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Accounting for adaptive capacity in FCERM options appraisal

Report – SC110001/R2

Flood and Coastal Erosion Risk Management Research and Development Programme

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

Flood and Coastal Erosion Risk Management (FCERM) has always faced the challenge of decision making under uncertainty. However, there is an increasing need to understand and develop solutions in the face of multiple uncertainties (in the climate, the economy and society) and often conflicting or competing agendas, while ensuring cost-effectiveness. These uncertainties will affect future flood and coastal erosion risks and our capacity to address them; they cannot be ignored or avoided, but need to be recognised and managed if we are to develop safe and sustainable solutions now and for the future.

Adaptation tends to focus upon managing the negative uncertainties associated with future change, such as sea level rise threatening coastal communities, drought and extreme weather impacting on human wellbeing. But, adopting more adaptable and flexible approaches can allow us to better embrace positive opportunities arising from improved scientific knowledge, changes in policy or even increases in available funding. Developing adaptive approaches can provide resilience to negative future change and enable opportunities arising from positive future change to be realised.

National policy and advice for the appraisal of investment in FCERM schemes promotes the use of managed adaptive approaches to address future uncertainty, yet these are not being adopted extensively with a continued tendency to favour precautionary approaches. The absence of clear methods and tools to value adaptive approaches is recognised as one of the obstacles to a change in thinking and practice. This research was commissioned by the Environment Agency to help fill that gap.

Two outputs have been produced. This Evidence Report provides the context, science and detailed thinking behind the second output, the Supplementary Appraisal Guide – *Promoting adaptive solutions and accounting for adaptive approaches in FCERM options appraisal*. The Supplementary Appraisal Guide is intended to be used alongside existing FCERM appraisal guidance for plans and projects and provides advice in relation to various stages of appraisal: defining problems and opportunities, setting objectives, generating and screening options, and introducing a decision tree approach to valuing managed adaptive approaches.

This Evidence Report explains how the Guide and tools have been developed and, importantly, how these have been influenced by practitioner feedback throughout via Project Steering Group meetings and considerations of draft outputs on an iterative basis, market analysis and market testing workshops, and final testing of draft outputs.

The Guide is a ‘living document’ and will be updated over time to ensure it reflects relevant developments in science and policy. This Evidence Report provides recommendations for future research and development to fully develop the Guide and associated tools into a comprehensive suite of resources for valuing managed adaptive approaches.

Acknowledgements

Thanks are due for the ongoing support and direction from the lead Project Contact and Project Manager at the Environment Agency – David Cotterell and Daniel Hine. The support of the Project Board, consisting of representatives from the Environment Agency, Defra and Natural Resources Wales, which has provided useful comments throughout, has also been appreciated.

In addition, we are grateful to members of the wider Project Steering Group (representatives from Defra, the Environment Agency, Natural Resources Wales, the Welsh Local Government Association, HR Wallingford, London School of Economics, Ouse and Humber Water Management Partnership, Torbay Council, United Utilities and URS) for their useful comments on the gap analysis, attendance at the workshop and consideration of the draft Supplementary Appraisal Guide.

Finally, sincere thanks are due to Environment Agency officers (Richard Williams, Steve Rendell and Howard Simpson) and consultants (Andrew Parsons, Halcrow, Will McBain, Arup, and Angus Pettit, JBA Consulting) who have tested the draft outputs and provided detailed written responses.

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1 Introduction

The Environment Agency commissioned JBA Consulting, working with Sayers and Partners, Professor Jim Hall, Professor Zoran Kapelan and Royal Haskoning DHV, to undertake a study to investigate how adaptive approaches could be better accounted for in Flood and Coastal Erosion Risk Management (FCERM) options appraisal. The project findings are reported in two outputs: a supplementary guide to current appraisal guidance for FCERM plans and projects entitled *Promoting adaptive solutions and accounting for adaptive approaches in FCERM options appraisal* (hereafter referred to as the Supplementary Appraisal Guide or the Guide) and this Evidence Report that explains the overall project approach and provides the evidence (justification and science) underpinning the content of the Guide.

The project has been overseen by a Project Board comprising representatives from the Environment Agency, Natural Resources Wales and the Department for the Environment, Food and Rural Affairs (Defra).

1.1 Adaptive capacity and managed adaptive approaches

There are many sources of uncertainty and drivers of future change that communities and decision makers could be better prepared for if more adaptable ways of thinking about and managing flood and erosion risks were adopted. It may not be possible to reduce uncertainty, at least in the short term, but recognising and accepting uncertainty and being better able to manage it can save money and time. The aim of this project is to promote and investigate approaches to valuing adaptable, flexible solutions which can help manage both the positive and negative aspects of future uncertainty.

The capacity of organisations, institutions and individuals to adapt to changes in their wider environment varies considerably between and within sectors. Improving and building such adaptive capacity is defined in the *UK Climate change risk assessment* (Defra, 2012) as ‘The ability of a system/organisation to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), moderate potential damages, and take advantages, or cope with the consequences’ (this is a modified IPCC definition). This study focused on improving the adaptive capacity of the FCERM industry encapsulating technical specialists, practitioners and stakeholders in the Environment Agency, Defra and other government departments, Regional Flood and Coastal Committees (RFCCs), Risk Management Authorities (RMAs) and private sector consultancies. The Supplementary Appraisal Guide, which is the key output from the project, will assist with the development and appraisal of managed adaptive approaches in plans and projects. It should also help encourage a wider culture change towards managed approaches that can be adapted over time.

The **managed adaptive approach** to FCERM aligns with principles in *Making space for water* (Defra 2005). This promotes a holistic and long-term approach to flood and coastal management, and reinforces existing climate change policy promoting ‘no regrets’ actions[1] and longer term adaptability. The approach advocates flexibility in FCERM responses, meaning that they are capable of addressing future challenges and opportunities (which are currently uncertain or unknown) as they arise.

The adaptive approach differs from the more traditional approach to FCERM – **the precautionary approach** – in which assumptions are made of what might happen in the future and investment is planned accordingly. When uncertainties are severe, a precautionary approach may involve excessive upfront investment, which could prove to be unwarranted, or, if change is even faster than anticipated, it may result in an unacceptable level of risk. This is not to say that managed adaptive and precautionary approaches should necessarily be considered as mutually exclusive; to a large degree, the adaptive approach is precautionary in that it ensures options are open for future change rather than applying locked-down solutions that are not capable of further adaptation.

[1] The definition of no regrets actions according to UK CIP (undated) is adaptive measures that are worthwhile (i.e. they deliver net socio-economic benefits) whatever the extent of future climate change.

These two approaches are illustrated in Figure 1.1.

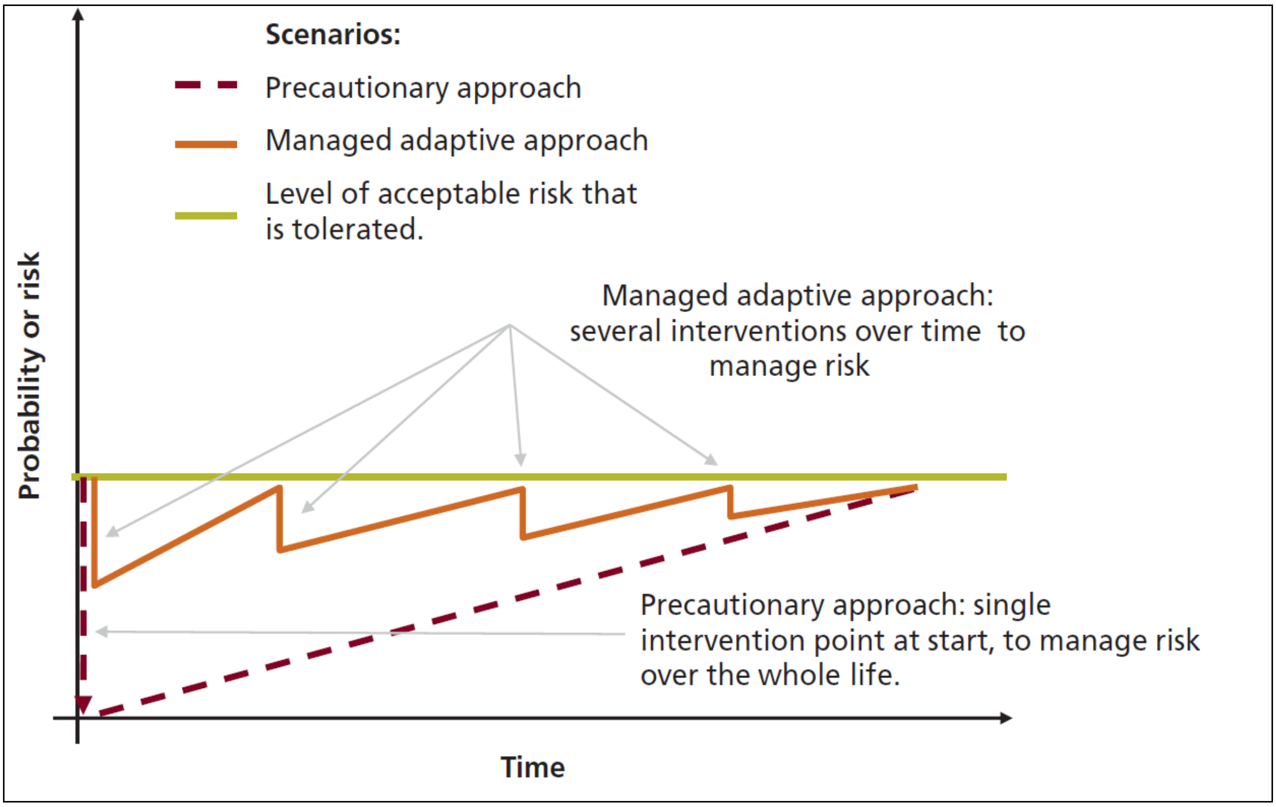


Figure 1.1 Precautionary and managed adaptive approaches (Defra 2009b)

Managed adaptive approaches include structural (hard and soft) and non-structural responses to FCERM; a number of examples are summarised below:

- Soft engineering provides tangible protection to coastal communities by adapting to and supplementing natural processes while providing wider benefits such as enhanced habitats, better aesthetics and improved ecosystem services.
- Building the potential for future adaptation into new flood defences (e.g. building foundations that are larger than required for the current height of the defence enabling heightening in the future if required).
- Delivering practical support to facilitate relocation for those at risk (e.g. through discussions with utilities and other service providers and identification of possible sites for relocation).
- Design for exceedance principles[2] have been established for over a decade and integration of this approach in multi-functional projects is a key non-structural response to uncertainty. An example is ensuring green infrastructure provision ties in with flood management schemes where an overflow route is used to manage the uncertainties in performance and climatic conditions.
- Adoption of resilience measures, such as property level protection, and emergency plans within new regenerated development within the flood cell to manage uncertainties in defence or surface water system performance and modelling uncertainties.

1.2 Context

The adaptive approach is promoted in key national policy statements including *Making space for water* (Defra 2005, the Environment Agency's national FCERM Strategy (Environment

[2] Design for exceedance principles mean that FCERM measures are designed to safely and sustainably accommodate periods in which surface water volumes exceed the capacity of the drainage system during an extreme rainfall event.

Agency 2011) and Defra's policy on FCERM investment decisions and climate change (Defra 2009a). In addition, the Green Book (2003) provides HM Treasury Guidance for Central Government and a framework for the appraisal and evaluation of all policies, plans and projects. HM Treasury and Defra (2009) have produced supplementary guidance to the Green Book on accounting for the effects of climate change, which sets a high level framework for bringing the effects of climate change into the heart of the appraisal process so interventions are developed and optimised that are adaptable to future uncertainties. The Environment Agency's FCERM appraisal guidance (2010a) and its advice on adapting to climate change (2010c) also advocate adaptive approaches as do the National Planning Policy Framework (NPPF) (DCLG 2012a), the Welsh Government's Planning Policy Wales (Edition 5, 2012) and its accompanying Technical Advice Note on Development and flood risk (2004).

The advice on climate change produced by the Environment Agency (2010c) provides the framework for this study. Part of the justification for developing further advice and tools to progress managed adaptive approaches was related to the limited application of this advice. The Environment Agency advice is intended 'to ensure that an economically credible appraisal, taking account of the uncertainties associated with climate change, can be made to support government investment decisions'.

Accepting and managing uncertainty is not easy and, while there are few arguments against the benefits of affordable and flexible solutions, there can be difficulties with their justification, development, valuation and implementation in practice. Previous research (Defra 2009b) has identified specific barriers to the development and appraisal of adaptive approaches, namely:

- a lack of systems thinking involving narrow problem definition;
- a focus on the status quo; risk and uncertainty aversion;
- an inability to value the benefits of adaptation and the costs of not adapting;
- the lack of an evidence base explicitly identifying examples of adaptive approaches or evidencing their efficiency, effectiveness and general improved performance.

In addition, while there is policy support for adaptive approaches and guidance is available for their appraisal, limited explanation is provided for **how** project managers, stakeholders and decision makers should develop and gain support for adaptive approaches and **how** these should then be appraised. This is the fundamental purpose of the Supplementary Appraisal Guide. This project has investigated the prevailing culture and mindsets regarding adaptive approaches, seeking to understand why precautionary approaches tend to remain the fallback option, despite the above raft of supporting policy and guidance

In recent years significant advances have also been made in both the underlying methods available for analysing uncertainties in FCERM such as decision pathways/information-gap approaches in Thames Estuary 2100 (Environment Agency 2012c), robustness/flexibility analysis in FLOODsite (2009) and real options and optimisation methods in Flood Risk Management Research Consortium 1 and 2 (see http://www.floodrisk.org.uk/). Data has also improved with the publication of UKCP09 probabilistic climate change projections (Defra 2009c). Therefore, when combined with the requirements and steer from government legislation and policy, the time appears right to make a step change in the way adaptive capacity is built into FCERM decision making. Thus, this project is timely – both in terms of the maturity of the science and the increasing demand from stakeholders for methods and tools that can clearly demonstrate the value (economic or otherwise) of 'building' future adaptability and flexibility into FCERM strategies, plans and projects.

It is also a time of institutional capacity building, particularly within recently formed lead local flood authorities, where new knowledge, expertise and skills are required (and being acquired) to inform the management of uncertain flood and coastal erosion risk now and in the future. This presents a good opportunity to 'embed' adaptive thinking in the next generation of FCERM professionals, practitioners and stakeholders, and ensure that they have the appropriate resources to assist with their everyday decision making.

For the outcomes of this project to be successfully adopted, it has been recognised that other challenges will impact on a public RMA's ability to develop its adaptive capacity in practice. These include recent changes to spatial planning policy, arrangements for allocating government funding to local FCERM projects via the Partnership Funding policy and the need for the National Capital Programme Management Service (NCPMS), within the Environment Agency, to provide greater support for adaptive approaches when scrutinising FCERM appraisals.

1.3 Purpose of report and target audience

The purpose of this report is to provide the evidence, context, detailed explanations and science behind the production of the Supplementary Appraisal Guide. It also sets out the project methodology and, importantly, provides recommendations to improve the robustness of the appraisal of adaptive approaches for FCERM. Thus, the Guide should be seen as a living document; future updates will be required informed by additional research and policy developments when available.

The target audience for the report is the Environment Agency (scientists, research and development, technical officers and project officers), Defra and other government departments including HM Treasury, the Welsh Government and Natural Resources Wales, consultants undertaking appraisals, and regional and local stakeholders who wish to understand the science and thinking behind the requirements stated within the Supplementary Appraisal Guide.

