Real options for coastal adaptation

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Introduction

The uncertainty that characterises adaptation decision-making challenges many traditional valuation tools, which lack the sophistication to deal with the uneven distribution of costs and benefits over time. Increasingly, methods for valuing 'options', that preserve flexibility over time, are being recognised as an important tool for decision-makers coping with uncertainty.

'Options' were originally developed for financial markets, where someone would hold the right, but not the financial obligation, to buy or sell a particular stock at a point in time for a specified price. The same approach has been transferred to government and other users who seek to maximise the benefits of an investment by retaining the right but not the obligation to make certain investments. These rights have values as they are used to assess financial options and risk transfer before an investment decision is made (ACIL Tasman 2012; Black and Scholes 1973; Watkiss et al. 2013).

> Real Option Analysis (ROA) quantifies the investment risk associated with uncertain future outcomes. It is useful when considering the value of flexibility of investments as it can inform how a project adapts, expands or scales back in response to unfolding events (Watkiss et al. 2013).
>
> Flexible and reversible options handle deep uncertainty by allowing for learning about climate change (and impacts) over time. They are designed in such a way that they can be adjusted or reversed over time when additional information becomes available (Dittrich et al. 2016).

This guidance note summarises the Real Options Approach (ROA) with a specific focus on its application to coastal adaptation. It includes a number of examples of real options in practice. The use of real options in adaptation generally, and coastal adaptation specifically, is relatively immature. We provide a hypothetical case study to illustrate the use of real options over time and extend existing practice by demonstrating how deliberative engagement strategies can support navigating decision-points such as thresholds and triggers.

Applying the real options approach to coastal adaptation

> How is ROA different to traditional economic analysis?
>
> 1. ROA shows that sometimes it makes more sense to wait for new information rather than investing immediately.
> 2. ROA shows that it may make sense to start the initial stages of a project (keep it alive) as the project may become more attractive at a later date (Watkiss et al. 2013).

ROA extends the use of methods for valuing financial options contracts to valuing real options. Rather than being specified in a contract, 'real' options result from real world sources of flexibility. For example, if a seawall is not needed right now, then if you don't build it now, you keep the option to build it later. This flexibility is valuable because while you wait you do not experience the costs of having a seawall, and you might find later, that you don't need to build a sea wall at all. By waiting, you can learn about sea level rise, better ways to build sea walls, and alternative actions people haven't even thought of yet. Holding a real option delays costly actions and preserves the flexibility to learn and adapt to change. ROA is therefore based on the premise that uncertainty is dynamic rather than deep, and may be resolved over time as knowledge is improved (Dittrich et al. 2016).

However, preserving flexibility has both costs and benefits. For example, there are benefits from providing homeowners and industry with certainty about the long-term future of an area. ROA provides an approach to understanding these kinds of trade-offs.

Linking Real Options to the Adaptation Decision System

ROA can be a resource intensive activity. In part, this is due to the nature of the analyses required for ROA, as obtaining the data for modelling requires significant effort. The costs of acquiring different kinds of information vary greatly; from assumptions, estimates, expert opinion, or new primary data.

A key strength of the ROA approach is the opportunities it provides to learn over time i.e. the value of information. ROA works well as a part of the iterative decision-making process that is part of an '*adaptation pathways'* approach. Continuing engagement with stakeholders provides opportunities to learn about changes in the nature of the trade-offs that underlie adaptation decisions as the future unfolds.

This type of trade-off analysis can be represented by decision-makers who invest in a seawall, beach nourishment and dune revegetation where they are typically required to balance coastal protection, property values, recreational amenity and ecological habitat.

Figure 1 identifies the core steps for adaptation planning, as set out in CoastAdapt. We illustrate a three-pass operational cycle to support adaptation decision making Table 1; a first-pass (or scan), second-pass (or portfolio), and third-pass (or project). While ROA can be deployed for a first-pass assessment (scan), this step is more likely to be restricted to a vulnerability assessment and identification of options risks and costs at a high level. Here, the use of simpler appraisal tools (e.g. 'replacement cost' and 'cost benefit analysis' (CBA) is likely to be fit-for-purpose. Depending on the nature of the assessment, other tools such as 'portfolio analysis' or 'cost effectiveness analysis' may also be better suited to economic appraisal for second-pass assessments (portfolio) e.g. if the decision is to invest in coastal infrastructure or adaptation for the agricultural sector. (See the *Valuation*

Approach Guide for a more detailed description of the approaches referred to here). ROA, however, is well suited to assisting a decision-maker to evaluate between options or bundles oF options for third-pass assessments. This is now discussed.

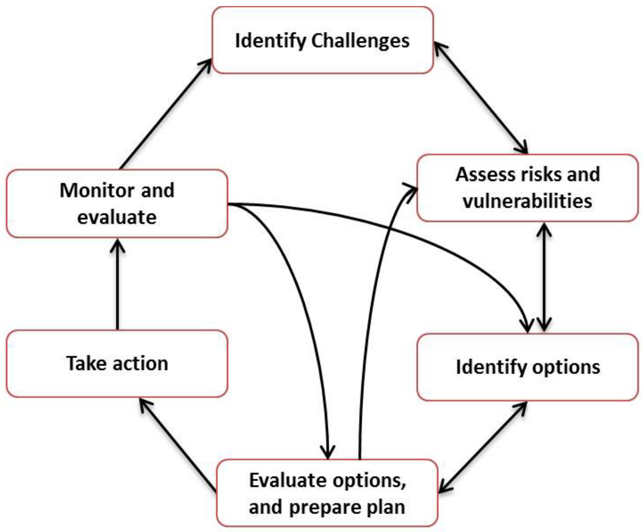

Figure 1: CoastAdapt – Coastal Climate Adaptation Decision System. Source: © NCCARF 2016

When to use Real Options?

