini_2013_Robust_optimisation_of_urban_drought_security.pdf> (accessed 02.11.15).
Nalau, J., Preston, B.L., Maloney, M.C., 2015. Is adaptation a local responsibility? Environ. Sci. Policy 48, 89–98. http://dx.doi.org/10.1016/j.envsci.2014.12.011.
Pillora, S., 2010. Australian Local Government and Climate Change, Working Paper no. 1. <https://opus.lib.uts.edu.au/bitstream/10453/42075/3/LG-Climate-Change.pdf> (accessed 20.06.17).
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. <http://www.sydneycoastalcouncils.com.au/sites/default/files/MCA_of_Coastal_Adaptation_Options_for_Local_Government.pdf> (accessed 25.01.16).
Productivity Commission, 2012. Barriers to effective climate change adaptation, Report No. 59, Final Inquiry Report. <http://www.pc.gov.au/inquiries/completed/climate-change-adaptation/report/climate-change-adaptation.pdf> (accessed 21.01.16).
Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA), 2013. PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change. Consultation Document. United Nations Environment Programme, Kenya.
Ray, A.J., Webb, R.S., 2015. Understanding the user context: decision calendars as frameworks for linking climate to policy, planning and decision-making. In: Climate in Context: Lessons learned from the RISA Program, Parris A, et al. (Eds.), Wiley & Sons, pp. 27–49.
Reeder, T., Ranger, N., 2011. How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project. <http://www.wri.org/sites/default/files/uploads/wrr_reeder_and_ranger_uncertainty.pdf> (accessed 07.04.16).
Riesch, H., 2013. Levels of uncertainty. In: Roeser, S., Hillerbrand, R., Sandin, P., Peterson, M. (Eds.), Essentials of Risk Theory. Springer, Netherlands, pp. 29–56.
SGS Economics and Planning, 2014. Local Government in Tasmania is adapting to climate change. <https://www.sgsep.com.au/publications/local-government-tasmania-adapting-climate-change> (accessed 22.12.16).
SGS Economics and Planning, 2012. Tasmanian Coastal Adaptation Pathways Project. Kingston Beach – Final Report. <http://www.kingborough.tas.gov.au/webdata/resources/files/TCAP%20Kingston%20Beach%20Final%20Report-1.pdf> (accessed 25.01.16).
Siebentritt, M., Halsey, N., Stafford-Smith, M., 2014. Regional Climate Change Adaptation Plan for the Eyre Peninsula. Eyre Peninsula Integrated Climate Change Agreement, South Australia.
Smith, T.F., Low Choy, D., Thomsen, D.C., Serrao-Neumann, S., Harman, B., Baum, S., Myers, S., Sharma, V., Bussey, M., Matthews, J., Roiko, A., Carter, R.W., 2015. Adapting Australian coastal regions to climate change: a case study of South East Queensland. In: Glavovic, B.C., Kelly, P.M., Kay, R., Travers, A. (Eds.), Climate Change and the Coast: Building Resilient Communities. CRC Press, London, United Kingdom, pp. 269–284.
Stafford-Smith, M., Horrocks, L., Harvey, A., Hamilton, C., 2011. Rethinking adaptation for a 4°C world. Philos. Trans. R. Soc. A 369, 196–216. http://dx.doi.org/10.1098/rsta.2010.0277.
Travis, W.R., Bates, B., 2014. What is climate risk management? Clim. Risk Manage. 1, 1–4. http://dx.doi.org/10.1016/j.crm.2014.02.003.
Treasury, H.M., 2003. The Green Book – Appraisal and Evaluation in Central Government https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf (accessed 11.06.15).
UKCIP, 2015. UKCIP adaptation wizard. <http://www.ukcip.org.uk/wizard/> (access 24.09.15).

Walker, W.E., Haasnoot, M., Kwakkel, J.H., 2013a. Adapt or perish: a review of planning approaches for adaptation under deep uncertainty. Sustainability 5, 955–979. http://dx.doi.org/10.3390/su5030955.

Walker, W.E., Lempert, R., Kwakkel, J.H., 2013b. Deep uncertainty. In: Gass, S., Fu, M. (Eds.), Encyclopaedia of Operations Research and Management Science. Springer, US, Boston, pp. 395–402.

Watkiss, P., Hunt, A., 2013. Method overview: Decision support methods for adaptation, Briefing Note 1. Summary of methods and case study examples from the MEDIATION project. Funded by the EC's 7FWP.

Watkiss, P., Hunt, A., Blyth, W., Dyszynski, J., 2014. The use of economic decision support tools for adaptation assessment: a review of methods and applications, towards guidance on applicability. Clim. Change 132 (3), 401–416. http://dx.doi.org/10.1007/s10584-014-1250-9.

White, N.J., Haigh, I.D., Church, J.A., Koen, T., Watson, C.S., Pritchard, T.R., Watson, P.J., Burgette, R.J., McInnes, K.L., You, Z.J., Zhang, X., Tregoning, P., 2014. Australian sea levels – trends, regional variability and influencing factors. Earth Sci. Rev. 136, 155–174. http://dx.doi.org/10.1016/j.earscirev.2014.05.011.

White, C.J., Carlsen, H., Robertson, A.W., Klein, R., Lazo, J.K., Kumar, A., Vitart, F., Coughlan de Perez, E., Ray, A.J., Murray, V., Bharwani, S., MacLeod, D., James, R., Fleming, L., Morse, A.P., Eggen, B., Graham, R., Kjellström, E., Becker, E., Pegion, K.V., Holbrook, N.J., McEvoy, D., Depledge, M., Perkins-Kirkpatrick, S., Brown, T.B., Street, R., Jones, L., Remenyi, T.A., Hodgson-Johnston, I., Buontempo, C., Lamb, R., Meinke, H., Arheimer, B., Zebiak, S.E., 2017. Potential applications of subseasonal-to-seasonal (S2S) predictions, Meteorol. Appl. (in Press).

Wilby, R.L., Dessai, S., 2010. Robust adaptation to climate change. Weather 65 (7), 180–185. http://dx.doi.org/10.1002/wea.543.

Willows, R.I., Connell, R.K. (Eds.), 2003. Climate Adaptation: Risk, Uncertainty and Decision-Making. UKCIP Technical Report, UKCIP, Oxford.

Wise, R.M., Fazey, I., Stafford-Smith, M., Park, S.E., Eakin, H.C., Archer Van Garderen, E.R.M., Campbell, B., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. Global Environ. Change 28, 325–336. DOI http://dx.doi.org/ 10.1016/j.gloenvcha.2013.12.002.

Woodward, M., Kapelan, Z., Goudby, B., 2014. Adaptive flood risk management under climate change uncertainty using real options and optimization. Risk Anal. 34 (1), 75–92. http://dx.doi.org/10.1111/risa.12088.