1.4 Structure of the report

The remainder of the report is structured as follows:

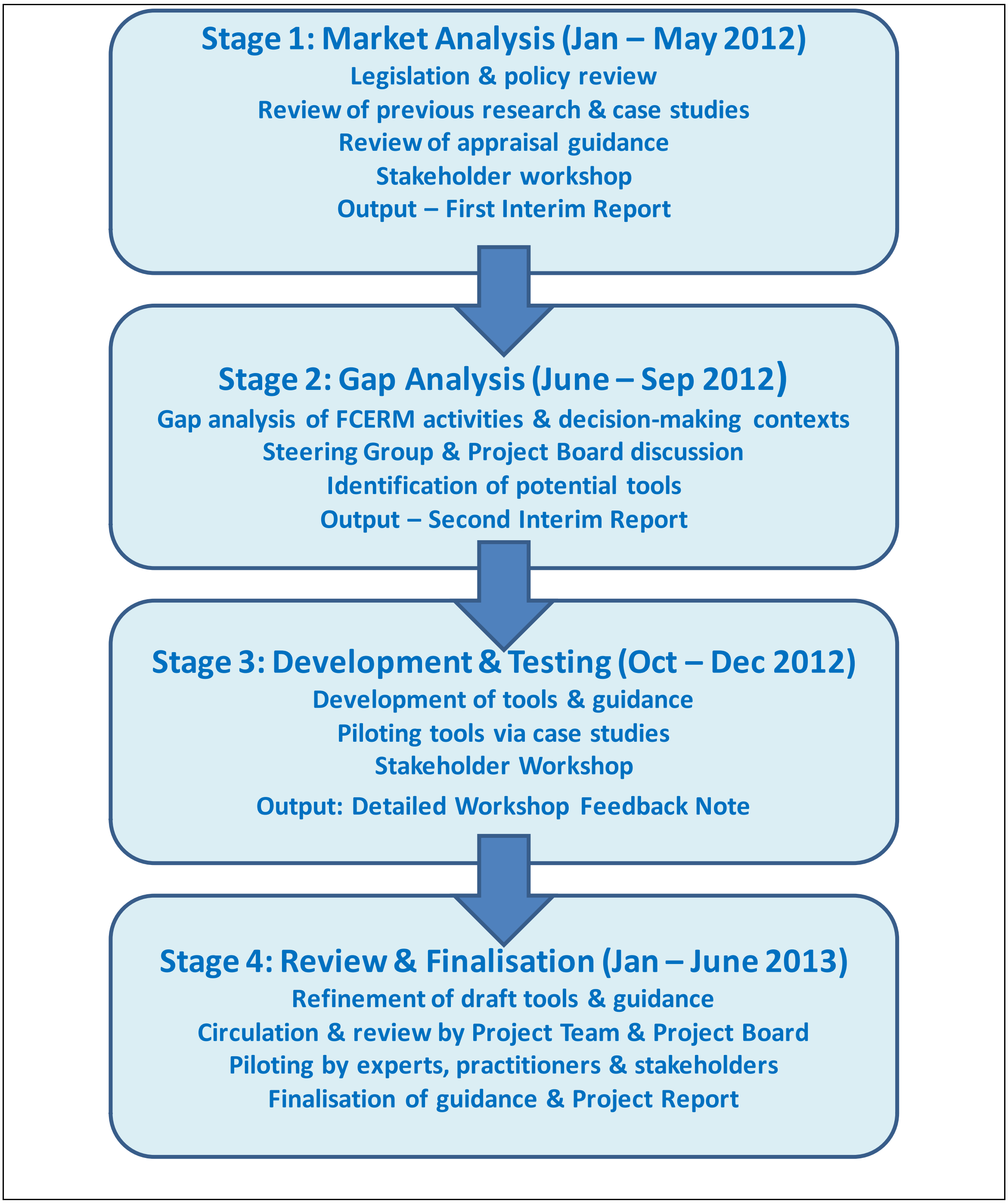
- Section 2 details the study approach and methodology employed.
- Section 3 summarises the framework of the Supplementary Appraisal Guide.
- Section 4 addresses ‘building adaptive capacity’ in terms of culture and mindsets, defining problems and opportunities, and objective setting.
- Section 5 focuses on ‘developing managed adaptive approaches’, specifically, the generation and screening of options.
- Section 6 provides the evidence behind ‘valuing managed adaptive approaches’ through the appraisal process.
- Section 7 investigates the role of national and local planning policy in supporting managed adaptive approaches.
- Section 8 provides the study’s conclusions and sets out recommendations for further research.

2 Study approach and methodology

2.1 Overall approach

The project was undertaken over 18 months (January 2012 to June 2013) and was phased into four stages as depicted in Figure 2.1. The approach developed over the study period on an iterative basis, which is explained within this section.

Figure 2.1 Overall approach of the project



2.1.1 Stage 1: Market analysis (January – May 2012)

This stage investigated the types of responses required to improve on the current situation and support a culture change on adaptive thinking within the appraisal process. The resultant output was Interim Report 1, which provided a clear understanding of the current 'market'; that is, where there is most potential to enhance adaptive capacity within FCERM and what is needed to embed adaptive thinking into everyday working.

More specifically, the following tasks were undertaken during Stage 1:

- Investigation of the current status of adaptive capacity, known barriers to its more widespread adoption and potential opportunities.
- Case study review (Thames Estuary 2100, Wash Shoreline Management Plan and Southampton FCERM Strategy) to understand how managed adaptive approaches were being developed in practice.
- Consideration of new challenges such as Partnership Funding and the NPPF.
- Stakeholder workshop held in March 2012 to obtain views from FCERM practitioners on understanding and awareness of adaptive approaches, opportunities to enhance adaptive capacity within FCERM, how best to develop and account for adaptive capacity in FCERM decisions, and identification of the resources required to help progress 'adaptive thinking' within FCERM decision making.

The first Interim Report reached three overarching conclusions regarding the intended purpose of the project and final outputs, which were taken as the starting point for conducting Stage 2 gap analysis:

- Helping to inspire the right culture and type of (adaptive) thinking.
- Providing supporting methods and tools for decision support and valuation, in particular:
  - matching particular methods for evaluating adaptive capacity to particular decision contexts;
  - encouraging people to think adaptively (i.e. generating and screening of flexible options);
  - helping to develop the economic justification for an adaptable approach.
- Providing worked examples that bring the vision set out in the Green Book supplementary guidance to life, reflecting the new reality of Partnership Funding and smaller fluvial or surface water schemes.

The report also concluded that the study should be targeted at both non-technical decision makers and the general public, and experienced FCERM practitioners. In addition, it recommended that the study's outputs should be relevant for use by practitioners in England and Wales which have separate (and different) appraisal guidance and funding arrangements.

2.1.2 Stage 2: Gap analysis (June – September 2012)

Stage 2 extended the scoping phase undertaken in Stage 1 to identify gaps and suggest potential methods for promoting and appraising managed adaptive approaches in a range of decision contexts across FCERM (e.g. strategic planning, scheme appraisal, detailed design). This exercise identified the decision areas with the greatest implications for managed adaptive approaches and the clearest need for supplementary tools and guidance. Interim Report 2 presented the key findings from the gap analysis and made recommendations for the tools and guidance to be developed in the remainder of the project, which were confirmed through consultation and discussion with the Project Board and Project Steering Group.

Figure 2.2 summarises the proposed tools (at that point) in relation to each of the decision-making contexts.

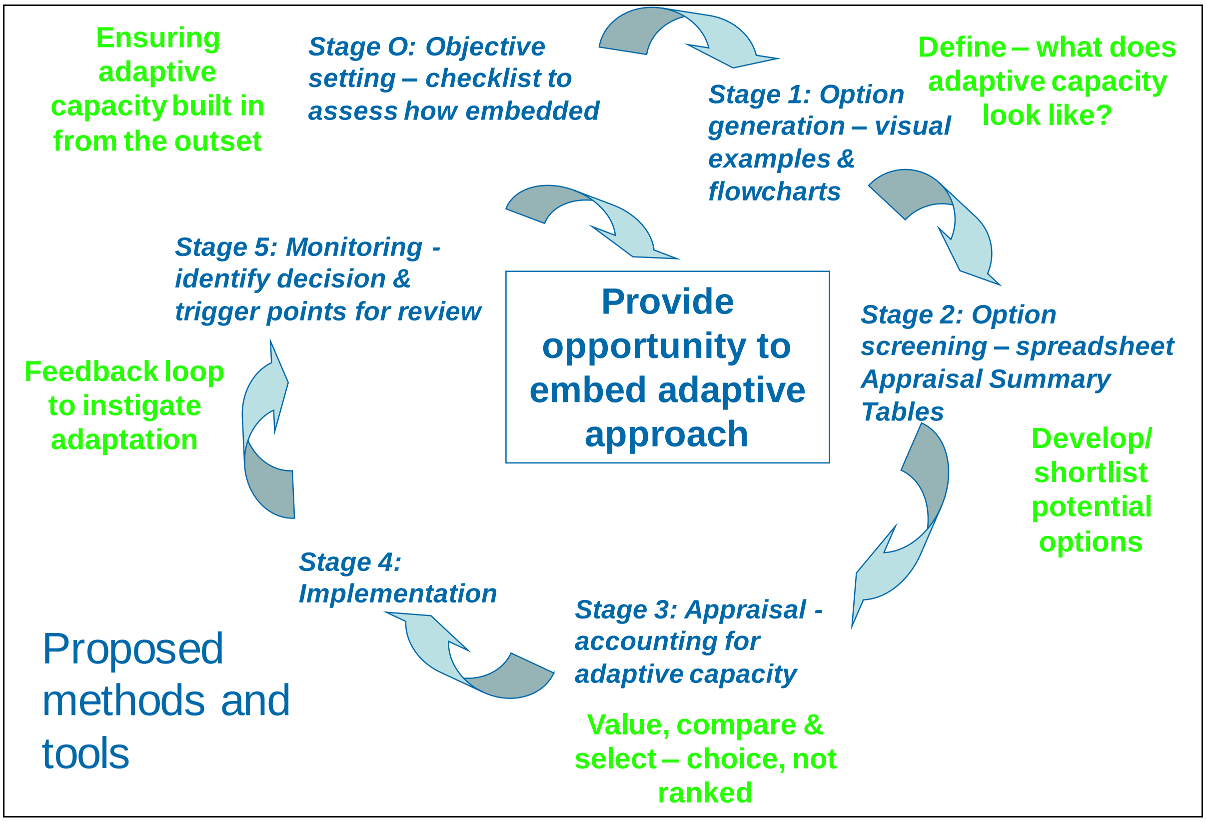


Figure 2.2 Proposed methods and tools to address specific decision-making contexts

The guidance and tools proposed within the Interim Report 2 were as follows:

- **Objective setting** – broad guidance suggesting how adaptive capacity should be taken into account at this stage.
- **Option generation** – decision flowcharts to set out a route to the development of adaptive options supported by illustrations to enable practitioners to better visualise managed adaptive approaches.
- **Option screening** – a multi-criteria decision analysis (MCDA) approach with the provision of a spreadsheet that enables different options to be scored and ranked against generic and customised criteria.
- **Appraisal** – development of a straightforward decision tree focused approach that can represent a limited number of uncertainties and scenarios.
- **Monitoring** – provision of broad guidance to help identify decision and trigger points at which implementation will be reviewed to identify whether the approach needs to be refined.
- **Spatial planning** – review of the NPPF and supporting technical guidance, Planning Policy Wales and accompanying relevant technical advice notes to identify any required changes to ensure that national policy documents promote an adaptive approach.

2.1.3 Stage 3: Development and testing (October – December 2012)

Stage 3 involved developing the individual tools/guidance (identified in the previous task), piloting these through case studies and presenting the revised approaches at a stakeholder workshop.

Section 3 sets out the framework for the resulting Supplementary Appraisal Guide and sections 4, 5 and 6 summarise specific elements of the Guide explaining how these have been developed and the evidence on which they are based.

Case studies

Case studies were used to investigate how managed adaptive approaches are being developed, appraised and implemented in practice, and also used to pilot the developing tools and guidance on real life examples. Case study areas were selected to reflect a range of characteristics – types of flooding, urban/rural, stage within scheme development process and willingness to be involved. This involved moving from an initial longlist to a shortlist of four (plus a synthetic example). A further hypothetical example, using real data, was employed to test the appraisal tool. The final case studies selected are briefly described below:

- **Alt Crossens** (Sefton/West Lancashire) – development of a fluvial strategy within a highly productive agricultural lowland catchment facing multiple future uncertainties in terms of climate change, food security, fuel prices and national policy.
- **Morpeth** (Northumberland) – Flood Alleviation Scheme (FAS) to address fluvial flooding; over 1,000 properties are currently at risk of flooding. The scheme is currently under development supported by over £20 million Partnership Funding and external contributions.
- **Pwllheli Pilot: Climate Change Adaptation Strategy** (Gwynedd, Wales) – strategy developed to address the significant challenges posed by the current and future flood risk to the town of Pwllheli and its surrounding area. Much of the more recent development (last 100 years) lies within both the tidal flood plain and the defended flood plain.
- **Wash East Coastal Management Strategy** (Norfolk, King's Lynn, Lincolnshire) – currently under development following the conclusion of the Wash Shoreline Management Plan 2 (SMP2), which covers the coastal frontage between Wolferton Creek and Old Hunstanton. The strategy concerning future sea defences is being developed within the context of future uncertainties (funding, climate change and economic, social and environmental sustainability).
- **Hypothetical case study 1** – use of data from a specific area subject to fluvial flooding to test and help develop the decision tree appraisal tool.
- **Hypothetical case study 2** – study to explore the development of a tool to assess the economic case for the inclusion of real options in flood risk management strategies. The risk management strategies were compared to reveal the overall higher performing option, as well as if and where the preference shifts between options. The real options methodology was applied to two adaptive management scenarios: (i) building flexibility into a flood defence to enable future raising and (ii) purchasing water-front land to reduce the build-up of vulnerability and enable future defence raising.

The overall objectives of the case studies were three-fold:

- To understand why an adaptive approach has been adopted in some areas with the intention being to understand what factors help facilitate adaptive thinking and inform conclusions with regards to changing culture and mindsets.
- To pilot the approaches (methods and tools) to help account for adaptive capacity in FCERM options appraisal using real world examples and refine these where appropriate.
- To demonstrate examples of best practice in spatial planning.

The approach adopted to undertake the 'real life' case studies consisted of a review of relevant local information (e.g. project appraisal report – PAR), an interview with the relevant project manager to gain an insight into the background to the project and the reasoning behind taking an adaptive approach, and testing of relevant draft tools and guidance to assess their applicability and value.

The case studies were employed to explore a range of tools/guidance developed for each of the decision-making contexts. In some cases, it was relevant to look at several stages in the appraisal process; in others, only one was investigated. Findings from the case studies are reported in sections 4, 5 and 6; findings and common themes are drawn out and detailed in relation to each of the appraisal stages rather than individual reports on each case study.

Spatial planning and development management

Spatial planning and development management has been included as, while this is not subject to formal options appraisal, land-use allocation policy provides a framework within which FCERM plans and projects are often developed. Spatial planning and development management provide an opportunity to consider non-structural responses to FCERM such as temporary land use on the coast, space allocated for flood storage etc. Case studies have been used to provide examples of how managed adaptive approaches can be promoted via planning policy. A review of national and local planning policy and the degree to which this promotes or constrains the development and implementation of adaptive approaches is reported in section 7.

Workshop

A stakeholder workshop was held in Birmingham in November 2012 which was attended by over 35 FCERM practitioners and stakeholders. The purpose of the workshop was to engage practitioners and stakeholders in the project, and obtain their observations and views on the approaches being developed.

Discussions with the Environment Agency following the workshop highlighted the need for a full set of guidance which addressed each stage of the FCERM appraisal guidance for projects (FCERM AG) and similar guidance for the appraisal of plans (Shoreline Management Plans (SMPs), Surface Water Management Plans (SWMPs) and Catchment Flow Management Plans (CFMPs)).

2.1.4 Stage 4: Review and finalisation (January – June 2013)

The final stage of the project has involved refining the Supplementary Appraisal Guide and associated tools and testing these with stakeholders (volunteers from the workshop), the Project Steering Group and consultants.

Following circulation of the draft Guide and a set of consultation questions, five detailed responses were received. Consistent comments were provided which highlighted the following:

- The Guide needs to be reduced in length with less context and discussion and a focus on plain English throughout.
- More case study examples are required to demonstrate application of the tools, especially the decision tree analysis to support appraisal decisions.
- Alternative futures could be considered too 'open' leading to appraisers dedicating a lot of time to developing these; standardised futures should be provided which can be applied in a range of different situations.
- Linkage with national and local planning policy should be more explicit.
- Explicit direction is required regarding exact application of each element of the Guide and the expected outcomes.
- The Guide should be clearer, perhaps by including a flowchart in the introduction/overview, about the situations in which the Guide and its tools should be used; it is not appropriate for simple projects.

2.2 Project Board and Project Steering Group

The Project Board comprised representatives from the Environment Agency, Natural Resources Wales and Defra and was responsible for overseeing the project and commenting on all draft outputs. The Board met a total of six times via face-to-face and virtual meetings. In addition, Board representatives were present at both the market analysis and market testing workshops.

The Project Steering Group was drawn from interested attendees of the market analysis workshop in March 2012. The Group met on a virtual basis to discuss the gap analysis, and was invited to comment on the Supplementary Appraisal Guide during Stage 4. Members comprise representatives from Defra, the Environment Agency, Natural Resources Wales, the Welsh Local Government Association, HR Wallingford, London School of Economics, Ouse and Humber Water Management Partnership, Torbay Council, United Utilities and URS.

2.3 Consultation and market testing

Since project inception, it was recognised by the Project Team and the Project Board that the study outputs needed to be of practical and relevant use to FCERM decision makers and practitioners undertaking and scrutinising the appraisal of FCERM projects. Therefore, consultation, engagement and market testing has been of crucial importance throughout the project. Figure 2.3 shows the stakeholders that have contributed to the project detailing the different perspectives they represent.

The key aspects of consultation and market review within the project have been:

- Market analysis – stakeholder workshop, March 2012
- Review of Interim Report 1 – Project Board, workshop attendees – May 2012
- Review of Interim Report 2 – Project Board, Steering Group – September 2012
- Market testing workshop – Project Board, Project Steering Group and wider stakeholders – November 2012
- Market testing of the supplementary guide – Project Board, Project Steering Group, volunteer decision makers and consultants – April/May 2013.