ROA extends on conventional CBA because it seeks the optimal time to invest in a way that maximises value and is able to incorporate 'dynamic' uncertainty. Like CBA, ROA is suitable when the decision-making body has the power to implement the options under consideration, and the influence of these decisions on people is accounted for by processes that are considered to be legitimate. Since climate change can influence both the set of options under consideration and mean new groups of people are affected by decisions, caution should be used before extending existing decision-making processes to consider adaptation issues. As illustrated in Figure 2, ROA can work well provided the following conditions are satisfied.

1. The investment decision:
   a. is currently reversible but likely to be hard to reverse or irreversible once underway or completed
   b. is large, has a long lifespan
   c. is likely to be sensitive to changes in climate hazards
   d. presents a risk of over or underinvestment (Dittrich et al. 2016; Watkiss et al. 2013).
2. The decision-maker has some flexibility with respect to the timing of the investment (as a single step or in stages) (Dittrich et al. 2016).
3. By waiting, a decision-maker is likely to gain 'valuable' new information regarding the success of the investment (Dittrich et al. 2016).
4. Sufficient resources are available for the assessment.

The reader is referred to the *Valuation Approach Guide*, for a description and comparison of the approaches listed in Figure 2.

What is the value of waiting?

It is important to note that a decision to delay investment is a decision nevertheless, and therefore it should be made with as much knowledge as possible. Careful thought should be given to the costs and benefits of seeking new information (see *Information Manual 4: Costs and benefits* for a more detailed discussion). There may be higher value to be gained in waiting if uncertainties are larger. If waiting is likely to decrease flexibility in decision-making then there is lower value in waiting longer. A shrewd decision-maker will understand these limitations and set in place various thresholds to ensure that there remains value in seeking more information and/or waiting. The Values-Rules-Knowledge framework (Gorddard et al. 2015) presented in the *Valuation Approach Guide*, provides a neat diagnostic tool to identify possible knowledge gaps and the value of gathering more information, including the value of social processes and potential boundary conditions (e.g. possible and legitimate options) that can assist with the clarification of the decision-making context.

Table 1: Data gathering for ROA within the context of C-CADS. Source: Adapted from Stafford-Smith 2016.

C-CADS steps:	Identify challenges	Determine vulnerabilities	Identify options	Evaluate options, risks and costs	Take action	Monitor and evaluate
Typical activities	Identify goals, scope decision-areas affected (scale) and how to manage the process, gather key stakeholders and experts, and choose approaches, timeframes		Risks, opportunities (especially no-and-low regrets options), response measures, responsibilities	Assemble adaptation options, appraise adaptation options including thresholds and triggers, develop an implementation plan	Accept risk and uncertainty, sign off, timing, implement	Monitor for emerging effects Evaluate success, share lessons, plan to iterate
Operational cycle	**Scan (first-pass)**		**Portfolio (second-pass)**		**Project (third-pass / implementation)**	
Decision-maker	First consideration of impact of climate risks; coarsely-defined scope; limited understanding of stakeholders and their expectations. Example products: **Output** – high level plan that identifies key areas / themes where future analysis is needed; 'no regrets' options. **Outcome** – decide what areas require future planning effort; and where investments might be made that yield net social benefits regardless of uncertainty.		General understanding of the climate risks faced, and priority areas identified for attention. Example products: **Output** – portfolio analysis identifying areas for detailed investment planning. **Outcome** – development of a broad adaptation pathway across affected areas, including potentially novel trade-offs and new governance and decision-making processes to develop feasible and legitimate options.		Strong understanding of climate risks faced by the organisation and related decisions (e.g. non-climate but related risks); focus on one or more previously prioritised areas. Example products: **Output** – investment implementation plan. **Outcome** – adaptation (investment) plan implemented (deliberate decision to delay investment may be first step).	
	Cost and quality of data and modelling					