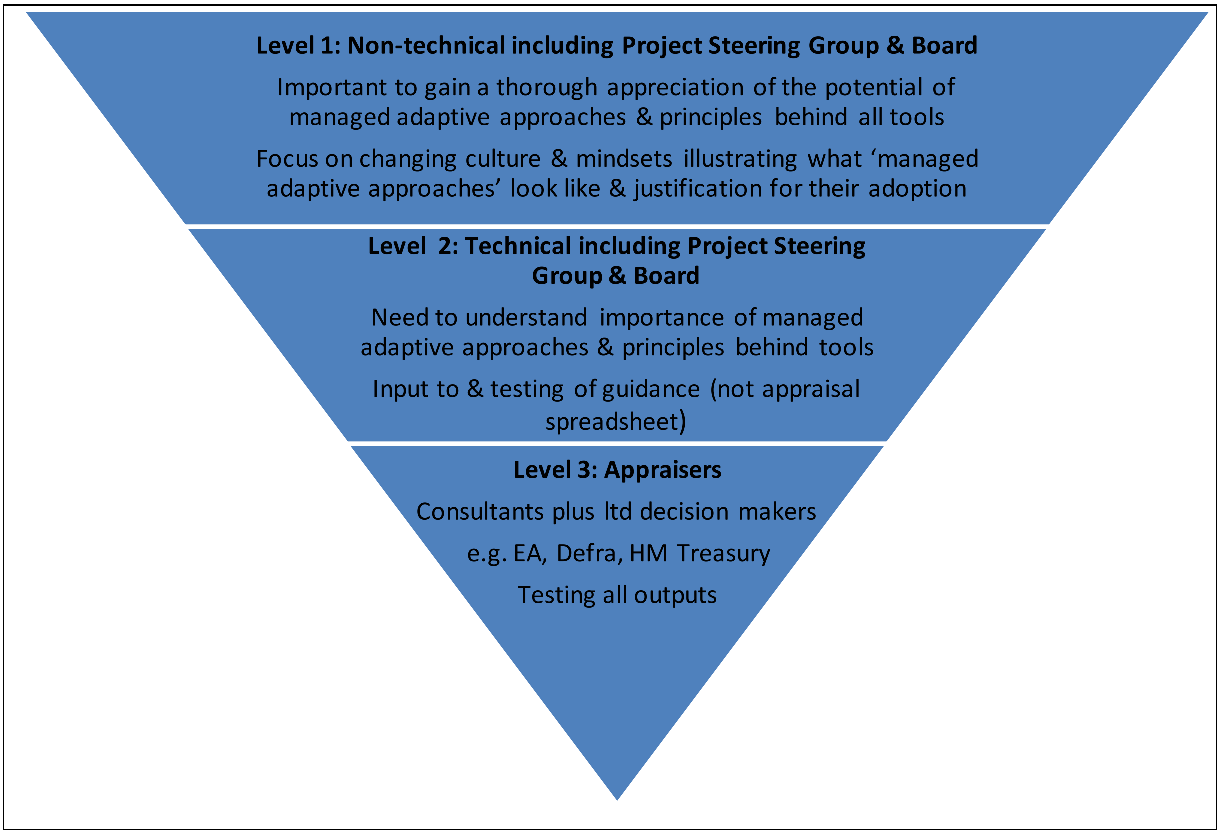


Figure 2.3 Stakeholder contributions

2.4 Summary

This section has shown how the project direction and scope has iterated and been refined according to the requirements of key stakeholders. The resultant key deliverable is the Supplementary Appraisal Guide, with this Evidence Report providing the surrounding context and underlying justification for the Guide.

3 Supplementary appraisal guide framework

3.1 Introduction

This section sets out the purpose of and framework for the Supplementary Appraisal Guide. Its content is then summarised and explained in sections 4, 5 and 6.

3.2 Purpose and principles

3.2.1 Purpose of the Guide

The intention of the Guide is to provide supplementary advice and support including practical tools and approaches that can help promote and appraise managed adaptive approaches. It is not mandatory guidance, but supplements existing guidance for the appraisal of FCERM plans and projects and should help with the 'How do I do it?' question which is lacking in current guidance.

3.2.2 Key principles

The advice within the Supplementary Appraisal Guide has been developed with the intention of ensuring that it is **proportionate** and **relevant** to the problem or opportunity that is being addressed. The effort dedicated to the appraisal needs to be sufficient to ensure that the right choice is made to address the specific circumstances, challenges and opportunities in evidence. In some instances this may be achieved with very limited effort; in others much more detailed consideration will be required. The Guide is applicable to both cases, but will require more in-depth investigation and analysis where complex situations require difficult choices. The Guide can be used as a prompt and reference source for the more straightforward and constrained responses, while more detailed advice and tools are provided to assist more strategic and complex situations arising from multiple uncertainties. The Guide is applicable to the development and appraisal of high level strategies and plans as well as local schemes and projects. It should also help assist in situations where there are competing interests such as land-use and/or socio-economic objectives, which may compete against working with natural processes.

The following principles highlight the key attributes that should characterise managed adaptive approaches:

- **Sustainable** – building flexibility and ensuring that investments can be adapted to future circumstances is a very practical way of achieving sustainability. The Guide promotes whole-life and long-term thinking, exploring how different approaches are likely to perform in multiple futures and therefore can assist in developing approaches that are both adaptive and sustainable.
- **Flexible** – flexible approaches avoid 'locking-in' responses, which cannot be readily adapted in the long term and can result in significant 'sunk costs'. Embedding flexibility is intrinsic to being adaptive and this flexibility should also be reflected by adopting an iterative approach to the development of projects and plans and undertaking their appraisal. The ongoing nature of adaptation means it should be viewed as a continuous, cyclical process rather than an endpoint that can be attained – adaptation can never be completed. Similarly, uncertainty can never be completely removed; adaptive approaches accept uncertainty and should be

capable of responding to future changes in conditions. Therefore, continuous monitoring and review is required (of the operation of responses, socio-economic and climate conditions and emerging scientific research and information) to identify when and how adaptation is required.

- **Resilient** – building in measures that will continue to perform when exposed to either extreme events that exceed design conditions or unforeseen future change provides a useful contribution to managing future uncertainty by building in resilience.
- **No regrets, low regrets and win–win measures** – these measures offer worthwhile investments no matter how the reality of the future turns out. Benefits that satisfy multiple agendas will gain greater support from stakeholders than single-issue solutions which could be costly and only reap the benefits in limited alternative futures.
- **Whole system 'thinking' and collaboration** – the Supplementary Appraisal Guide focuses on addressing multiple agendas under a range of uncertainties; the role of stakeholders is important in ensuring that adaptation options meet the needs of more than one particular agenda (economic, environmental, social). Adaptation measures should be developed and implemented in a way that does not make it difficult for others to manage their climate risks or other uncertainties or objectives.

3.3 Content and use

3.3.1 Guide content

The main content of the guide is set out in four key sections: 'Define problems and opportunities', 'Set objectives', 'Generate and screen options', and 'Appraise the options'. The content differs slightly from that originally proposed following the 'gap analysis' exercise (see section 2.1.2). This resulted from the insights gleaned from undertaking the case studies, consultation via the market testing workshop and the process of drafting the Guide which highlighted the importance of including the 'Define problems and opportunities' section and suggested that a 'Monitoring and review' section did not add sufficient additional value to be included.

3.3.2 Using the Guide

The guide is discretionary and will not be appropriate for all plans and projects due to the detailed considerations required; for example, with regards to different rates/scale of climate change or economic growth in the future. The flowchart (Figure 3.1) suggests how the Guide should be used for three different situations: small, straightforward projects unlikely to be impacted by future uncertainty, projects or plans that are already in place and require 'retro-fitting' to improve their future adaptability and new complex projects or plans facing multiple future uncertainties where stakeholders are keen to maximise the potential for adaptive approaches from the outset.

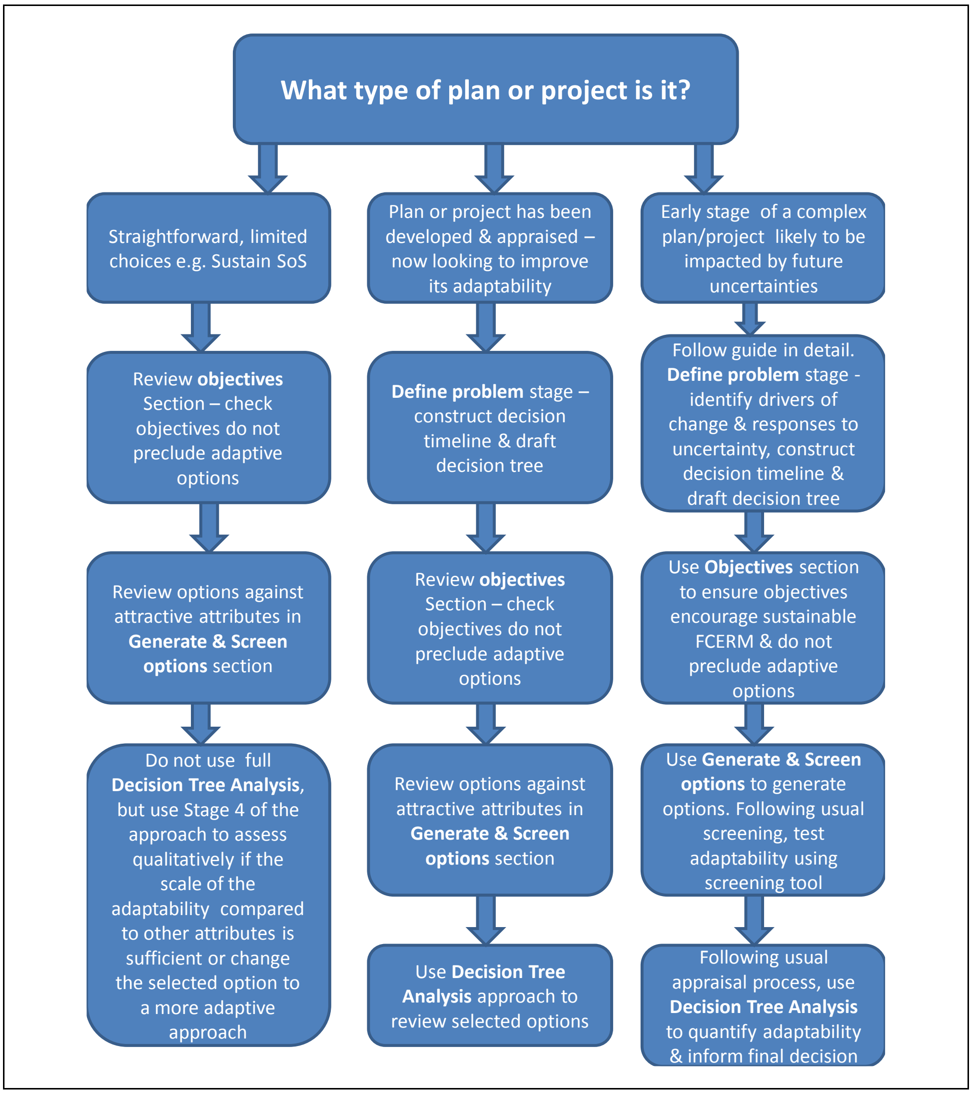


Figure 3.1 Application of the Supplementary Appraisal Guide

3.3.3 Linkage to other appraisal guidance

Figure 3.2 shows how the different elements of the Guide (second row down) fit with the FCERM AG (Environment Agency 2010a), HM Treasury Green Book (2003) and guidance for the appraisal of FCERM plans (Defra 2009a, 2011a, 2011b). The Green Book provides the framework for all other elements and therefore the process for each should be seen as iterative and containing feedback loops rather than being followed and implemented in a sequential manner.

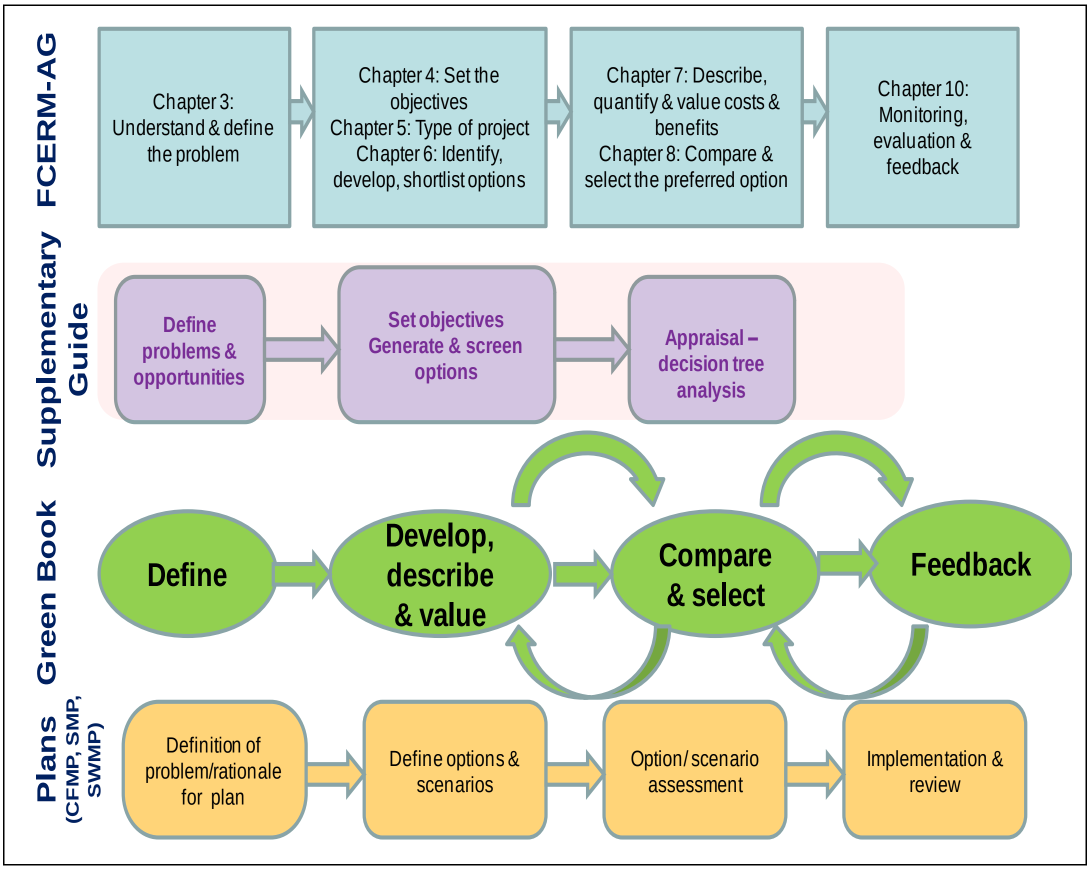


Figure 3.2 Fit with FCERM plan and project appraisal guidance

In addition to the key sources of appraisal guidance depicted in Figure 3.2, there are two crucial supplementary documents (produced by HM Treasury/Defra and the Environment Agency) providing further guidance on appraisal and climate change including managed adaptive approaches. Table 3.1 summarises the details of both.

Table 3.1 Summary of HM Treasury/Defra and Environment Agency supplementary documents

HM Treasury/Defra 'Accounting for the Effects of Climate Change', (2009)	Environment Agency (2010c)
The guidance highlights the need to consider the risks and effects of climate change if a programme, policy or project: • has elements affected by the weather • has a long-term lifetime • involves significant investment or has high value at stake • provides or supports critical national infrastructure • involves decisions with significant irreversible impacts • has significant interdependencies with other government activities or the wider economy • addresses contingency planning or business continuity needs. The guidance details requirements for risk assessments to assess the vulnerability and adaptive capacity of the activity – it offers tools for climate change risk assessment, including decision trees. Real options analysis is offered as an options appraisal framework to incorporate the uncertainty of climate change and the value of flexibility into decision making. The Thames Estuary 2100 is included as a case study.	This advice identifies climate change factors for use in FCERM planning and appraisal, which covers river flow, rainfall, mean sea level, storm surges etc. It promotes a managed adaptive approach which it suggests 'would ensure a fairer and more flexible spread of public investment' than precautionary approaches which 'lead to greater levels of investment at fewer locations'. The advice recommends that sensitivity analysis should be undertaken across the range of plausible change over the life of the assessment and the identification of adaptation responses that may be required. The method presented follows through the steps of building on the assessment of current risks, assessing potential future sensitivities, identifying feasible options and refining options, followed by monitoring evaluation and review.

These guidance documents set out the justification for managed adaptive approaches and present a framework for how these should be appraised; however, they do not provide explicit advice on how to actually undertake the work required. Therefore, they have been taken as the platform for this adaptive capacity study, with the Supplementary Appraisal Guide intended to provide a useful additional guide for practitioners to value the benefits of adaptability.

3.4 Relevance to England and Wales

During the study period, several discussions were held concerning the degree to which the Supplementary Appraisal Guide could be applicable to both England and Wales due to the different guidance that applies. FCERM AG is only relevant to the Natural Resources Wales, with Defra project appraisal guidance (Defra 1999) still being used by other RMAs. In England, FCERM AG applies to the Environment Agency and other RMAs. It was agreed that, as the principles of The Green Book apply to both England and Wales and the Guide is firmly centred on the precepts of the Green Book, it should provide overarching, generic guidance which is equally applicable to FCERM appraisal in both countries.

The next three sections (Sections 4, 5 and 6) provide the evidence behind each element of the Guide.

4 Building adaptive capacity

4.1 Introduction

This section is concerned with ‘Building adaptive capacity’ and highlights the importance of underlying culture and mindsets, the defining the problem/opportunity stage of the Guide and objective setting. Monitoring and review is also briefly discussed in relation to the need to set out trigger points early on in the process, which indicate when adaptation is required.

4.2 Culture and mindsets

There is no specific guidance concerning changing mindsets and culture, but the Supplementary Appraisal Guide includes reference to the importance of stakeholder collaboration and engagement from the outset and findings in this section have informed references to stakeholder collaboration in the Guide.

4.2.1 Evidence

Part of the rationale for the study being commissioned was the need to change ways of thinking and address the constraints that are preventing the widespread adoption of managed adaptive approaches. This sub-section sets out the key evidence and issues from the two workshops and the case studies with regards to changing mindsets to enable more adaptive thinking and decision making.

Market analysis

The current FCERM appraisal guidance (FCERM AG) and FCERM plan guidance relating to CFMPs, SMPs and SWMPs include many references to the need to take an adaptive approach, but do not provide explicit guidance on how to build this into all stages of development and appraisal. The Supplementary Appraisal Guide is therefore intended to support FCERM practitioners and local stakeholders in:

- developing projects and plans that can be readily adapted to accommodate future change;
- justifying the choices made through an appraisal process that is able to explicitly account for the benefits and costs associated with embedding adaptive thinking.

Accepting and managing uncertainty is not easy, and while there are few arguments against the benefits of affordable and flexible solutions, there are difficulties with their justification, development, valuation and implementation in practice. Previous research has identified key barriers to the development and appraisal of adaptive approaches as detailed in section 1.2.

Working with uncertainty requires the development of responses that keep as many options open as possible; this means that required future levels of investment are also uncertain. In addition, the development of adaptive approaches comes at a cost; both in terms of the time and effort required developing such responses, and the costs incurred in the design and implementation of schemes which incorporate flexibility.

The changing (increasing) ‘benefits’ that may be accrued due to potential increased value of the receptors following provision of enabling FCERM infrastructure are not easily included within a conventional appraisal (under the rules of the Green Book). This narrow view is counter to an adaptive approach and the inclusion of socio-economic changes (e.g. future development and increasing economic vulnerability is a legitimate future uncertainty). Without such inclusion, distinctly different FCERM responses may be developed that are maladapted to future circumstances.

Figure 4.1 illustrates the importance of system thinking, a considered approach to handling uncertainty, and proper valuation and comparison of costs and benefits to ensure that adaptive approaches are developed and properly considered in appraisal.

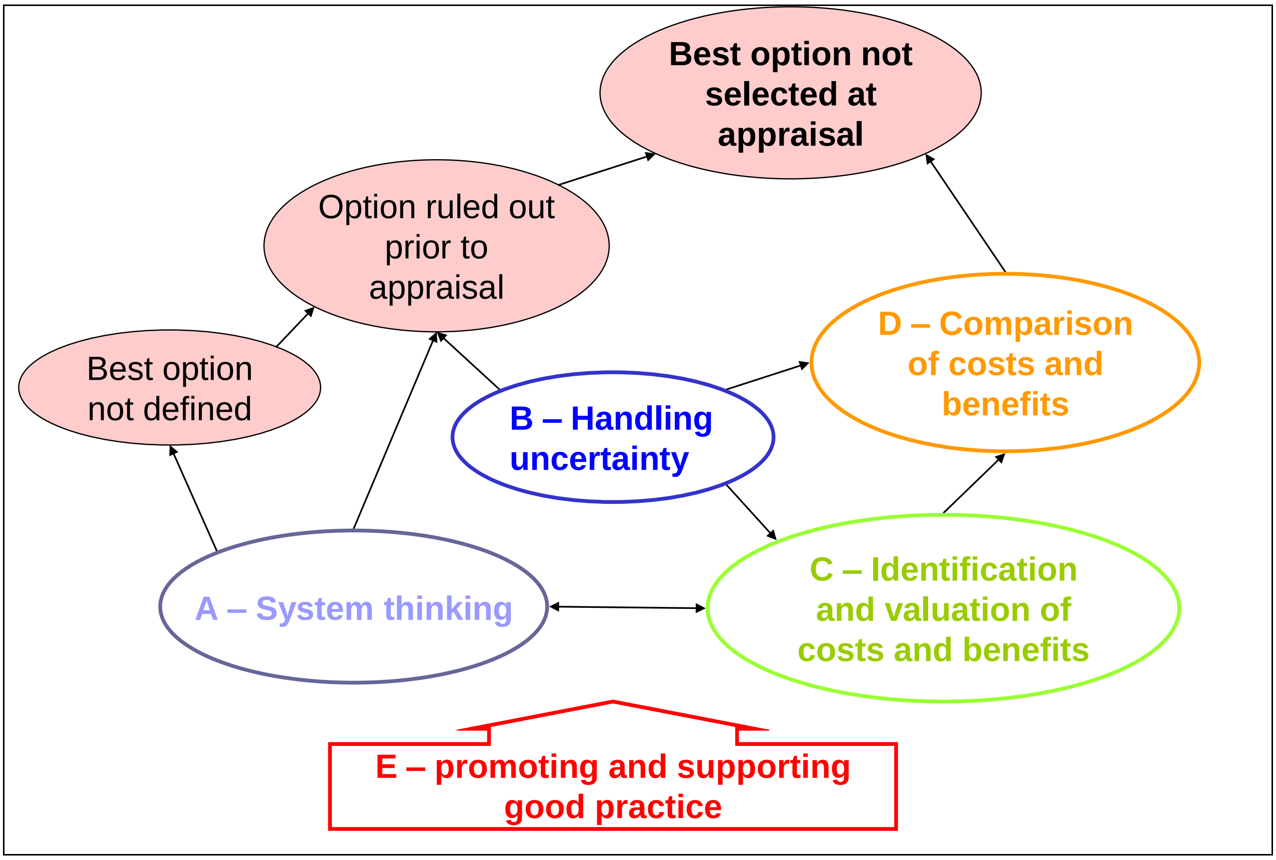


Figure 4.1 The cumulative impact of barriers to adaptation within appraisal (from Defra 2009b)

Users considered that any new guidance or approaches developed should enable practitioners to explore the economic justification for adaptive approaches, and should dovetail with existing approaches as far as possible rather than providing a totally new methodology. In addition, the provision of a non-prescriptive road map populated with examples was identified as an appropriate way forward. It was also suggested that the approaches examined should not be restricted to structural responses, but should include non-structural solutions such as land set aside for flood storage and land-use planning.

Overall, it was recognised that, while tools and approaches can always be improved, the more fundamental challenge is the need for culture change in the way that appraisal is conducted to facilitate more adaptive outcomes. It was suggested that this needs to be considered early on in the decision-making process during problem definition and objective setting to help embed adaptive thinking. Finally, while existing appraisal guidance does point towards the development of managed adaptive approaches, it is ‘too easy’ to follow the types of decisions that have been made in the past rather than having the courage to use all of the guidance and develop innovative, adaptive approaches. This project should inspire the right thinking and culture to improve awareness of what good adaptation looks like and broaden mindsets to consider adaptive approaches where they may previously have been dismissed.

Case studies

Key drivers for pursuing adaptive approaches differed between settings and contexts. In some cases, the main imperative was meeting the requirements of the most recent guidance on incorporating the impacts of climate change within FCERM activity, which promotes a managed adaptive approach. In others, particularly coastal examples, local stakeholders working with consultants recognised that an adaptive approach was the only cost-effective and feasible way forward. However, it was also clear that in some cases adaptive approaches have been adopted to put off decision making which is not socially or politically acceptable and save money (or avoid investing) in the short term. Local communities, and decision makers, tend to be focused on short-term, rather than longer term risks and costs. Thus, adopting an adaptive approach (particularly where this is seen as putting off a decision rather than a comprehensive, strategic approach) can be viewed as a delaying tactic. Conversely, in other locations, where long-term problems and solutions need to be faced and embraced, stakeholders have become engaged in the crucial issues and understood the need for adopting measures that can be adapted in the future according to coastal erosion or increased rainfall as a result of climate change.

The importance of supportive higher level strategies and plans (e.g. SMPs) cannot be underestimated. It is much easier to engage stakeholders in the development of adaptive approaches and sustainable solutions when the platform has been put in place for these by higher level strategic management plans. But it is also important to be aware that plans can preclude adaptive approaches if they promote a ‘locked-in’ approach.

A key point that was highlighted is the importance of timing. Securing interest and support for adaptive approaches is likely to be easier where there is evident flood and coastal erosion risk. However, where the future risk is significant and intervention can take years, or even decades, to be realised, then a proactive approach is needed some time before flood and coastal erosion risk and the defence system reach a critical point. The advantage of developing an adaptive strategy some time in advance is that it provides the freedom within the planning process to look further into the future, to some extent free of the immediate concerns. This promotes strategic thinking and the development of a flexible strategy. The crux of achieving an adaptive approach is that the strategy as a whole is flexible and responsive to future change; the individual constituent measures do not have to be. Building up a strong economic and financial argument for adaptive intervention over the long term is of key importance in securing support from a wide range of stakeholders.

One case study identified the main obstacle to taking a managed adaptive approach as the interpretation of guidance, which steers towards a precautionary approach and the strong culture in FCERM to design conservatively. Against this background, a managed adaptive approach was only possible through a combination of strong (political) pressure, a positive and proactive partnership and a project team that was prepared to challenge common practice and develop innovative approaches.

Market testing workshop

The market testing workshop, held in November 2012, identified the fundamental challenge in promoting adaptive approaches as convincing end-users and decision makers to support the concept. It is intended that the tools produced through this project and the following knowledge transfer programme should assist in achieving this objective.

4.3 Define problems and opportunities

4.3.1 Summary of guidance

This section was not originally identified as an area requiring additional guidance, but it became evident through the case studies and discussion at the market testing workshop that specific advice was needed at this crucial, early stage to discuss and consider adaptive approaches with stakeholders. Three specific issues are highlighted in the guidance: considering alternative futures, assessing the benefits of an adaptive approach and developing decision trees.

Considering alternative futures

The argument underpinning the requirement for adaptation is the need to develop approaches that can be adapted to uncertain futures, whether these relate to climate change, economic development, population growth and/or funding policy and security.

The Supplementary Appraisal Guide highlights the need to understand and collate evidence on the drivers of future change and then assess the potential impacts and opportunities should these changes be realised.

The Guide promotes the consideration of factors influencing decisions that are outside the control of the flood and coastal erosion risk manager. Appraisal can be made as simple as possible by choosing a small number of factors that (as far as possible) are independent from one another. However, in practice climate change, economic development, population growth and funding security are to some extent interdependent. Further research is required to investigate how best to identify, quantify and manage these uncertainties, and assess the impact of any interdependencies. Similarly, more research is required to assign weightings to different futures; currently, the example provided in the Guide applies equal weightings but makes reference to using UKCP09 climate change projections (Defra 2009c) as a basis for informing weightings. However, this only accounts for the climate change element of the identified future, The market testing resulted in requests for 'standardised' future scenarios to inform the futures (futures are made up of a combination of scenarios). These are already available via UKCP09, but not for other future uncertainties such as an increase in economic value or population change.

Assessing the benefits of an adaptive approach

The Supplementary Appraisal Guide is focused on providing support for the appraisal of managed adaptive approaches. However, it is recognised that these will not be relevant or appropriate in all cases (e.g. if the flood or coastal erosion risk situation is tightly confined to a specific location, responses are constrained by geography, technology or environmental impacts, or the flood or coastal erosion risk is so severe that immediate action is required).

The Guide includes a stage at the start of the appraisal process in which the benefits of a managed adaptive approach are assessed (against criteria such as the extent of competing interests and the significance of future uncertainty for decisions). This can then form the basis for capturing adaptability in the appraisal.

Developing decision trees

In this section, the concept of decision trees is introduced. These are an effective approach to considering future uncertainty. Decision pathways are built around the key trigger points which require decisions and potentially investments to be undertaken. The trigger points define when a decision must be made so that there is sufficient time for any of the potential interventions to be made.

Decision trees can help in visually presenting the impacts of specific decisions and assist with the development of long-term strategies. As a result of the future uncertainties it is not possible to decide a full pathway into the long term, say 100 years. Typically, strategies and plans concern the short to medium term. However, within these short/medium-term decisions it is essential to take account of the longer term implications.

4.3.2 Evidence

Evidence from the case studies and the market testing workshop proved the importance of including extra guidance for this first stage of appraisal as it sets out the foundations for why and how a managed adaptive approach is crucial to address future uncertainties.

Case studies

Case studies provided a key insight into the importance of this stage in terms of:

- Recognising the potential for future conflicting priorities and that the prominence of each of the main issues guiding decisions on land use and water management will change with time (e.g. carbon emissions reductions, food production and its reliance on oil, improving ecosystems).
- The importance of public engagement to convey the potential climate change consequences for environmental, economic and social issues covering, for example, the future flood or coastal erosion risk to communities, the impact on transport routes and the general use of an area plus potential conflicts between uses. In one area, for example, the dominant drive to protect against tidal flooding had led to a greater (short-term) risk of fluvial flooding. In such cases, it is important to recognise from the outset that conventional approaches to FCERM may not be sustainable given the increasing risk in the future.
- The need to look beyond immediate flood risk challenges to system-wide issues. Consideration needs to be given to the impact of addressing the probability and consequence of flooding and coastal change on the broader socio-economic and environmental value and development of areas. The definition of the problem leads to a strategic and sustainable FCERM response, which includes structural and non-structural risk management measures that are effective, environmentally sensitive and socially acceptable. The problem is not specifically flooding or coastal change, but the broader impact on the environment, society and the economy and should be addressed as such.
- Some case studies identified that, where flood risk or coastal erosion is immediate and has a threat to life, more constrained options may be appropriate to ensure that this can be managed as a matter of urgency. However, longer term solutions with broader objectives that are capable of future adaptation should also be investigated; these can be implemented as funding becomes available.
- Case studies identified the importance of appraising proposed responses in situations where flood or coastal erosion defences are already in place. In practice, schemes are rarely developed in areas where there is no existing protection in place, but defining the problem should not be constrained by the status quo. The automatic view may be that existing approaches need to be extended or increased in future, whereas adaptive approaches will only be adopted where there is a willingness to think more broadly and innovatively.
- In situations where significant multiple uncertainties are evident (e.g. funding (national and local), climate change and ensuing sea level rise and storminess) there could become a point where maintaining the line of defence is no longer sustainable in economic, social or environmental terms. This can have a fundamental impact on the area in question. In such situations, a managed adaptive approach is the only way forward (unless a large, potentially uneconomic, funding source can be secured) and, in general, stakeholders will accept this once presented with the facts.
- A detailed understanding of flood risk/coastal erosion extent, evolution and interaction of flood/coastal cells over time is required so that adaptive options can be matched to flood/coastal erosion risk as it evolves. In addition, establishment of water level/sea level/erosion triggers for management and intervention, and the associated lead-in times for various works is required.
- This stage should introduce the concept of decision pathways and decision trees as a way to visualise an adaptive approach/strategy. These provide a good method for presenting the impact of different decisions over a range of time periods depending on how future uncertainties are realised.

The case studies illustrated the importance of taking a broad perspective at this stage, considering multiple futures and not taking a limited or fixed view too early in the process. The case studies also highlighted that some situations will be very constrained by nature/severity of flood risk, technical, location or environmental issues and existing flood defences. In these cases, only a fairly narrow definition of the problem is possible, which also leads to a limited choice of options.

Market testing workshop

Three key issues were identified at the workshop, which largely reflect points highlighted by the case studies. First, is the need to consider other uncertainties as well as climate change (e.g. population growth/demographics, food security) recognising that specific future uncertainties impacting on an area are context specific. Second, identifying autonomous and independent futures is difficult; although not within the scope of this project, additional guidance on defining futures was requested. Assigning weights/probabilities to specific futures informed by their component scenarios was considered to be particularly challenging. Defining future weights in an informed but qualitative manner was the preferred approach. Finally, it was noted that the development and communication of decision trees requires a change in mindset. Specific guidance was also requested to assist with the construction of decision trees.

Market testing of draft guide

Several ‘testers’ highlighted the need for greater clarity with regards to the applicability of the guidance to different types of projects to ensure proportionality and that small, straightforward projects are not subjected to complex consideration of multiple futures etc. This is set out in Figure 3.1. In addition, testers also called for further guidance on futures including the inclusion of standardised versions, which should be considered an area for further research to inform a future update of the Guide. Finally, testers recommended that the linkage between the development of non-structural approaches and the land-use planning system should be highlighted.

4.4 Set objectives

4.4.1 Introduction

The way in which objectives are set fundamentally influences the way that plans and projects are developed and implemented. In recent years, FCERM objective setting has been extended to include a range of risk-based outcomes: economic, environmental and social. In turn, this has driven the development of more rounded risk management and promoted the move away from simply flood defence. Equally, adaptation can only be accounted for in the appraisal process if objectives are set that promote flexibility and embrace the notion that the future will be different from today.

4.4.2 Summary of guidance

The guidance focuses on ensuring that objectives are set which facilitate and encourage the development of adaptive responses, where possible/appropriate, and do not preclude them. To embed adaptation more meaningfully within the project objectives it is suggested that the existing approach is extended to explicitly consider promoting long-term sustainability, adaptation and resilience. In essence, this means ensuring that objectives promote sustainability over the whole appraisal period under the alternative future storylines, are effective under the widest set of all plausible future uncertainties and do not unnecessarily constrain future choice, and are able to withstand a range of threats and recover (rapidly) from a disruptive event.

Example objectives are provided which enable and promote the development of managed adaptive approaches; examples are also provided of objectives which could preclude adopting such approaches.

When monitoring progress against objectives, it is important that embedding the potential for adaptation is articulated in the indicators that are selected.

4.4.3 Evidence

There has been considerable discussion throughout the study period between the Project Team and with stakeholders (e.g. at the market testing workshop held in November 2012) as to whether objectives should explicitly encourage an adaptive approach, or whether these should have a broader focus (e.g. achieving sustainable flood management). The latter has been agreed as the recommended way forward with example objectives provided; the key principle is that objectives should not preclude an adaptive approach, but do not need to explicitly prescribe one.