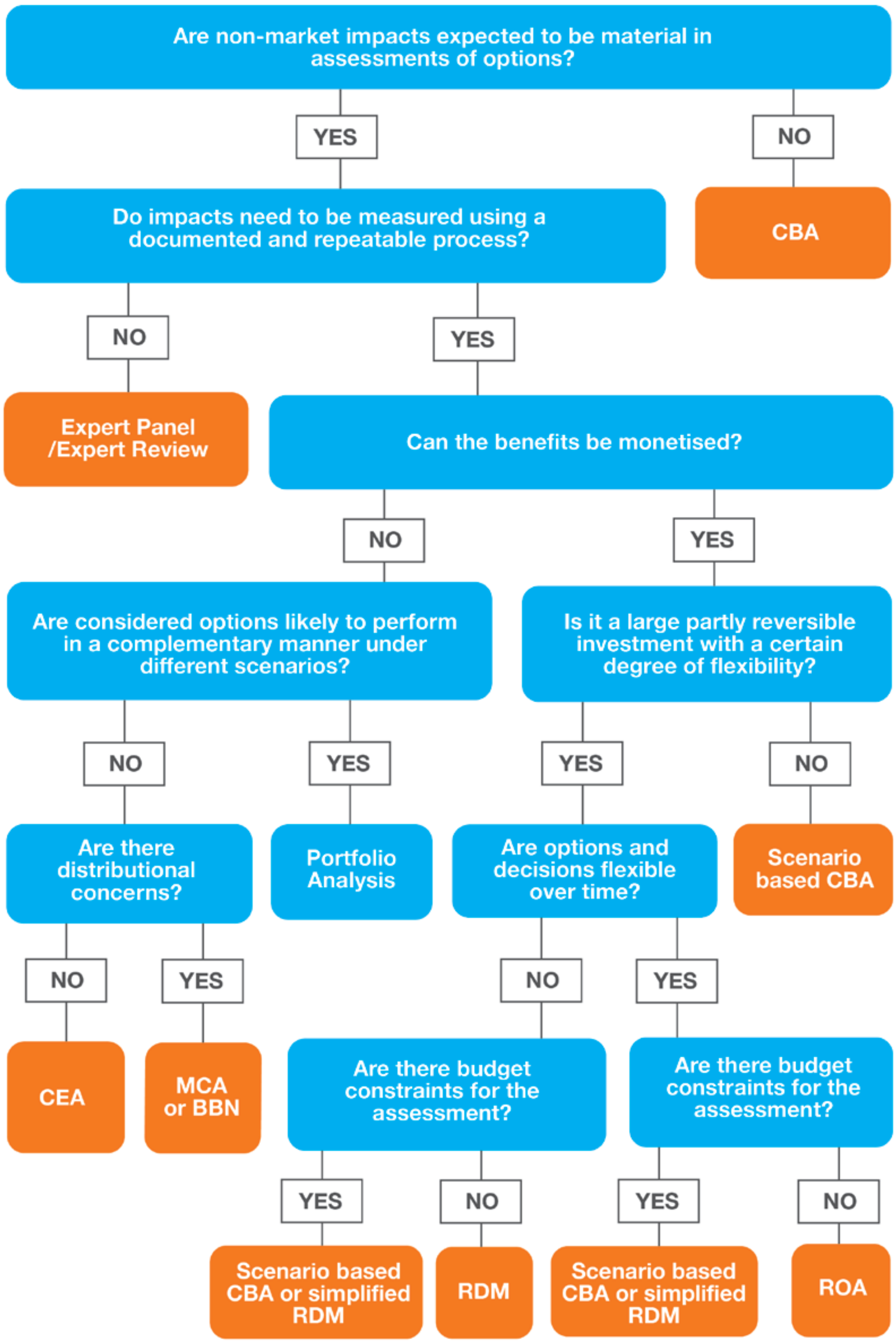

Figure 2: Matching the valuation approach to the decision context. Source: Adapted from DEFRA 2013; Dittrich et al. 2016; Hatfield-Dodds 2005.

Core principles of real options analysis

ROA seek to model the value of flexibility and the timing of actions under conditions of uncertainty (Copeland and Antikarov 2001; Dixit and Pindyck 1994; Sanderson et al. 2016). Trade-offs between acting sooner and acting later are affected by the value of flexibility and the value of new information. By deciding not to act now, you preserve the option to act later. The value of this option is determined by the value of flexibility (i.e. when actions have consequences that are expensive to reverse) and the value of information (i.e. the prospect of learning something that could change your decision). In comparison with conventional forms of CBA, ROA has the potential to better represent incomplete knowledge and uncertainty.

There are many different approaches to ROA that all seek to estimate the value of flexibility and information under conditions of uncertainty. An important distinction is between approaches that use 'calendar time' and those that use 'index time'. For example, a ROA in calendar time could estimate the value of a delaying building a sea wall for one year with the expectation that new relevant information about sea level rise could be received within a year. In comparison, an index time approach would estimate the values that, if observed, would trigger the construction of a sea wall.

Utilising ROA to analyse adaptation, we can characterise adaptation decision pathways as sequences of alternative regimes delineated by decision thresholds. Decision thresholds are the conditions that would trigger a transition from one regime to the next. For example, Buurman and Babovic (2016) demonstrate how a ROA can be used to provide a structured approach for dealing with the complexity and uncertainty of adaptations for managing flooding in Singapore. Uncertainty comes from many sources, climate change impacts, technological change, and societal preferences.

All forms of uncertainty can potentially provide an incentive for learning relevant information before implementing adaptation actions whose consequences are costly, or impossible, to reverse. For example, Buurman and Babovic (2016) suggest a framework of eight stages:

1. Framing – objectives and scope
2. Analysis – identification of possible future scenarios
3. Actions – identification of actions and their triggers
4. Optimisation of actions and options – analysis of the costs and benefits of alternative actions
5. Development of adaptation pathways – map sequencing and path dependencies
6. Selection of preferred pathways – compare the costs and benefits of alternative pathways
7. Specify and implement plan – set out on chosen pathway
8. Monitor and execute – observe the variables that define the triggers, i.e. initiate transitions along the pathway.

Tips and traps

- ROA is appropriate when irreversibility and uncertainty are key characteristics of the decision problem (Dixit and Pindyck 1994; Mezey and Conrad 2010). Using conventional forms of CBA that discount expected net benefits ignore the value of options and may well lead to the approval of projects that should not be undertaken (Mezey and Conrad 2010).
- There are technical limitations to applying quantitative approaches to ROA (Mezey and Conrad 2010).

- There are limitations due to theoretical difficulties of quantifying the option values that result from deeper forms of uncertainty. Alternative methods are needed to understand the consequences of option values that result from other sources of chance, such as when the system that generates outcomes is poorly understood and is itself changing in unknown ways (Randall 2011).
- ROA provides flexibility around large investment decisions by providing flexibility to introduce new economic information as uncertainties are resolved.
- ROA is complex, expensive and requires large data points around both future climate and economic inputs.
- ROA approaches may limit the inclusion of non-market values.
- There is potential for a simpler application of ROA through the use of decision trees and more qualitative use of information (Watkiss et al. 2013).
- ROA supports an iterative approach and iterative delivery/staging for risk management.
- ROA assumes that uncertainty is dynamic rather than deep, i.e. dynamic uncertainties such as climate impacts may be resolved to a degree over time as knowledge is improved (Dittrich et al. 2016).