Case studies revealed that an iterative approach to setting objectives developing initially from the various high level plans, legislation and policy was a logical way forward. This involved developing objectives that reflected strategic imperatives which focus on local problems and opportunities. Objectives can then help shape options to test public opinion concerning the potential use of specific areas.

In one example, early stakeholder engagement highlighted the importance of exploring managed adaptive approaches when developing objectives. This stage involved identifying the triggers for change and developing initial versions of decision trees. Partners and stakeholders were very receptive to these ideas and contributed to their development. This scoping stage was essential to embedding a managed adaptive approach.

Overall, the case studies and market testing demonstrated the crucial importance of considering FCERM as part of the wider sustainable management and development of areas which inherently supports an adaptive approach. Objectives which are outcome rather than process focused should ensure that adaptive approaches are facilitated and not precluded.

The final market testing responses suggested that the section should be substantially reduced and focus on highlighting the aspects of adaptive objectives and providing examples.

4.5 Monitor and review

4.5.1 Introduction

No specific guidance has been included in the Guide concerning monitoring as this is covered sufficiently in existing FCERM plan and project guidance.

4.5.2 Evidence

Case studies were unanimous in highlighting the importance of monitoring trigger points to ensure that adaptive approaches can be implemented when and where appropriate. Such trigger points vary depending on, for example, physical points on the ground reached by coastal erosion requiring a different approach, performance of existing flood defence infrastructure (e.g. number of times flood barrier put in place) and new information becoming available regarding climate change projections, economic growth and development, and/or funding regimes and availability. Investigating and identifying trigger points at an early stage in the process will give reassurance to stakeholders that appropriate action will be taken at the right time.

The Thames Estuary strategy (TE2100) identified a monitoring and ongoing re-evaluation process. The monitoring process provides the triggers to the decisions in the pipeline. For example, if monitoring reveals that climate change is happening more quickly (or slowly) than predicted then the strategy can be reappraised in the light of new information and options can be brought forward (or put back). Clearly, some decisions will require considerable lead-in time prior to implementation. The lag time between 'deciding to intervene' and the delivery of change in the management was considered, allowing for up to 30 years for major decisions to come to fruition. The indicators identified covered mean sea level, peak surge tide level, peak fluvial flood flows, condition of flood defences, frequency of closure and reliability of barriers, developed area and value/type of development, extent of erosion/deposition, intertidal habitat areas including mudflat and saltmarsh, land-use planning and development activities and public/institutional attitudes to flood risk.

Three key areas were highlighted; however, it was considered that these should be included within the 'Define problems and opportunities' section of the Guide as they are more relevant to this earlier stage of the process, rather than within any specific guidance concerning the process of monitoring:

- Importance of identifying trigger points at an early stage in the process.
- Trigger points are context specific, but are likely to focus on the condition of defences, external conditions (climatic, environmental and socio-economic), points reached on the ground or a combination of all three.
- The importance of keeping up to date with predictive modelling and the need to be prepared to intervene before defences fail – rather than waiting until this actually occurs. This should prevent immediate reactions to events with responses that are not within the agreed suite of actions.

4.6 Summary and areas for further research

Defining the problem is a crucial stage. Investing resources, time and stakeholder commitment at this time is required to establish the platform to develop adaptive responses. Trigger points and monitoring indicators should be identified at this early stage to ensure that appropriate action is taken when required.

Explicitly adaptive objectives are not required; appropriate objectives are likely to be broader and addressing strategic flood management. However, in setting objectives, it is essential to ensure that they do not preclude the development of adaptive approaches.

Monitoring is an essential element of ensuring the development, appraisal and implementation of adaptive approaches, but **no detailed advice is required regarding the monitoring process** as that contained within existing appraisal guidance is sufficient providing the requirements have been set out early on.

Two specific areas for further work have been identified: first, the need for additional research on identifying credible alternative futures and investigating the potential to develop 'standard' futures that help ensure adaptive solutions. Further work on assigning weights to these and assessing the interdependence of futures was also requested. The synthetic case study (presented in Appendix A) provides additional insight into this area, but further work is required to translate this into user-friendly guidance for practitioners. Finally, further advice and practical examples are required to assist practitioners in developing decision trees, particularly for more complex situations.

There is also a potential research question surrounding whether there is a need for FCERM funding arrangements to provide incentives for adaptability, if it is considered that there is some market or institutional failure surrounding adaptive approaches being given proper consideration. More work to understand whether there is a national rationale to correct for any such failures through funding arrangements could be beneficial.

5 Developing managed adaptive approaches

5.1 Introduction

This section summarises the Guide content provided in relation to developing managed adaptive approaches, specifically the generation and then screening of options, and provides the justification for and evidence underpinning the content of the guidance.

5.2 Option generation

5.2.1 Summary of guidance

A key driver for this study was the limited adoption of managed adaptive approaches, in part due to the FCERM industry having difficulties in visualising exactly what these are and how they operate. The advice concerning the generation of options assists by identifying attractive attributes of adaptive responses which should help ensure (although does not guarantee) that the associated option is resilient to future change or capable of modification. Terminology is important here, in that the option consists of a package of measures; individually these measures do not have to be adaptive – it is the overall process in which they are implemented, through the identification of trigger points, that is adaptive.

The list of attractive attributes is shown in Table 5.1, and examples of adaptive options are also provided for information.

Table 5.1 Attractive attributes for managed adaptive options

1) **Reducing vulnerability**:
    - Consideration 1a: Have all reasonable opportunities to reduce vulnerability been taken?
    - Consideration 1b: Have steps been taken to limit future increases in vulnerability?
    - Consideration 1c: Has a full examination of the range of futures identified the potential for a significant increase in risk requiring a radical approach to managing the receptors?
2) **Making space for water**:
    - Consideration 2a: Have opportunities to make space for water and function been maintained/ enhanced?
    - Consideration 2b: In making space for water, can the scale of the receptors at risk be reduced?
3) **Delivering co-benefits and co-funding:**
    - Consideration 3a: Have opportunities for present day co-benefits and co-funding been enhanced?
    - Consideration 3b: Have opportunities for future benefits been maintained/enhanced?
4) **Building in flexibility:**
    - Consideration 4: Does the option include the potential for future modification?
5) **Deferring/removing or abandoning**:
    - Consideration 5a: Could it be removed/stopped with minimum impact on resources and the environment?
    - Consideration 5b: Can investment be delayed without an intolerable build-up of risk or forgoing of current opportunities?

5.2.2 Evidence

Case studies

A key finding from the case studies was the need to develop a package of options (structural and non-structural) that overall constitute an adaptive approach depending on when they are instigated. These should be developed with stakeholders in order to enable ownership/co-production of options and be informed by a comprehensive understanding of the socio-economic and environmental pressures on the area and consideration of a wide range of potential responses.

In one case study, a long-list of options was developed within a process of exploring how the system might respond under different management approaches. The emphasis was on explaining and demonstrating to stakeholders how the system could be managed in different ways. The process was designed to engage people so that issues not previously considered could be identified in discussion and to ensure that the fundamental differences in management type would inform the understanding of the choices being made. Implicit within the approach was that alternative options might emerge and that people were not being asked to make a decision concerning any specific option, but that they were given the opportunity to discuss future management within a realistic scope of options. Such an approach allowed consideration of options that may otherwise have been rejected out of hand. Embodied within the approach to identifying structural options was the consideration of how different structural approaches might require associated non-structural measures. This includes public awareness, improving the resilience of properties to flooding, improving flood warning, improving emergency planning, upland catchment management, sustainable drainage systems and development planning.

Conversely, another case study highlighted the issue that, in some situations, options can be limited by the local geography and the nature of flooding, particularly where the latter is severe and the key driver is to raise the standard of protection. In such situations, broader catchment style and wider sustainability type approaches are unlikely to be developed in the short term.

Finally, in a truly adaptive approach, particularly where futures can be defined by points on the ground (e.g. specific locations that may be affected by coastal erosion), trigger points can be identified upfront which necessitate decisions and potentially investments to be undertaken. The trigger points define where a decision must be made to ensure there is sufficient time for any of the potential interventions to be realised. These trigger points then determine the specific options that could be implemented in the future.

The attractive attributes of adaptive options were considered in relation to the process used to identify options in one specific case study. Key recommendations are summarised below:

- The first attribute concerning the reduction of vulnerability originally stated explicitly that this should be done in preference to providing protection. However, the case study exercise revealed that adaptive options could include protection measures and therefore the reference to 'in preference to providing protection' should be removed.
- There is potential to increase the scope of the desirability of making space for water to making space for function.
- When considering funding, it was suggested that there is no guarantee that options which are funded by multiple partners would be more adaptable to changes in funding priorities compared with those funded by a single source. It is possible that some potential alternative funding partners may require options that are less adaptable than others. However, considering the opportunities for funding from multiple sources is sensible in developing long-term responses; options that deliver multiple benefits for different stakeholders rather than completely satisfying an individual stakeholder are most likely to be adaptable to future funding changes. A natural integration of FCERM within multiple agendas including planning and ecosystem services provides an assurance that at least some benefits will continue to be developed 'no matter what happens'. These types of schemes will tend to look

at wider agendas and will facilitate discussions concerning solutions that are changing the status quo.

The key issue is the importance of setting options in the framework of a managed adaptive approach. The flowchart that was originally developed in relation to attractive attributes suggested that each of the attributes needed to be met, rather than should be encouraged as far as possible. In one instance, this approach was considered as a potential constraint to developing options (as each option did not meet all of the attributes), which is not appropriate at the stage of developing a long list. Therefore the case study suggested that the flowchart questions would be better used as a series of prompts to encourage the project team to consider alternative options and bring in or retain those which incorporate adaptability.

Market testing workshop

Feedback from the market testing workshop reiterated the point that the proposed flowchart should be used to ensure an overall package of options that includes some which are adaptive – it should not be a requirement that each option is adaptive.

Market testing

Some responses suggested that the checklist approach could be more appropriate for scrutinising rather than generating options. It is suggested that each option considered should then be assessed against the attributes to identify if it could be made more adaptive. An interesting point raised was that non-structural options may not be deliverable under a FCERM-based plan as traditionally such plans are related only to the management of defences not land-use change. This reflects back to the need to change mindsets; there is no reason why FCERM plans should not include non-structural options and this comment firmly reasserts the need for the Supplementary Appraisal Guide.

5.3 Option screening

5.3.1 Summary of guidance

The guidance suggests that the attractive attributes used to generate options can also be applied to help screen out (or indeed screen in) options following feasibility screening, and short listing. The attributes can also be used to help refine options to make them more adaptive. The attributes can be employed as a qualitative discussion tool, used to supplement the appraisal summary tables (ASTs) or used to undertake a more quantitative assessment. The latter allows a graphical presentation of the relative merits of all options with their range of uncertainties and is summarised in the section below.

5.3.2 Evidence

The screening of options, and the best approach to be employed, has been discussed at length within the Project Team, with the Project Board and with stakeholders via the market testing workshop. The final guidance highlights how the 'attractive attributes' can be used to help identify which options have more or less potential for future adaptation. It is not suggested that this approach is used to knock out options or select the 'best' one – its intent is discussion not decision making. At the very least, consideration should be given to the adaptability of proposed options alongside other screening considerations. However, this can also be undertaken through a more detailed, quantitative approach, such as that set out in Box 5.1. The performance of option attributes can be represented diagrammatically – a spider diagram can be a useful visual aid – which can be used as a discussion tool with stakeholders.

Box 5.1: Option screening: proposed quantitative assessment approach

Option screening and development

This option screening approach can assist in identifying which options are most adaptive; helping the FCERM planner to both develop and shortlist those options that should be taken forward into more detailed appraisal analysis. The idea is to assess the relatively wide range of options generated in terms of not just conventional criteria (e.g. cost, potential future flood/coastal erosion risk reduction etc.) but also a number of other criteria which promote the concepts of resilience and adaptive capacity. These criteria should reflect the previously identified attributes of adaptive approaches.

The option screening tool is based on the multi-criteria decision analysis (MCDA) approach. More specifically, the compromise programming MCDA method (Cochrane and Zeleny 1973) is used to perform the ranking of options given criteria. This is a well-known MCDA method and has been selected here because of its generic nature, simplicity, transparency and robustness in use.

The option screening analysis starts by providing the following data in the tool:

- **List of options to be screened and ranked.** For each option considered, the option name/identifier and a brief description need to be provided. The list of options should be generated using the methodology set out in relation to this stage, given a specific FCERM problem. Note that the generation of options is likely to be location specific; hence there are no pre-specified options in the tool.
- **List of criteria that will be used for initial screening**, i.e. ranking, including criteria name/ID, units, criteria weights (used to express user preferences) and the information on whether the given criterion values are being maximised or minimised. Note that, unlike in the case of options, the tool comes with the number of predefined criteria which we believe should be considered during the initial screening (see above). Having said this, if the user does not want to use some of these criteria, all he/she needs to do is set the respective criterion weight value equal to zero. Also, in addition to the predefined criteria list, the tool enables the user to specify a limited number of additional criteria that he/she considers important for the specific plan or project analysis. Note that the list of criteria specified should be, as much as possible, appropriately exhaustive (reflecting all the meaningful considerations) and mutually exclusive (thus avoiding embedding a bias through undue weighting to the same issue).
- **The decision matrix values** (see Table 5.2), i.e. the value of each criterion for each option analysed. Note that these values should ideally come out of some preliminary engineering analysis but, if this is not possible, engineering judgement/experience and/or past data can be used too. Note that the tool does not require specifying the absolute criteria values – what matters are the relative criteria values between different options. For example, assuming that detailed cost data is unlikely to be available at the screening stage, the user may provide indicative costs for different options, either in monetary units (based on past projects/experience) or simply as a categorical number (e.g. on scale 1 to 10, 1 being the lowest cost, the cost of this option is 3 etc.).

Table 5.2 Decision matrix

	Criterion 1	**Criterion 2**	**...**	**Criterion M**
Option 1	X_{11}	X_{12}		X_{1M}
Option 2	X_{21}	X_{22}		X_{2M}
...				
Option N	X_{N1}	X_{N2}		X_{NM}

Once the above data is provided, the ranking of options is performed based on the distances calculated for all options considered. Distance D_i represents the distance between the i^{th} option criteria values and the so-called ideal point (where all criteria values are at their ideal, i.e. best possible values). This distance D_i is calculated as follows:

$$D_i = \left[\sum_{j=1}^{M} w_j^p \tilde{X}_{ij}^p \right]^{1/p} \quad \text{(i=1,2,...,M)}$$

where:

p	norm order (default value of 2 used representing the Euclidian norm)
$\tilde{X}_{ij}$	normalised X_{ij} decision matrix value
w_j	normalised j[th] criterion weight.

The normalised criteria values are calculated as follows:

$$\tilde{X}_{ij} = \begin{cases} \dfrac{X_{ij} - X_{\min,j}}{X_{\max,j} - X_{\min,j}}, & \text{if j-th criterion is minimised} \\ \dfrac{X_{\max,j} - X_{ij}}{X_{\max,j} - X_{\min,j}}, & \text{if j-th criterion is maximised} \end{cases}$$

where X_{ij} are the original decision matrix values specified by the user and $X_{\min,j}$ and $X_{\max,j}$ are the smallest and largest criteria value for the j^{th} criterion. The normalisation ensures that smaller distances are obtained for criteria values closer to the ideal ones irrespective of whether the given criterion is minimised or maximised. Note that the option screening tool can be used to identify robust options by selecting those which are constantly ranked high irrespective of different user preferences (i.e. different criteria weights).

Undertaking this assessment in Excel can then produce a spider diagram (see Figure 5.1), which is helpful in visually displaying the relative strengths of different options:

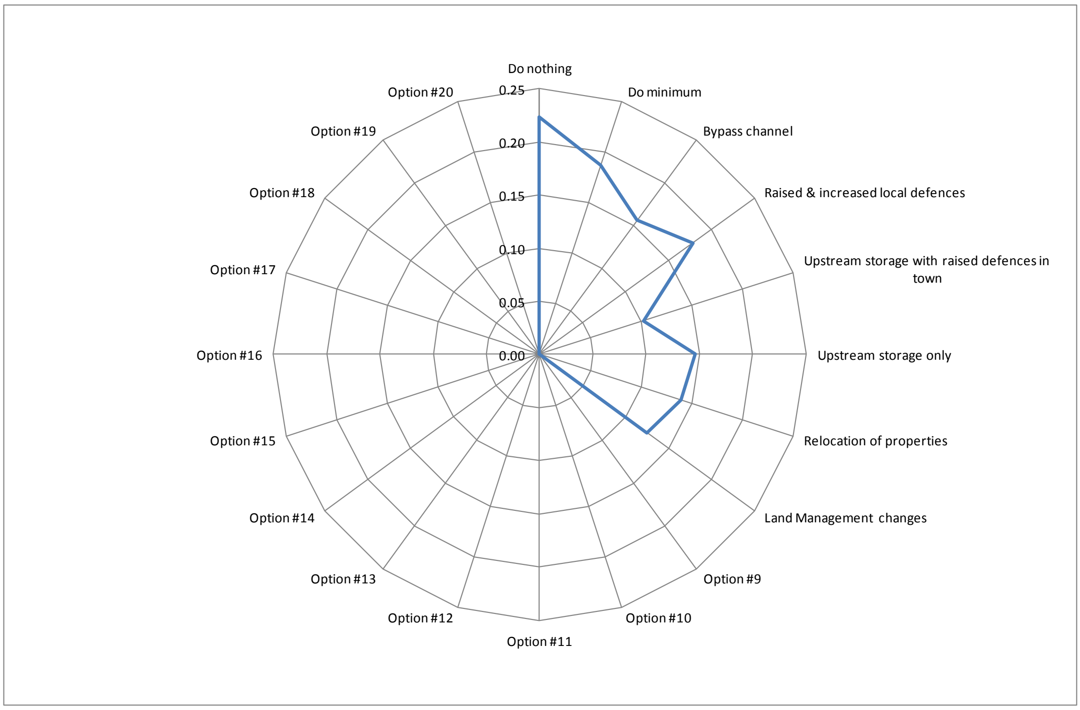


Figure 5.1 Results from option screening exercise

This option screening approach should be used only as a support tool in making decisions on which options to develop further and take into more detailed appraisal. The FCERM planner should, in addition to using this tool, consider other, qualitative-type criteria. The findings from this type of analysis could supplement the information currently provided in ASTs to assist in deciding which options to take into the full appraisal. A prototype tool built on the above calculations has been developed.