Case study 1 - Developing flexible adaptation pathways for the Peron Naturaliste Coastal Region of Western Australia

Background

The Peron-Naturaliste region is just south of Perth in southwest Western Australia and extends for over 200 km along the coast. Covering nine local government areas, the region is a generally low-lying sedimentary coast comprising large and small towns and hamlets. Extensive tracts of coastline are vulnerable to coastal extremes and climate change. The 2011 project led by ACIL Tasman for the Peron-Naturaliste Partnership (ACIL Tasman 2012) set out to assist decision-makers and the community to respond to the impacts and opportunities posed by climate change. The study commenced with a regional economic analysis, and then focused on specific options for four localities, each different in kind. The approach/model used future climate outcomes to derive future scenarios for assets at risk.

Phase 1 – hazard mapping

A regional coastal hazards study was undertaken. This activity focused on developing coastal hazard mapping to support the economic assessment of adaptation options at regional and local case study scales. Hazards mapped included projected coastal inundation and erosion for time frames up to 2110. The approach used was a synthesis of existing coastal hazard studies (including extreme water level distributions derived from tide gauges) and a regional erosion study.

Phase 2 – region-wide assessment

A region-wide assessment was undertaken to generate an indicative understanding of the overall resource cost of adaptation to coastal climate risks within the region as a whole, rather than to design strategy. The study focused on improving understanding of the cost, in general terms, of protecting those assets where the value at risk exceeds the cost of protection.

A number of key abstractions and simplifications were made to facilitate this higher level assessment: assets were classed and given representative values; the merit of protecting asset classes was considered (e.g. farmland) rather than specific coastal protection infrastructure; and assets were examined at snapshots in time rather than continuously to 2110. The cost of adaptation was compared with the value at risk under a number of scenarios. Results suggest that efforts should be put into the protection of assets such as community infrastructure, and current (and future) residential and commercial land; and that there is limited value in implementing high value protection strategies for rural and agricultural land, public open space and conservation areas.[1]

Phase 3 – case studies

A Real Options approach (ROA) was chosen as the assessment methodology because it offered the project team the flexibility to wait and to consider uncertainty and how this might be resolved over time to improve confidence. For each of the four case studies under examination there was a five-step assessment process undertaken for each option, for each asset in each case study area, and for combinations of options where a staged solution was recommended.

Table 2: Five-step ROA assessment process.

Step	Assessment
1	A climate change model was used to generate several thousand different future scenarios, which map out how climate change might affect the region over the coming century. The physical changes were then converted into scenarios for value at risk for each asset in each case study area over the same timeframe.
2	The Net Present Value (NPV) of a stream of benefits (that is, improvements in value at risk) that occur from implementing a particular adaptation option for each asset in each case study area in each year for each scenario was compared with the stream of benefits (that is, value at risk) of doing nothing in each case – referred to as the 'NPV difference'.
3	The real options model was then run and provided estimations of the NPV difference at each point in time for each scenario.
4	The real options model was used to compare the net benefit of acting (that is, NPV difference minus the cost of the option) in each time period in each scenario with the expectation of the net benefit of acting in the next time period. It then showed all of the periods when it pays to act now for each scenario; when the current net benefit is greater than the expectation of the future net benefit.
5	Optimum solutions were then generated for each scenario based on the available information and taking into account cost, timing and confidence. Optimal responses were determined across a series of several thousand model runs and translated into an adaptation pathway that represents the best combination of options.

Summary of proposed solutions

For Peppermint Grove, one of the four case studies examined, the hazard assessment reported that up to 300 m of land was at risk from erosion by 2100. Without intervention the entire settlement would be lost. Inundation (land is currently approximately 2 m above MSL) and salt water intrusion also poses a significant risk. It was recommended that protection structures (groynes) should be built

[1] The economic assessment excluded social, cultural and environmental considerations, and recommends that future assessments are based on a broader assessment of values.

to safeguard the settled areas, but that only half of the agricultural land be protected because of the lower value at risk. This could be complemented with dune stabilisation works in certain locations including some channel fill work to prevent large scale saltwater intrusion. Connectivity (flooding from seawater) plays a significant factor and some areas were only recommended for protection if there was also intervention in surrounding sites. This is reflected in the advice to sequence investments over a period of time. Further investigations were also recommended in order to better understand the impact of freshwater flooding and saline incursion on land value. A clearer understanding of benefits (possibly reduced) would indicate that a revised adaptation pathway is needed.

The optimal timing for the commencement of the staged investment for Peppermint Grove extends over a five-year period from the date of the report. However, it was noted that erosion in the early years was unlikely to damage infrastructure and investment could possibly be delayed, with some loss of beach the result.

Project limitations

Project limitations and assumptions were well-articulated by the authors and further review was recommended to complement institution building and stakeholder engagement activities, the latter of which did not feature in the project. Key limitations of the study were described.

- Data limitations – in the absence of data, or where limited data exists about future climate impacts, conservative assumptions were used in the hazard assessment model. It was recognised that this may lead to the recommendation of higher cost or sub-optimal decisions.
- Economic appraisal and development of adaptation options excluded consideration of social, cultural and environmental factors / values.
- The project considered future climate impacts as dynamic and resolvable over time. Existing land use considerations were maintained into the future e.g. no consideration was given to a changes in land use such as conversion of farm land to residential blocks and the impact this would have on evolving risk. As a result, not considered were deep uncertainties such as changes to economic and demographic structure of the region.