5.4 Evidence

Case study experience

The case studies' experience of option screening tended to focus on screening out those options that were unviable, rather than considering those that could be more appropriate than others, as has been suggested by the MCDA tool. However, screening out options on viability grounds can lead to removing adaptive options early on in the process before they have been given thorough consideration. Therefore it is suggested that the consideration should be given to adaptability at the short-listing stage along with the consideration of more ‘knock-out’ criteria such as economic viability or social/political acceptability.

This issue also caused some confusion among case study consultees – was the MCDA tool intended to screen options out or develop them? One case study suggested that for the appraisal of plans a judgement based process supported by the assessment of the options against appraisal criteria using appraisal summary tables (ASTs) and strategic environmental assessment (SEA) was more appropriate.

The options developed by two of the case studies were assessed using the option screening tool (see Box 5.1) to investigate whether it would have assisted the decision-making process. Findings from this exercise are detailed below:

- A significant amount of thought is required to develop meaningful scores for each of the categories. As relative scoring is proposed for all variables other than indicative cost, the use of the tool becomes very subjective.
- The approach of distilling the assessment of options into numerical ranking could be interpreted as providing a ‘correct answer’. This could then have the potentially detrimental impact of constraining rather than promoting adaptation. This shows the importance of how the tool is used. It is suggested that the ranking and development of the spider diagram should be undertaken with stakeholders to help communicate how well individual options perform, thus demonstrating their relative adaptability. It should not be used as a decision-making tool that highlights the correct answer to addressing problems or maximising opportunities in a particular location.
- It was suggested that specific adaptive attributes (potential for unforeseen consequences, degree of reduction in vulnerability, security of funding, degree of buy-in, degree to which removable/stoppable with minimum impact) could be incorporated into the screening stage. However, a MCDA tool was not universally welcomed although some stakeholders interviewed could see the benefits of using such a tool at the options screening stage.

At the market testing workshop, some concern was expressed regarding the potential use of the option screening MCDA tool and duplication/overlap with the approach currently used via ASTs. It was suggested that the additional ‘adaptive’ criteria could quite easily be treated as supplementary to that in the ASTs. The final decision was that the MCDA spreadsheet should not be included as a part of the core guide, but referenced as a possible broader approach that could supplement the intelligence provided within ASTs and/or be used as a communication and discussion tool. Market testing resulted in the suggestion that the screening criteria should be reduced to a smaller number (e.g. three) and then be used as a check following the usual viability screening.

The Supplementary Appraisal Guide is non-prescriptive; it stresses the importance of considering the potential adaptability of options at the screening stage, but this can be achieved through a variety of approaches – a discussion with stakeholders or the use of a detailed MCDA tool. The key issue is that adaptability should be considered at this stage.

5.5 Summary and areas for further research

While some **individual measures may be adaptive, this is not a requirement in itself**. The key issue is that the overall approach and process for implementing measures – the overarching option or strategy – is implemented in an adaptive manner.

The case studies highlighted that the recommended MCDA spreadsheet approach to assist option screening could be viewed as a simplistic way of identifying a ‘correct’ solution that had been recommended as a result of subjective assessment. This view was also reflected at the stakeholder workshop held in November 2012 to test the guidance and tools under development. However, the Project Team consider this has some value provided that it is promoted and used in the correct manner – as **an aid to discussion concerning the adaptability of individual measures and options,** rather than as a scoring and decision-making tool.

Practitioners and decision makers could be assisted in using the MCDA tool through the **provision of additional guidance concerning the scoring and weighting** of individual variables.

6 Valuing adaptive capacity

6.1 Introduction

The future is uncertain over the decadal timescales typically involved in appraising flood management plans. As a result, it is essential that future changes in flood and coastal risk are appropriately assessed. To assess future risk, options that are being considered now can be evaluated under a range of future scenarios. In planning for an uncertain future, it may be advantageous to retain flexibility when making investment decisions. This flexibility represents adaptive capacity (i.e. the potential to bring in future adaptation) and promotes robust solutions that are resilient to future change.

The purpose of option appraisal is to enable shortlisted options to be evaluated in more detail leading to the selection of the preferred option for investment. The appraisal is undertaken on a whole-life basis, using discounting to calculate the net present value (NPV) of these options. However, using the existing appraisal processes to represent the performance of alternative options under a range of alternative futures is difficult. To fully evaluate the benefits of an adaptive approach requires an additional appraisal, which does not focus on the options, but the merits of particular decisions at certain points in time that allow a greater or lesser degree of adaptability.

Existing appraisal guidance does not explicitly take account of the value added by considering flexibility in the decision-making process and therefore does not currently incorporate this potential contribution to adaptive capacity. However, the FCERM AG includes some guidance about accounting for future change and uncertainty, based on the use of decision trees and the application of real options analysis. This provided the starting point for development within the project. Specifically, the FCERM AG suggests:

If possible, you should consider managed adaptive approaches as these are typically better able to adjust to differences to the predicted increases in risk. This is because delaying certain actions provides the opportunity to better respond to future changes as they happen, rather than trying to predict them and respond in advance (as would be required when using precautionary approaches). They may also be economically more attractive as costs can be spread over longer periods of time.

The appraisal guidance recommends early identification of the potential for flexibility at the options identification stage and the use of scenario tests to take account of climate change uncertainty. We suggest that this should be undertaken earlier – at the ‘Defining problems and opportunities’ stage.

Although the existing guidance provides illustrations of principles, the methods or tools needed by the practitioner to evaluate adaptability under future uncertainty are not elaborated further. In the Green Book supplementary guidance (HM Treasury/Defra 2009), references are made to the real options approach and an idealised case is used to illustrate the approach. However, this is felt to be overly simplistic and does not really assist the flood and coastal erosion risk manager or appraiser in assessing the economic value of an adaptive approach.

Market testing reported in section 3 revealed that there remains a gap between the concepts outlined in the Green Book supplementary guidance and the application of those concepts. This section introduces some further approaches that can be used to help bridge the gap and reports on progress made in trialling these ideas and the remaining difficulties and limitations that have been identified.

6.2 Characterising future uncertainties

6.2.1 Alternative futures construction

Of the many external factors that affect flood and coastal erosion risk, three in particular have been identified as relevant in most situations (recognising that the relevant drivers for individual locations will always be context specific). These are:

- potential change in climate and its impacts (flows, sea levels, waves);
- economic growth, or decline;
- funding security.

All three factors are largely outside of the control of the flood manager, and hence are referred to as 'autonomous'[3]. There could be a very wide range of uncertainty about each factor, and about the way in which changes might occur in combination between the factors. In this situation, it is useful to adopt a scenario analysis approach, where a number of alternative futures are created to be representative of uncertainty about the future. These futures are developed from a combination of scenarios covering, for example, climate change, economic growth and funding security.

While scenario analysis has been used in FCERM (for example in the Foresight project, (Defra 2004) there is no common standard set of scenarios available. Hence this project has included in its draft guidance some suggestions about how suitable autonomous futures may be defined. For example, Table 6.1 shows assumptions that could be used to form six autonomous futures.

Table 6.1 Six illustrative autonomous alternative futures

Climate change (increased river flow)	**Increase in economic value**	**Funding conditions (availability of Partnership Funding)**
20% increase in flow	None	No local contributions
10%	None	No local contributions
5%	None	No local contributions
20%	30% increase in value of properties on the flood plain	Local contributions @ 20% of total costs
10%	30% increase in value of properties on the flood plain	Local contributions @ 70% of total costs
5%	30% increase in value of properties on the flood plain	Local contributions @ 20% of total cost

It has been recognised through the project workshops, and final market testing, that users involved in appraisal studies would welcome additional support in determining a suitable set of alternative futures, possibly including development of standardised data that could be applied by any user.

6.2.2 Benefits calculations

Alternative futures influence the appraisal calculation by modifying the benefits (damages avoided) that are anticipated for any given investment pathway.

For example, if an investment were made to raise flood defence standards to counter a 20% increase in river flows, then under a future of climate change adding 20% to flows, plus a 30% increase in value of properties on the flood plain, the benefits would increase to account for damage avoided at those properties.

[3] Note that the term 'autonomous' refers to 'all future developments which are not purposefully influenced by flood risk management measures and related policy instruments' (de Bruijn et al. 2008). Care should be taken not to confuse this usage, relating to external changes, with the separate concept of autonomous adaptation, referring to adaptation that occurs without the need for deliberate intervention.

In practice, proportionality is important. In a detailed study, the benefits obtained under each future should therefore be derived by modelling. However, as a short-cut for sensitivity testing, it is suggested that benefits under one scenario are evaluated and then a multiplier used to represent the effects of other futures.

6.2.3 Use of probabilities – scenarios

There are some subtle and sometimes difficult issues surrounding the meaning and interpretation of probabilities when considering uncertainties about the future. A common understanding of probability is that it describes the frequency with which an event or outcome is expected. This can be interpreted, for example, as relating to the counts of observations within a sample, or to rolling dice.

However, this is not the interpretation of probability that applies to the UKCP09 climate projections (Defra 2009c). In the UKCP09 projections, probability is not an objective measure of how often a particular outcome is or would be expected to occur under repeated trials or observations (such as the probability of obtaining a six when rolling dice). Rather, it is seen as the relative degree to which each possible climate outcome from a large ensemble is supported by the evidence available, taking into account current scientific understanding of climate science and observations (Murphy et al. 2009). If the evidence changes in future, so will the probabilities.

Such probabilities relating to changes in an unknown future are sometimes referred to as 'subjective' in that they incorporate some subjective judgements about model choices (e.g. which climate model codes to use), model structure (e.g. which equations to include in the model code), and uncertainties about model parameters or coefficients (both for present and future states of the world). It is important to note that although there is an element of subjectivity in these choices, they are not arbitrary in the sense that the choices reflect scientific knowledge and experience.

It is, therefore, very difficult to allocate probabilities based purely on subjective assertions by stakeholders. In the particular case of the UKCP09 projections, it is important to note that the probabilistic analysis also includes some use of climate observations to constrain the model predictions.

It is therefore recommended that if probability weights are to be used to represent climate uncertainty then the UKCP09 weights should be used, and **not over-ridden by stakeholder judgements**. Probability weights that are not supported by peer-reviewed scientific evidence like the UKCP09 reports will be open to challenge when appraisals are being reviewed.

No weighting is applied to the choice of greenhouse gas emissions scenario in UKCP09. The differences between emissions scenarios in the UKCP09 projections are small compared with the range of uncertainty about the modelling, at least until beyond the 2050s. For the purpose of flood appraisal, discounting at HM Treasury rates means that cash flows far into the future contribute less to the NPV or benefit cost ratio (BCR) than those over the next 30 years or so (at standard Treasury discount rates the cash flows 30 years into the investment are multiplied by 0.36, and at 50 years by 0.23). Therefore, the influence of alternative emissions scenarios is considered of secondary importance.

Flood risk information derived from UKCP09

Information for non-probabilistic analysis: There is existing guidance available to help in defining scenarios suitable for use in FCERM. The Environment Agency's climate change advice (2010c) provides a standard range of projections for peak river flows in England (broken down by river basin district and for three future time horizons) and for sea level rise. The Environment Agency also provides a package of information[4] about other parameters relevant to local flood risk, such as seasonal and extreme rainfall projections and guidance on how

[4] Climate change tools to support local flood risk management strategies, available from http://www.environment-agency.gov.uk/research/planning/135749.aspx.

these information resources can be applied pragmatically to assess the influence of climate change on flood risk.

Probabilistic information: The projections for changes in peak river flows can be found in the form of distribution function graphs in the outputs of recent Defra research project FD2648 (Defra 2011a). An example of the information is shown in Figure 6.1 for changes in the 1/20 annual exceedance probability (20-year return period) peak river flow for catchments typical of each river basin district. The Defra (2011a) report provides more explanation and detailed results for river basin districts and flow return periods.

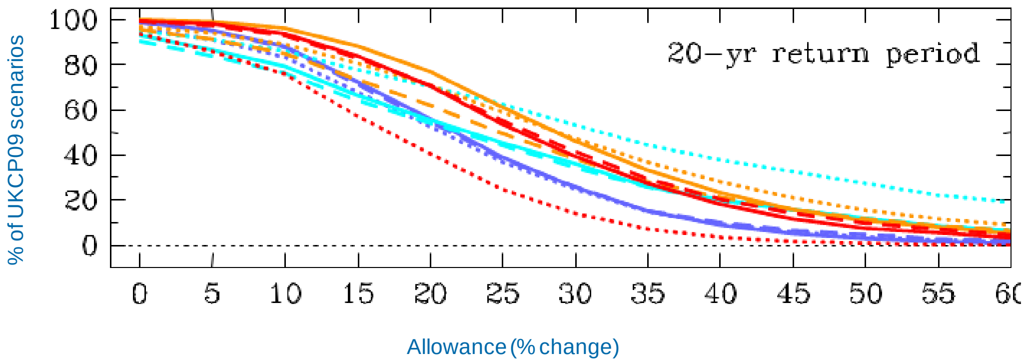


Figure 6.1 Distribution functions for typical catchments in each river basin district (coloured lines) giving the percentage of UKCP09 climate probabilistic projections for which a given peak flow change factor 'allowance' would be exceeded

For sea level rise the UKCP09 marine projections (Lowe et al. 2009) give uncertainty ranges, and Ranger et al. (2010b, Annex B.1.i) give an example of the use of these ranges with assumed probability distributions fitted to the UKCP09 ranges.

Other scenarios

Where stakeholders wish to express beliefs about the relative weighting associated with scenarios involving factors other than climate, then these weights should not be treated as fixed, but used only to explore the sensitivity of the appraisal to changing assumptions about the weighting. Evidence may be available to justify the range of uncertainties tested for demographic or economic growth. Where uncertainties are genuinely severe, then it is more appropriate to report the range of results under differing future assumptions and seek to extract some insights about sensitivity and robustness.

6.2.4 Use of probabilities – futures

In a formal framework for adaptation decision making in the UK, set out by Ranger et al. (2010a), there is a distinction to be drawn between situations in which decision makers have access to probabilistic information about future changes, and those in which they do not. The framework presented in the Ranger et al. study is used as a basis for the method developed in this report.

For adaptation studies in the UK, there are probabilistic climate projections available from UKCP09, which are discussed in more detail below. It may be more difficult to obtain probabilistic information in relation to the other factors influencing future flood risk decisions.

Whether or not probabilistic information is available has important implications for the choice of methods used in the appraisal analysis. Consider a case where the decision maker wishes to appraise a proposed flood defence investment plan with known costs under (say) ten futures. For each of these ten futures, assume that a model of the flood defence system has been used to establish the benefits in terms of avoided damages that would accrue from the investment. Knowing the investment costs and the benefits streams under each future, the decision maker can calculate economic performance according to the usual Green Book methods, for example in terms of NPV or a discounted BCR.

In this situation, it may be useful to summarise the results by calculating the average of the NPV or BCR values over the ten futures. Statistically, this would be referred to as the decision-maker's **expectation** of the economic performance. For example, for NPV the arithmetic mean, or expected value can be computed as:

$$E(X) = (1/10)X_1 + (1/10)X_2 + \ldots + (1/10)X_{10}$$

where X_i is the economic performance in the i^{th} future. Note that the performance under each future is multiplied by a weight, which is 1/10 here because there are ten futures. Statistically these multipliers are representative of probability weights. By taking the arithmetic mean of the future outcomes, the decision maker has therefore in effect asserted a weighting scheme. In this case the weights are equal, which can be interpreted as an assertion that each of the ten futures has equal probability. It is important to note that this is not automatically equivalent to asserting a 'position of ignorance' about the relative probability of the ten futures.

The real options approach can be viewed as an extension of expected economic performance in which future choice (or 'optionality') is incorporated into the calculation.

Decisions under deep uncertainty

Sometimes there is ambiguity about the future such that alternative futures do not have probabilities defined in any objective sense. This situation can be regarded as **deep uncertainty**. There are formal methods available to aid decision making under deep uncertainty (see Sayers et al. 2012). In reviewing the relevant approaches, Ranger et al. (2010a) commented:

> *It is important to be aware... that many of the decision methods discussed are topics of active research. There is thus still much debate about whether they can (and should) be applied in practice.... We do not believe there is a 'best' method, and readers must form their own judgements about the relevance of a given method to their decision problem.*

For this reason, we restrict our analysis to the more straightforward case in which ambiguity about the future means that it is not sensible to apply any weighting to futures.