Case study 2 - Coastal inundation at Narrabeen Lagoon: Optimising adaptation investment

Background

Narrabeen Lagoon, on the northern beaches of Sydney, is one of about 70 intermittently closed and open lakes and lagoons (ICOLLs) spread along the coast of New South Wales. When the lagoon is blocked (a naturally occurring phenomenon), it can be filled by rain and floodwaters and flood surrounding land and houses. Approximately 1400 residential and 260 commercial properties are identified in flood affected areas around Narrabeen Lagoon. In 2010, AECOM undertook a series of case studies which analysed the benefits and costs of adaptation in response to risks of climate change. It focused on the impact of flooding from Narrabeen Lagoon to the surrounding built environment. Its aim was to provide decision makers with better information on: the impact of climate change on existing coastal hazards; how to incorporate uncertainty into decisions; and the social costs and benefits to the communities of the different adaptation measures that could be implemented to reduce inundation.

Approach

The study design consisted of seven stages from scoping the work through to communicating the results, described in Table 3.

Table 3: Narrabeen Lagoon methodology

Stage	Activities
1. Study design 2. Climate change projected flooding 3. Determine flood cost relationships	**Design and initial investigation** • Design and test economic model • Preliminary analysis of Pittwater region • Set study boundary for geographic location, climate parameters and direct and indirect costs • Determine climate changes likely to affect extreme rainfall, storm surge and sea level rise • Combine historical flood data with climate change projections to develop probability distribution curves for each climate variable as model inputs • Discussion or debate about the science of climate change • Identify economic costs of a range of flooding impacts around Narrabeen • Identify lagoon costs including damage, disruption and health costs • Develop cost curves as model inputs
4. Preliminary modelling to determine cost impacts 5. Identify, cost and prioritise adaptation options 6. Run and optimise economic model 7. Analyse and communicate findings	**Modelling adaptation options** • Run a series of simulations to determine key cost impacts • Hold an adaptation options workshop with Council to identify and prioritise adaptation options for Narrabeen Lagoon • Develop detailed costs for implementation and maintenance of adaptation options as model inputs • Run a set of economic model simulations with all model inputs • Use model to optimise size, scale and timing of adaptation options • Analyse economic findings to determine preferred adaptation strategy for Narrabeen Lagoon • Draft report to communicate key findings and finalise report after comments received

Summary of results

The study considers both direct costs as a result of flood damage (e.g. damage to property and infrastructure), and indirect costs, which were classified as travel disruption and physical and emotional health damages. While the cost of travel disruption was modelled, it was assumed that local residents had internalised the benefits and costs of living in the area so no additional impact was modelled.

Costs and benefits for the recommended adaptation measures (see Table 4) are presented along with a discussion of value of avoided costs for the local community. The study recommends a portfolio of measures to maximise the net economic benefits of adaptation compared to no adaptation; and which yield higher benefits when taken together. Benefit Transfer was used to estimate the willingness of residents to pay for flood mitigation measures and is consistent with the approach taken in the Peron Naturaliste Partnership study to utilise 'decision-relevant' information where it is likely to inform higher level decisions (e.g. go or no-go).

Table 4: Portfolio of adaptation measures for Narrabeen Lagoon

2010	2035	After 2100
Lakeside levee: increase height to 2.7 m and length of existing levee to offer greater flood protection	**Lagoon opening:** permanent opening of 70m will reduce severity of flood events	**Progress Park levee:** construct new earth mound levee to 2.5 m offering protection for commercial and industrial sites
Flood awareness: early warning system and education to better prepare residents and businesses to take steps to minimise loss and disruption		**Nareen Creek levee:** flood wall and gates constructed to 2.3 m to protect lower reaches of the catchment from backwater flooding
Planning control: suggested increase in minimum floor height for new buildings and renovations (specific height not modelled)		

As an example, the adaptation measure for the opening of the lagoon considered the Net Present Value (NPV) base case of 'no adaptation' against the following possible measures: permanently opening the lagoon entrance at 70 metres in 2010, 2035 or 2050; or permanently opening the lagoon entrance at 100 m in 2010, 2035 or2050, or not at all (2101). AECOM found that permanently opening the lagoon at 70 m in 2010 has a mean NPV of $0.6m. Delaying this measure until 2035 increases the mean NPV to $3.9m, because the probability of flooding increases over time under most of the changing climate scenarios. However, beyond 2035, the benefits begin to decrease. Permanently opening the lagoon at 100 metres is not a cost-effective option because the costs are more than the 70 metres opening for little additional benefit. This is illustrated in Figure 3 and 4. Note that in a real world decision-making context, the specifications for future actions (assuming those pathways were locked in) e.g. build levee to 2.5 m in 2100, would not be defined so far in advance.

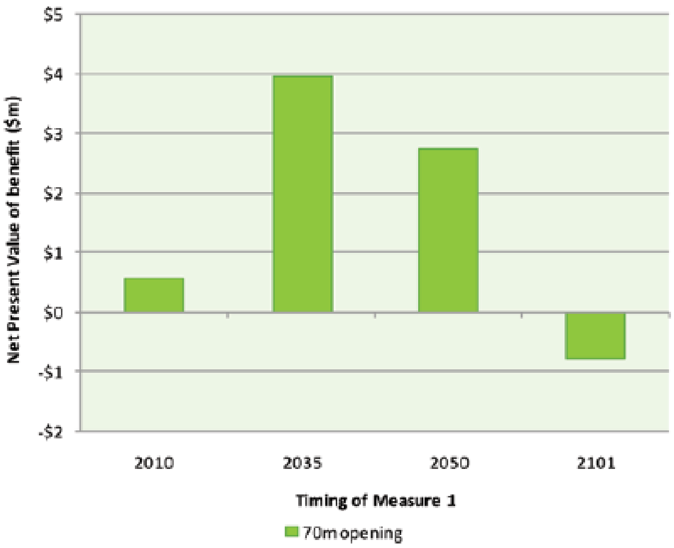

Figure 3: Mean NPV of permanently opening lagoon to 70m compared with the base case of no adaptation. Source: AECOM 2009 in AECOM 2010, p.59.