In the classic Maximin decision method (choosing the option that has the best 'worst case' performance) the analyst evaluates the outcome of each proposed investment option for each of a number of alternative futures. Here, economic performance may be expressed in terms of NPV, BCR or other outcome metrics. The Maximin approach is a very pessimistic decision rule, although it has the advantage that it can be applied to any metric of performance applied consistently over the full set of options and futures because it is based on ranking the options. In seeking to account for capacity to adapt within flood risk management decisions, a ranking of options and futures leads to simple measures of the robustness of decisions under future uncertainty.

A less pessimistic decision method is to seek an option that minimises the lost opportunity, or regret, should a worst case scenario materialise. This is the Minimax regret rule. The analysis begins with a table of options and future outcomes. It then proceeds, for each future, by comparing the outcome of the best performing option in that future with each of the outcomes in turn. For interval metrics describing economic performance, such as NPV, the comparison should be based on the difference between outcomes. For ratio metrics, such as BCR, the regret is based on the ratio between outcomes.

The resulting table is known as the regret table and measures lost opportunities. A Minimax regret decision rule then chooses the option that has the best 'worst case' regret. When considering the potential adaptive capacity within a flood management decision, the focus is not on the decision rule but rather on the amount of opportunity (or regret) associated with future optionality.

6.3 Decision trees

Decision trees represent an intuitive and widely applied method of describing the evolution of a series of future investments, where each node within the tree represents a different management choice that can be taken, and each pathway through the tree represents a different 'decision pathway', comprised of various options. Decision tree structures have been applied in FCERM in the Thames through FLOODsite (McGahey and Sayers 2008) and Espace (EC projects, see http://www.espace-project.org/index.htm) as decision pipelines/pathways, and in the future developments of the Long-Term Investment Strategy (LTIS) in the form of policy sequences.

In constructing a decision tree to represent options available under a range of potential future conditions, where costs and benefits may vary over time, it is helpful to bear in mind two generically different management approaches:

- **Adaptive:** maximising adaptation and wait and see, where upfront costs are low and large investments are deferred into the future.
- **Precautionary:** acting as early as possible to manage potential risks, where upfront costs are high.

A decision tree may represent multiple possible future decision pathways that reflect decision strategies placing differing degrees of emphasis on a precautionary or adaptive approach.

Figure 6.2 illustrates an example decision tree. In this case, there are six endpoints within the tree, each representing the outcome of a unique decision pathway. Each node in the tree is a decision point and options can be identified with branches of the tree. Each decision node leads to one or more possible investments (shown as labelled boxes in the figure) which will have associated streams of costs and benefits. Note that the decision tree captures information about the options open to decision makers and not the autonomous future uncertainties.

The decision tree sets out a structured view of the way in which future investment choices could unfold. It may not be feasible to capture all possible choices, and so the initial option development requires the range of choices to be narrowed down through the initial screening (Chapter 5) into a manageable set of distinct options.

The decision tree analysis concentrates on appraising the choice to be made at the first node, which will be assumed to be the initial investment decision that we are facing now. Note that the illustration here is based on a choice between two alternatives, A and B, although the same analysis may be applied for a decision between multiple alternatives.

Examples demonstrating the use of decision trees in realistic FCERM settings are provided in Boxes 6.1 and 6.2 later in this section.

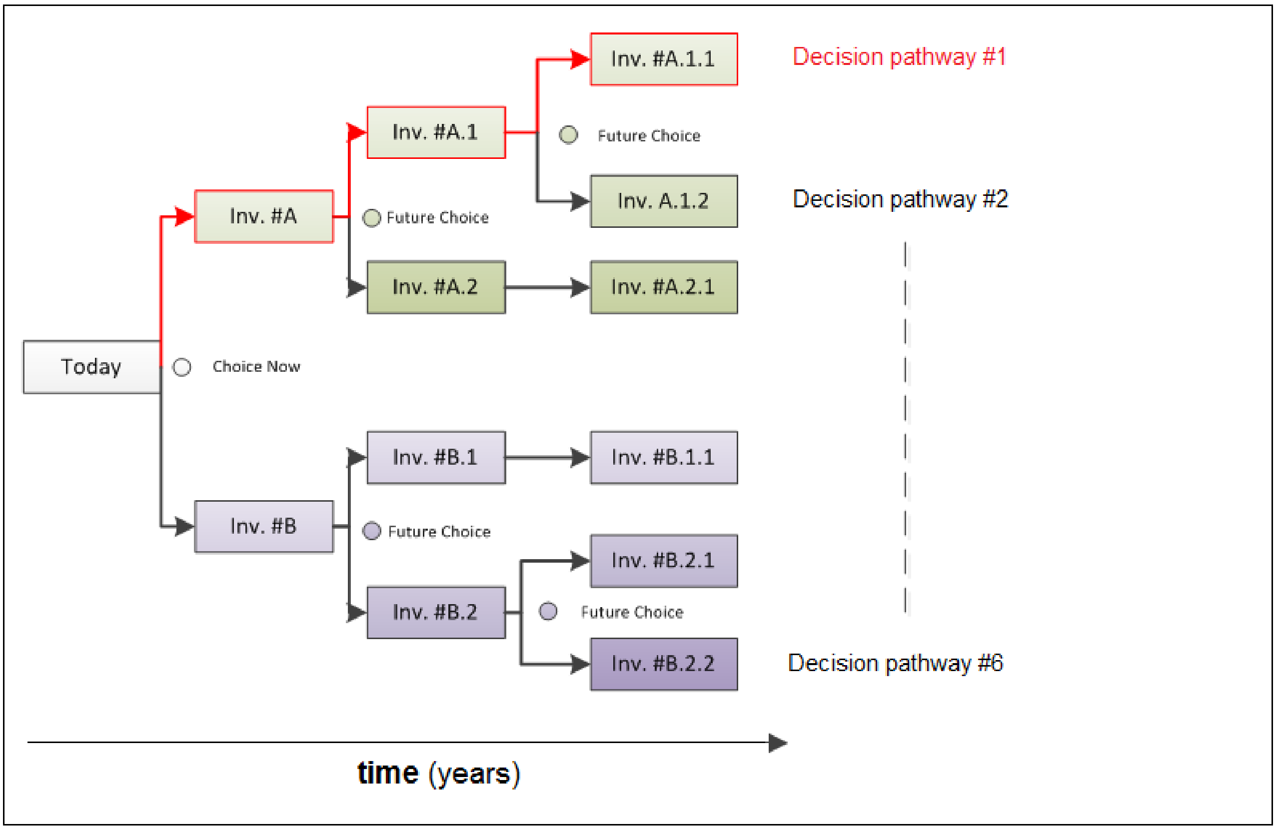


Figure 6.2 Illustrative decision tree representing six decision pathways and the associated choices that the FCERM manager may make, both now and in the future

6.3.1 Evaluating adaptive capacity in the decision tree

Decision tree analysis

The market testing and consultation revealed a need for a simple, pragmatic method that could be applied to help quantify measures related to adaptive capacity. This was based on the use of decision trees as a familiar option planning tool, combined with analysis of the alternative futures.

Metrics relating to the capacity to adapt within a plan

Performance metrics are required to evaluate quantitatively how well each branch of a decision tree will perform under future uncertainty. Ideally these metrics should be simple and understandable so as to provide decision makers with the necessary evidence that a particular decision is justifiable and sustainable. The metrics are proposed and are illustrated in worked examples within the following sections.

The following metrics are applicable whether or not the decision is being assessed using probabilistic futures:

- **Flexibility:** the number of future options that remain open following any investment choice (a measure of foreclosure).
- **Robustness:** the proportion of possible futures in which a given option has the highest performance.
- **Opportunity loss:** a measure of the potential benefits foreclosed by a choice, also known as **regret**, defined here by a comparison, in a given future, between the best outcome attainable from a chosen option and the best outcome attainable from any option (decision pathway).

For a choice between two options A and B, the opportunity loss associated with option A is $|\max(\boldsymbol{O}_A) - \max(\boldsymbol{O}_A, \boldsymbol{O}_B)|$, where $\boldsymbol{O}_A$ represents the set of outcomes that are available contingent on making choice A, expressed on an interval scale (e.g. NPV).

Conventionally, opportunity loss is expressed on an interval scale. However, for outcomes expressed on a ratio scale (e.g. BCR) a corresponding factorial opportunity loss can be defined. The factorial opportunity loss associated with option A would be $\max(\boldsymbol{O}_A, \boldsymbol{O}_B) / \max(\boldsymbol{O}_A)$. For example, if the best BCR achievable from option A is 6 and the best BCR from option B is 8 then choosing A loses the opportunity to achieve an outcome that is 8/6 = 1.333 times more cost-effective.

When probabilities (subjective or derived from analysis) are available for the analysis, it is possible to report a further metric:

- **Expected performance**: an average of the economic performance over all defined futures.

Conceptual example

The analysis needed to derive each of the four metrics described above is illustrated below using a simplified decision tree for a case where three autonomous futures have been defined. The data are hypothetical and for illustrative purposes (but a more realistic analysis has been developed as case studies in Boxes 6.1 and 6.2).

A standard discounted cash flow analysis is assumed, as per HM Treasury Green Book guidance and the FCERM AG (and so the figures represent hypothetical NPV calculations in this case). Benefits would be defined as the risk avoided in terms of annual flood damages with respect to a baseline. This baseline would typically represent the conditions that exist prior to the initial investment.

Analysis without probability weights

In the decision tree presented in Figure 6.3, before the practitioner has chosen to make either decision A or decision B, there are four available decision pathways, and the **flexibility** therefore equals 4. For either choice A or B, the flexibility reduces to 2.

The decision faced now is a choice between A and B. In each case, there are further options available leading to a choice between outcomes 1 and 2 if A is chosen now, and a choice between outcomes 3 and 4 if B is chosen now. The best outcome performance for each future is shown in Figure 6.3 in bold red text.

Robustness is evaluated by determining how well a given decision performs under each future. In this case, choice B offers the best performance in 2 out of 3 of the identified futures. Its robustness is therefore 2/3. The robustness of A is 1/3. Clearly option B would be preferred based on consideration of the robustness.

However, should the second future be realised, both of the decision pathways available in B would be out-performed by both of the decision pathways available in A. The regret table for choices A and B, assuming that the best available subsequent option (1, 2, 3 or 4) will always be taken in each future, is as shown in Table 6.2.

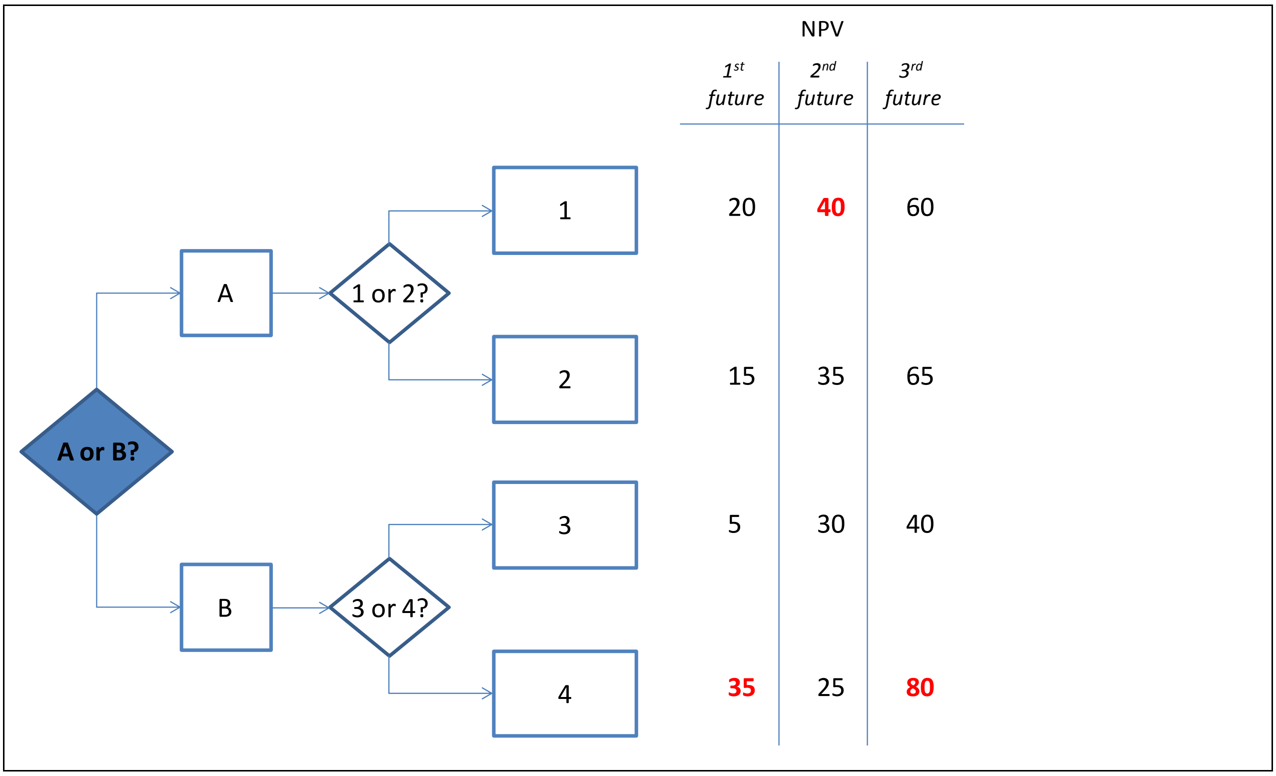


Figure 6.3 Illustrative decision tree with example NPVs used to determine performance measures

Table 6.2 Regret table for choices A and B

	1st future	2nd future	3rd future
A	35 – 20 = 15	0	80 – 65 = 15
B	0	40 – 30 = 10	0

The largest regret that would result from making the initial investment choice B is therefore 10. This represents the maximum **lost opportunity** from choosing B now and hence being able subsequently to choose between the future options 3 and 4, but forgoing future options 1 and 2 (which are only available if we make the initial choice A). Note that the Minimax regret decision rule would favour option B.

Analysis with probability weights

As an extension, consider the case where each alternative future can be weighted to reflect probabilistic information. For example, if the three futures have been chosen so as to have equal weighting then the **expected performance** can be calculated as the average performance for each decision pathway, in each future, as shown in Table 6.3.

Table 6.3 Expected performance for each future

Initial choice	Outcome	Expected value
A	1	40
A	2	38
B	3	25
B	4	47

This analysis evaluates the expectation with respect to the futures for autonomous change.

If it were to be assumed that the decision-maker's future choices are all equally likely, then a possible estimate for the expected performance of option A would be $E(O_A) = 0.5(40+38) = 39$

and $E(O_B) = 0.5(25+47) = 36$. These results would suggest a slight preference for choosing option A. However, this analysis would clearly ignore the adaptive capacity associated with the flexibility to choose between alternative outcomes within either option A or option B.

By using the concept of regret, the value of this flexibility can be expressed by comparing the base expectation with the outcomes that could be attained under each alternative future. Given the flexibility to make future choices, decision makers could potentially improve on the expected value for option B by 44 units of NPV (choosing outcome 4), should the third future materialise (80 (best outcome) – $E(O_B)36 = 44$). If option A were to be taken, then the best improvement available for any particular future would be only 26 units of value (again for the third future).

It is a relatively straightforward task with a spreadsheet-based decision tree to test the sensitivity of whether choosing specific weights compared to equal weights leads to a very different picture of adaptive performance.

The above analysis can then be summarised as shown in Table 6.4.

Table 6.4 Performance summary

Performance of each option against adaptive attributes	**Precautionary branch (A)**	**Adaptive branch (B)**	**Summary**
Flexibility	4 available decision pathways, reducing to 2 in this branch	4 available decision pathways, reducing to 2 in this branch	Equal flexibility
Robustness	This branch only performs better in 1 out of 3 futures	This branch is robust in 2 out of the 3 futures	Branch B performs best
Opportunity loss	NPV index value of 15	NPV index value of 10	Minimax regret rule would also favour B
Expected performance (assuming equal weights)	NPV index value of 39	NPV index value of 36	Slight preference for branch A, but using concepts of regret, branch B has the greatest potential to improve
Commentary	Marginally better expected performance, but not significant enough to adopt measures in branch A	Robustness metric would be one of the clearer indicators that branch B measures should be included in the full appraisal guidance option	Branch B offers more adaptive attributes and should be considered in more detail

It is possible that some options may perform better under some attributes than others. This assessment is not expected to produce ‘the right answer’, but to assist in discussions informing decision making and ensure that potential for adaptability is properly taken into account. Stakeholders will need to decide for themselves whether they consider expected performance to be of more importance than opportunity loss, for example.

The decision tree analysis provides a simple representation of adaptive capacity that requires only small extensions of existing appraisal techniques. However, the tree will quickly become very complex if there are many potential future options about parameters such as standard of protection, flood defence crest levels or the timing of investments. In this case, a more detailed investigation of the business case for a flexible investment plan can be made using real options analysis, and this is explored later in this section.

Box 6.1: Worked example

Town X is a small market town located in England. It has a population of around 5,000. The River C, a tributary of the River B, flows through the centre of the town. Town X has a history of flooding, the most notable recent events occurring when nearly 200 homes were flooded in both 2005 and 2009. The existing flood defences, constructed in the 1980s, are not able to provide the necessary standard of protection (SoP) to new properties that have since been constructed in the town. A new flood defence scheme is therefore required.