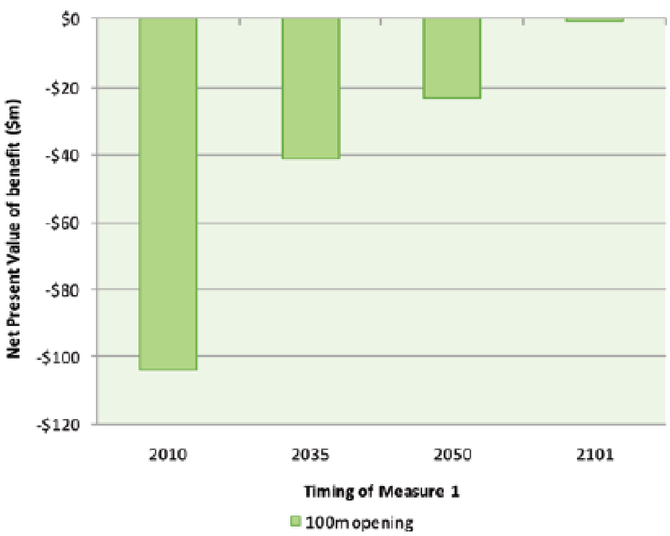

Figure 4: Mean NPV of opening lagoon entrance to 100m compared with base case of no adaptation. Source: AECOM 2009 in AECOM 2010, p.60

Project limitations

The demonstration project was designed to inform a national discussion on policy responses to manage the impact of climate change on infrastructure investment and maintenance. It demonstrates the value of a ROA approach, where uncertainty is dynamic and likely to be resolved (to a degree) over time. Limited consideration of biophysical and social/cultural values (e.g. stakeholder preferences are not known, some are inferred) and the (coincident) impacts from beach erosion constrain the direct application of this work for decision-making to support on-ground investment.

Case study 3 – Deliberative ROA in action (a hypothetical case)

Framing

We provide a hypothetical case study to illustrate the use of real options analysis (ROA) over time and to extend on existing practice. We do this by demonstrating how deliberative engagement strategies can be used in a complementary manner to navigate decision-points such as thresholds and triggers and to assist with go/no-go decisions. This case study also illustrates the shift from scan to portfolio through to project, where ROA is likely to be most useful. As discussed in the general guidance note on *valuation of adaptation options*, the importance of factoring in changes in conditions over time opens up the opportunity to use decision-making tools sequentially and iteratively as an adaptation decision pathway is developed and refined.

First-pass assessment[2]

- Decision makers in (hypothetical) Brucetown—a low lying regional commercial centre with a population of 10 000 residents, located a short distance up an estuary— have identified that a number of key public and private assets in the region will be exposed to coastal hazards more frequently and at a more intense rate in the future. The first pass assessment (scan) has also identified potential consequences for livelihoods, i.e. what is important or valued by the local community.
- Some alternative courses of adaptation have been considered through an initial estimate of costs and benefits (i.e. current value at risk plus the costs and benefits of acting). The assessment included a sensitivity analysis and information-gap analysis, which identified significant sources of irreversibility if particular investments were made as well as uncertainty around the impact of climate on coastal hazards, and the state of the economy in the future (e.g. imagine here that the regional economy is one in transition).
- The value at risk is considered 'acceptable' for now. A decision is made to preserve flexibility and the prospect of incorporating new information into a future assessment of the costs and benefits of climate adaptation i.e. a pathway process. Dot point '1' in Figure 5 illustrates a number of alternative decision options, and shows that for now, a clear decision has been made to 'wait and see'.
- The requirement for 'wait and see' is that thresholds for change need to be identified and triggers established that force a review of the current approach – these may be based on calendar time or index time, or a combination of both. For example, a decision may be made to wait until the next review of the coastal management plan, but also to engage in close conversation with the insurance industry so that any decision on risk can be made collectively.

[2] Each assessment illustrates use of the Adaptive Management method, where it includes ROA: Identify challenges; determine vulnerabilities; identify options; evaluate options, risks and costs; take action; and monitor and evaluate.

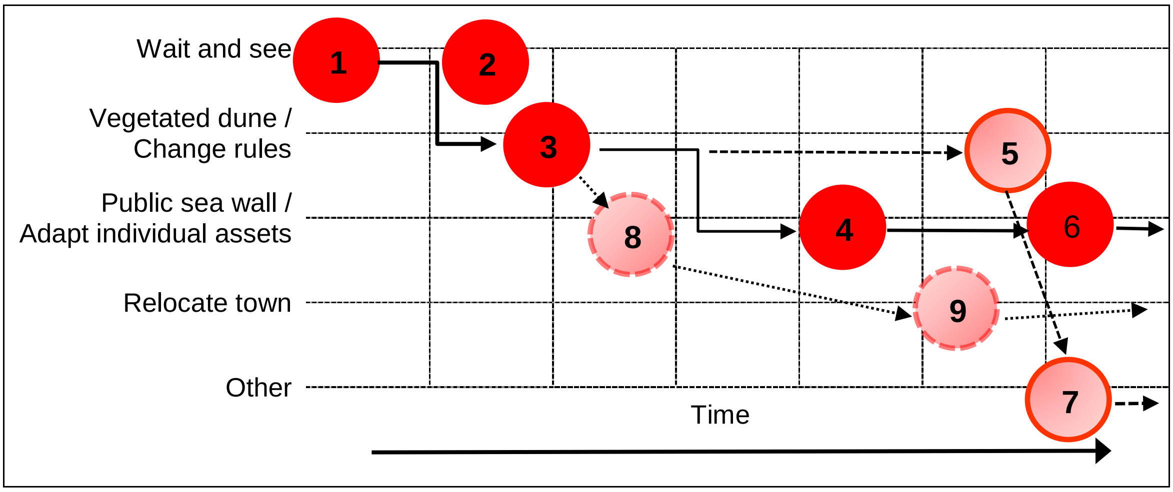

Figure 5: Possible type and sequencing of adaptation options

- Not all sequences of the adaptation regimes illustrated in Figure 5 may be possible. For example, until candidate options for 'other' have been identified, these can't be evaluated. Some actions will have irreversible consequences, e.g. 'wait and see' periods generally expire and cannot be revisited with the same set of options; and large infrastructure investments are also generally viewed as irreversible (although in practice reversibility is possible at high cost); this is illustrated in Figure 6.

Second-pass assessment (portfolio)

This phase of decision-making commences because one or more trigger points have been reached. In our example, one year out from the conclusion of the local government planning cycle (which is the trigger for a review of the coastal management plan), Brucetown and the surrounding region suffer significant damage from a storm, which is accompanied by high winds, heavy rainfall and elevated sea levels. Damage includes significant beach erosion, estuarine flooding and storm damage that has resulted in greater than expected damage to public and private infrastructure, and temporary (but extended) loss of recreational amenity because of beach closures. Extensive inundation of agricultural land has also contributed to the loss of crops and fish (due to high levels of dissolved oxygen in the estuary). Pressure mounts on Brucetown decision-makers to act.

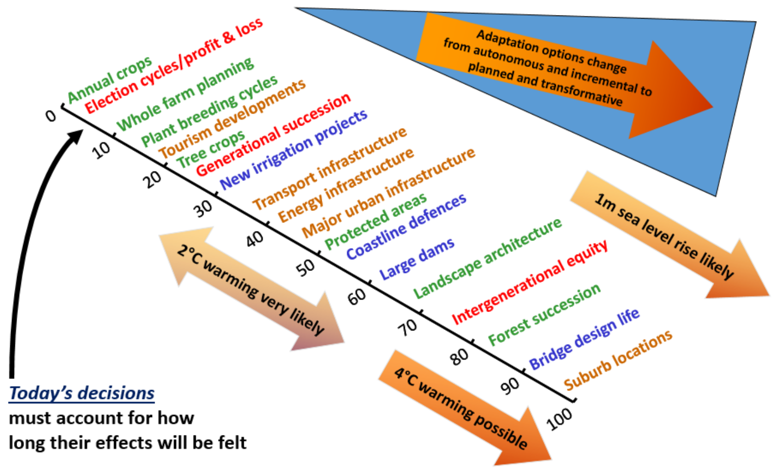

Figure 6: Adaptation timing and priorities. Source: Stafford-Smith et al. 2010.

- Government is advised by the scientific community that this type of coincident hazard event is projected to occur more frequently into the future and is likely to be more severe with higher projected sea levels. There is still uncertainty around the timing of these events. A survey of local residents indicates that a large minority are still sceptical about 'climate change'.
- The coastal management plan is reviewed, in more detail and at greater cost, identifying priority areas for planning and investment where the projected impacts of climate variability (i.e. extremes) and change on coastal hazards are expected to be significant. Two priority locations are identified, one in Brucetown and one in (hypothetical) Nickville, a small hamlet of 15 houses on the open coast approximately 5 km away.
- The 'value at risk' for Brucetown and its regional importance lead the community and decision-makers to an easy decision, which is that the town and the specific site is 'too important to fail'. A detailed management and investment plan must be developed.
- For Nickville, however, council and many in the community disagree with residents of the hamlet, who strongly favour a coastal management solution that protects the at-risk properties. Despite this divergence, there is strong agreement on the need to develop a management and investment plan.
- The review of the coastal management plan also recommends the adoption of a 'principles-based approach' to decision-making, and after significant debate, this is supported by the local community. Three key principles are adopted:
  - existing development – if the value at risk is seen as 'unacceptable', then strategies should be implemented to reduce or remove risk
  - new development – will not be subsidised within hazard/risk areas (adapted from Tasmanian Coastal Adaptation Decision Pathways project, 2012, http://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/climate_risks_and_opportunities/coastal)
  - those who benefit from living in hazard / risk areas should not do so at the expense of others (adapted from Tasmanian Coastal Adaptation Decision Pathways project, 2012,

http://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/climate_risks_and_opportunities/coastal).

- This cycle of planning has identified that the 'value at risk' for both Brucetown and Nickville have altered and that the 'wait and see' option must be revisited. This is illustrated in Figure 5, which shows the adaptation pathway at a juncture point. The review also identified significant sources of irreversibility and uncertainty around existing knowledge and recommended the use of a Real Options approach to adaptation pathways planning as part of the assessment of options in the third pass.
- Note that the ROA encourages a decision-maker to remain open to the possibility that over time new knowledge and adaptation actions may emerge that change expectations about the preferred options and also the preferred sequencing of options. For example, there may emerge a previously unknown adaptation regime (other in Figure 5) that has properties that mean it is preferred to a sea wall. Another possibility, might be that new knowledge demonstrates existing adaptation options— such as sea walls or relocating the town— are now considered suboptimal as possible adaptation regimes. This is illustrated in Table 5.

Table 5: Examples of decision-thresholds that would indicate a change in sequence or course along the adaptation pathway

Decision threshold	Wait and see	Vegetated dune / Change rules	Public sea wall / Adapt individual assets	Relocate town	Other
Time →					
Value at risk plus option of waiting is lower than 'do nothing' **Value at risk may be restricted to physical assets only or have a triple bottom line focus.**	Progress to next course of action or 'other'	Progress to next course of action or 'other'	Progress to next course of action or 'other'	Progress to next course of action or 'other (n)'	Progress to next course of action or 'other (n+1)'
A (Natural Capital) Habitat and diversity at risk	Keystone species numbers	Loss of wetland area	Hard to reverse. Decision made to hold line. Preference given to built-environment over nature. Decision may be made to skip this and move to next option.	Hard to reverse. May be undertaken in conjunction with earlier steps. May be skipped completely if 'other' option emerges as viable.	Desire to balance natural values with economic viability e.g. relocate species or infrastructure
B (Human Capital) Intellectual capital and knowledge	Knowledge of risks evolves	Knowledge of risks evolves	Knowledge of risks evolves Risk of population out-migration	Coincidence of major additional and unforeseen risk e.g. bushfire	Knowledge of risks evolves
C (Social Capital) Values, relationships and trust	Preferences change, community divided	Preferences change	Preferences change, weakening social ties	Preferences change	Preferences change
D (Manufactured Capital) Material goods and infrastructure	Infrastructure at risk X hectares of productive land inundated per flood event	Increased risk to infrastructure and/or economic opportunities	Increased risk to infrastructure and/or economic opportunities	Increased risk to infrastructure and/or economic opportunities	Increased risk to infrastructure and/or economic opportunities
E (Financial Capital) Currency that can be owned or traded	Willingness to act to manage risk suite	Willingness to act to manage risk suite	Willingness to act to manage risk suite	Willingness to act to manage risk suite	Willingness to act to manage risk suite

Third-pass assessment

For illustrative purposes, only the Brucetown example is described in this section. The reader is also referred to Table 5 for a more detailed description of decision-thresholds that would indicate a change in sequence or course along the adaptation decision pathway.

- Decision-makers must now focus their attention on the refinement of Steps 3 to 5 of the third-pass operational cycle (identify options; evaluate options, risks and costs; and take action), with a focus on the evaluation of options, risks and costs. A number of key questions must be answered in order to guide decision-making at this stage. For example (adapted from Wise and Capon 2016):
    - What are the potential consequences of systemic change on the community and livelihoods; what are acceptable limits of change for the community (often a proxy for vision)?
    - Do decision-makers currently have the mandate, resources, influence and desire to enable change, and if not, might this change in the future?
    - Are current decisions substantially different from 'adaptation decisions' (helps to understand appetite for risk)?
    - What are the lead times, consequences (e.g. costs, benefits, equity and distributional impacts, path dependencies) for decisions?
    - Is there sufficient knowledge / understanding about the nature of change, efficacy and effectiveness of interventions and what is the salience, credibility and legitimacy of this knowledge?
    - Are community values aligned (enough) i.e. are decisions or decision pathways considered to be legitimate, fair and wise?
    - How will the timing of decisions and actions be affected by the trajectory of change (whether driven by climate or change in community preference)?

Possible adaptation pathways -

- At decision point '2' in Figure 5, a trigger has been activated whereby the 'wait and see' strategy must be reviewed. Based on the 'value at risk plus options' a decision is made to change course and re-inforce existing sand dunes with vegetation in order to make the dunes more robust under extreme conditions. A 'soft' option such as this (i.e. dune nourishment and vegetation) preserves all future options. Simultaneously, decision-makers are evaluating what a change in rules such as restrictions on development in the hazard zone, is likely to have. At this point in time a decision is made to pursue soft options only.
- At decision point '3', it has been determined that a strategy to reinforce the coastline using 'soft options' cannot keep up with the loss of nearshore systems from increased coastal hazards. There is division amongst both decision-makers and key stakeholders as to the best course of action: if it should be a publicly-funded seawall (funded by a specific levy of impacted local residents) or individual adaptation of properties. Three potential courses of action now arise:
    1. Ultimately, a decision, supported by the community, is made to build a seawall (paid for through a combination of local resident levy and state government subsidy – this is decision point '4'. A substantial minority of decision-makers, however, favoured a change in the rules as a means of buying time (this is reflected in point '5', an alternative pathway). At a point further in time from '4', it is determined that the preferred strategy

to construct a sea wall is likely to be effective in the medium to longer term and there is no need to change course. An earlier decision to build the seawall with a wider foundation means that the height of the wall can be increased in the future if needed (decision point '6'). As a result of this determination, both residents and the business community are offered certainty around future decision-making and this generates a positive feeling towards development. Decision point '4' now creates an irreversible decision as a result of the lock in created by homeowners and businesses capitalising on the decision to protect a particular area.

2. In a parallel sequence at decision point '3', however, a determination to limit development in the 'at risk' area while waiting for more information has meant that decision-makers still have maximum flexibility (decision point '5'). As a result of preserving flexibility, the community is now able to capitalise on 'Other1' a new 'smart technology' that uses the earth's gravitational forces to distil storm impacts in real time (note this is a hypothetical future technology) and as a result has been able to firstly preserve biological diversity in the estuarine system; and secondly progress more rapidly and cost effectively (decision point '7').
3. In a third alternative, characterised as a risk averse yet brave approach, the community strongly favours the protection of natural systems, and supports a 'retreat' option that witnesses a gradual relocation of critical services and community to higher ground. The sequence to be followed may be to change the rules such as land use planning (decision point '3') and adapt those services that rely on proximity to the coast (dot point '8') such as economic and tourist businesses to ensure they are able to generate advantage for the maximum time possible, but with a clear plan to minimise the 'value at risk' over time through a relocation rather than protection strategy (decision point '9').

Conclusions

This case study has illustrated three potentially viable, yet different, courses of action for a decision-maker faced with broadly the same problem. The case study illustrates the importance and value of a deliberative process to characterise community preferences in a manner that aligns values and can assist decision-makers to capitalise on the options made available through a ROA decision-making process.

Recommended reading

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