Definition of futures

Seven futures have been identified in this example (see Table 6.5). They are a function of climate change, economic change and habitat change. It is assumed for illustration that each future can be weighted (equally in this case), but note that this is merely a basis to explore sensitivity to the weighting.

Habitat change represents the future arrival of a protected species at the reach of river, with the implication that any future action involving works within the river (in this case further raising of flood defence walls) will suffer a penalty in terms of either increased costs or reduced benefits because of the environmental impacts.

Table 6.5 Characteristics of futures

Future	Climate change (increased flow)	Economic value	Other	Weighting
1	Low	None		1/7
2	High	None		1/7
3	Low	+20%		1/7
4	High	+20%		1/7
5	Low	-20%		1/7
6	High	-20%		1/7
7	High	+20%	Protected habitat moves into local area	1/7

Economic change is assumed to occur linearly from 2008 (the initial investment) and reaches a minimum/maximum value (-20% or +20%) by 2025. This could be caused by an increase or decrease in population (and therefore housing development) within the flood cell between 2008 and 2025 (the stated regeneration period of the development plan), or a gradual increase in affluence of this market town, for example. No further economic change is observed after this point (this is a simplification for the sake of keeping this example straightforward). Climate change projections are evaluated at three distinct climate change points: 2025, 2055 and 2085. Between each of these points, the climate is assumed to change linearly (starting at the initial investment in 2008). The protected species is assumed to arrive in 2025.

Shortlisted options

The aim of the flood risk manager is to reduce the impact of flooding in the area being considered. This area (the flood cell) is highlighted orange in Figure 6.4. Three principal measures have been shortlisted that are anticipated to meet the desired aim over the duration of the appraisal period:

1. Raising the existing wall on the south bank of the river (both now and in the future) to protect all properties in the flood cell.
2. Installation of property level protection (PLP) to provide protection up to a height of 0.5 metres at all properties in the flood cell.
3. Construction of a bypass channel to remove all flooding at all properties in the flood cell.

These three measures are shown spatially in Figure 6.4.

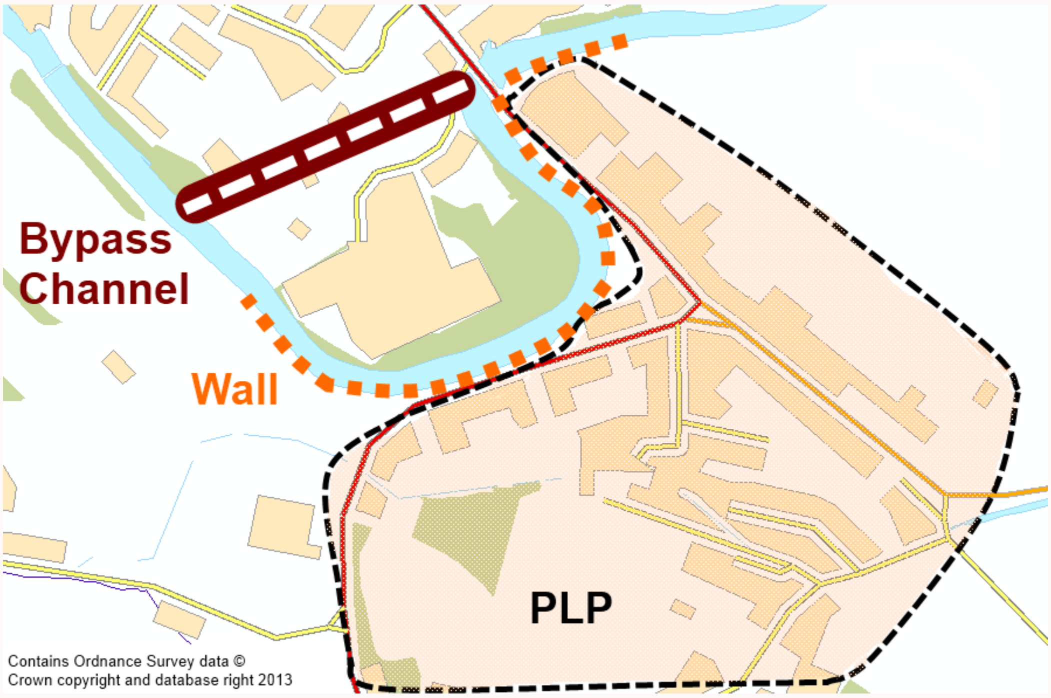


Figure 6.4 Case study layout

A decision tree is constructed that consists of four decision pathways and six options (combinations of measures), shown in Figure 6.5. Capital investments, maintenance costs and investment timings are also summarised on this diagram.

The upper routes – replacing the wall and strengthening the foundations – (routes labelled A1 and A2 in blue) involve large upfront costs. These represent a precautionary (or reactive) approach, where investments are 'locked-in' early in the appraisal period. The lower routes – installing PLP and maintaining the existing wall – (routes labelled B1 and B2 in orange) involve small upfront costs and larger future costs. However, the benefits are suitably lower due to the limited performance of PLP in the more extreme events. These represent a more adaptive approach, where investments are deferred to later in the appraisal period.

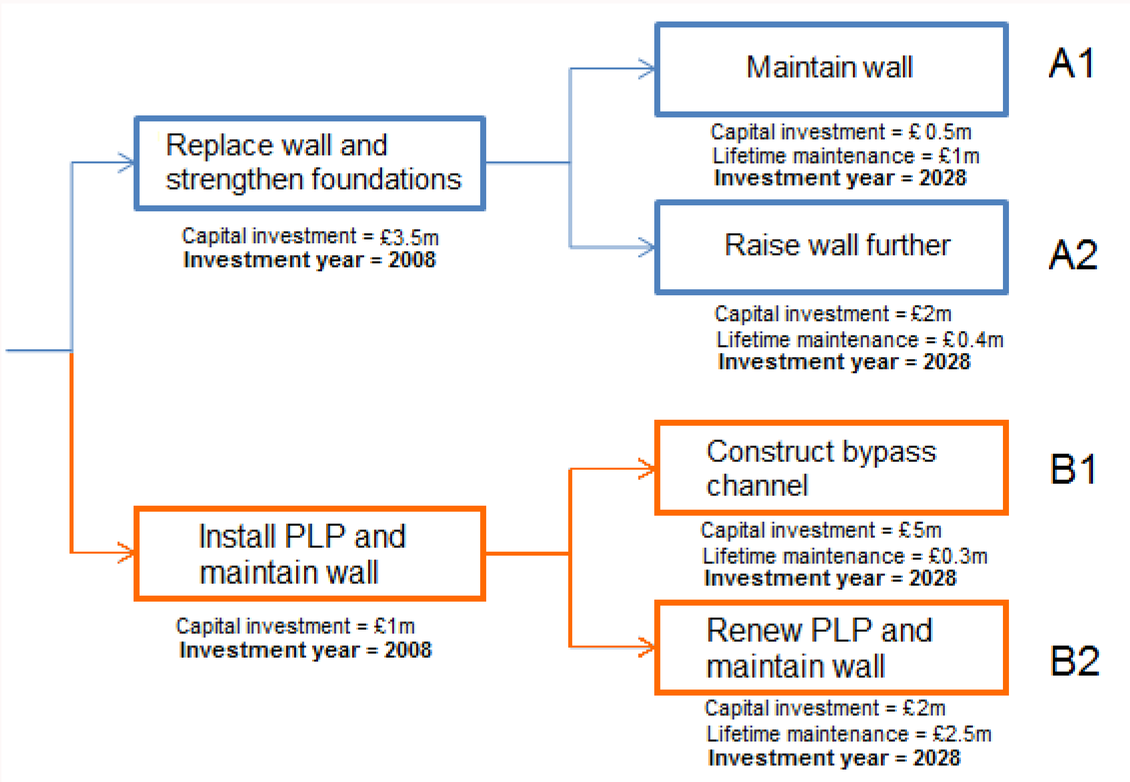


Figure 6.5 Case study decision tree example

Hydraulic model data was used to determine the economic damages associated with each of the proposed decision pathways, and a baseline was calculated in order to determine the benefits associated with each decision pathway. Further guidance on determining the baseline, costs and benefits is provided in Chapter 5 ('Type of project and baseline') and Chapter 7 ('Describe, quantify and value costs and benefits') of the FCERM AG.

Performance measures

The NPV was calculated for each of the decision pathways outlined in Figure 6.5 using standard discounted cash flow analysis, as per FCERM AG and HM Treasury Green Book guidance. The intention is to determine the **flexibility, robustness**, **opportunity lost** and **expected performance** for the tree, to help inform which decision pathway(s) should be taken forward to a fuller appraisal.

Table 6.6 presents the NPV (in millions of pounds) calculated for each decision pathway under each future, as well as the expected performance of each decision pathway. Values in bold represent the highest NPV that is predicted to occur under each future across all decision pathways.

Table 6.6 Performance of each decision pathway under each future

Future	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Weight	*1/7*	*1/7*	*1/7*	*1/7*	*1/7*	*1/7*	*1/7*	
Decision pathway								*Expected performance (NPV)*
A1	£14.36m	£13.00m	£17.16m	£15.53m	£11.56m	£10.48m	£14.51m	£13.80m
A2	£13.98m	£13.79m	£16.83m	**£16.60m**	£11.13m	£10.97m	£9.49m	£13.25m
B1	£14.43m	**£13.88m**	**£17.22m**	£16.56m	£11.64m	**£11.19m**	**£15.37m**	£14.33m
B2	**£14.53m**	£11.14m	£17.11m	£13.05m	**£11.94m**	£9.23m	£12.32m	£12.76m

The performance measures derived in this example have been determined by using a spreadsheet calculation that requires inputs such as investment costs, timings and benefits.

Analysis without weighting

i. **Flexibility**. Before the practitioner has chosen to make either decision A or decision B, there are four available decision pathways, and the flexibility therefore equals 4. Once either decision A or B has been taken, this flexibility will reduce to 2.

   In this example, flexibility does not vary between the options and therefore is not assessed. However, if an example that involved multiple decision pathways was being considered (e.g. decision A might lead to 6 options becoming available, while decision B might lead to only 2 options becoming available) then flexibility could be used to better highlight the adaptive properties of a particular decision.

ii. **Robustness** is evaluated by determining how well a given option performs under each of the 7 futures. In this case, option B produces the best performance in 6 out of the 7 possible futures. Its robustness is therefore 6/7.

   This value is high, and implies that option B is robust and will perform well under future uncertainties. Within option B, there are four futures under which B1 is anticipated to perform better than other decision pathways and two under which B2 would perform better. Hence the robustness of making choice B now is contingent on the optionality inherent in the choice between B1 and B2.

iii. **Lost opportunity**. The regret table for the initial options A and B is shown in Table 6.7 (in £m).

Table 6.7 Regret table

	Futures						
Options	*1*	*2*	*3*	*4*	*5*	*6*	*7*
A	0.17	0.09	0.06	0.00	0.38	0.22	0.86
B	0.00	0.00	0.00	0.04	0.00	0.00	0.00

Should future 4 be realised, both of the decision pathways available in B would be out-performed by decision pathway A1. The maximum lost opportunity that will result from making the initial investment choice B (and hence being able subsequently to choose any decision pathway in B but forgoing any decision pathway in A) is therefore £0.04m (derived by subtracting the maximum value in branch A under future 4, £16.60m, from the maximum value in branch B under future 4, £16.56m). This value is very small, and further implies that choosing to invest in B now is a robust decision.

If, alternatively, the practitioner decided to make initial investment choice A then the maximum lost opportunity would be £0.86m (derived by subtracting the maximum value in branch B under future 7, £15.37m, from the maximum value in branch A under future 7, £14.51m). This is 20 times greater than the lost opportunity from making initial investment choice B and further demonstrates the robustness of choosing to invest in B now.

Analysis with weighting

Expected performance can be calculated as the average performance for each available decision pathway. In this case, the best outcome is £14.33m available in decision pathway B1 (install PLP and maintain wall now; and construct a bypass channel in the future).

If the future optionality in the tree is ignored, then the expected performance of option A is £13.53m and for option B it is £13.55m. There is little difference between these two figures, and on expected value alone it would be difficult to make an informed decision. However, it is clear from the consideration of robustness and opportunity loss above that option B is preferable – further demonstrating the merit of these metrics.

Since the weightings associated with the futures are ambiguous, it is necessary to consider sensitivity to changes in those weights. For example, stakeholder beliefs might consider that the emergence of protected habitat in the reach is unlikely but may wish to check whether the analysis would change if the third future (in which option A performs best) is given greater weight. The implications of this can be tested by reducing the weight on the seventh future and redistributing this quantum onto the third future. This corresponds to asserting that the combination of high climate change, +20% economic change and emergence of a protected habitat in the reach is less plausible than the other futures, while low climate change and +20% economic change is given more emphasis than other futures. The result of this test is that the expected performance of option A increases to £14.16m while option B becomes £13.96m.

However, the robustness and opportunity loss analysis is not based on weighting and these metrics remain unchanged. Arguably the choice between options A and B remains finely balanced on grounds of NPV alone, but leans towards B on the basis of the non-probabilistic analysis.

Interpretation of results

If the decision maker chooses to invest now in decision B there will be 6 (out of a possible 7) futures in which the best expected performance or highest NPV will be realised. Furthermore, investing in decision pathway B will require relatively low ‘locked-in’ costs (less than a third of the costs incurred by investing in decision pathway A), and will delay making difficult decisions relating to the management of future uncertainty until a future time period. By doing so, adaptability is embedded into the decision-making process and future uncertainty is managed by waiting until better information becomes available.

There is only one future – future 4 (high climate change with +20% economic change) – in which neither of the options made available by investing now in decision B are predicted to result in the best expected performance. A2 (which involves a highly reactive process of raising defences multiple times) is the most economically valuable outcome under this future. However, it is not recommended that A2 is taken forward, given that option A is not robust (since it would only be preferred in 1 out of 7 futures), and generates considerable lost opportunity. These factors suggest that the adaptive capacity associated with option B is highly advantageous. It is instead suggested that decision pathways in option B are taken forward.

This example has demonstrated that:

- The adaptive capacity in multiple decision pathways can be explored through performance measures promoted in this guidance.
- Deferring large investments into the future and resisting reactive decision making is a policy that can be promoted through use of these performance measures.
- Finely balanced comparisons of economic performance can be augmented by information about robustness and opportunity loss contained within a decision tree.
- Expected economic performance can be sensitive to assumptions about probabilistic weights, but the non-probabilistic measures of robustness and opportunity loss can provide a useful alternative view.
- The approach taken here should ensure adaptive capacity is properly considered and valued during appraisal enabling informed choices about whether or not to proceed with adaptive options.

Box 6.2: Resilience to coastal erosion

A coastal strategy is being developed for an area comprising three different units. Unit A comprises an eroding cliff face that threatens some properties and infrastructure, Unit B is the centre of a coastal town which is currently defended by a promenade sea wall, and Unit C is at risk from flooding and defended by a mixture of hard defences and a natural shingle ridge. Unit C was selected for the analysis as it requires a managed adaptive strategic approach due to significant uncertainties around the future development of the key drivers, and there is high potential for short-term decisions to constrain options for the long term. This means that a decision tree analysis could provide real support to the strategy.

The Shoreline Management Plan (SMP) for the area has identified the situation as very complex and sensitive. Key issues are identified as the availability of funding to continue the current management approach, the potential risk to life in the area behind the shingle bank, and the possible future environmental impacts of shoreline management. The previous SMP determined that medium and long-term plans needed to be developed in more detail through a joint approach with all stakeholders. The options appraisal undertaken for the new SMP2 determined that in the short term, it is necessary and sustainable to hold the existing line of defence due to the time it takes to adapt and ensure that stakeholders are properly engaged and can influence future decisions. Holding the line may not be the right solution in the longer term; this decision depends on climate change and how the coastal processes respond to this as well as socio-economic developments that determine local affordability. A key challenge in the strategy is to determine how to hold the line in the short term, so that all relevant future options remain available.

Decision tree analysis

The main aim here is to explore the impact of decisions ‘now’ on the future; how do they influence the future performance of coastal management and, also, how do short-term decisions influence the optionality at future decision points?

The decisions ‘now’ concern how to hold the line in the short term. For this, the strategy is appraising a range of options characterised by two aspects: the standard of protection (SoP) and the balance between hard and soft defences.

Two options have been proposed that are likely to produce distinctive outcomes:

- sustaining the existing SoP, which varies from 1/10 chance to 1/50 throughout the frontage, with the existing mixture of hard and soft defences;
- improving the SoP to a uniform 1/50 per year throughout the frontage.

Using two options, two variants have been explored for providing a 1/50 per year SoP:

- keep the existing mixture of hard and soft (sediment nourishment) defences across the frontage;
- hard defences throughout the frontage.

The strategy explicitly recognises that holding the line is only sustainable until the point that any of three triggers are reached:

- funding (from national and local sources) is no longer sufficient;
- the environmental impacts (in particular of shingle recycling) are no longer acceptable;
- risk to life behind the defences is no longer acceptable (taking account of the locally well-developed emergency response arrangements).

We can estimate broadly when these triggers might be reached, but there is a significant uncertainty around this timing, and it also depends strongly on the short-term option selected. It is unlikely that they will be reached in any of the options or futures within the first 20 years.

This example makes a simplifying assumption that the decision that will have to be made when any of the triggers will be reached will occur at around 2050, which can be represented as the second branching level of a simple decision tree, illustrated in Figure 6.6. This simplification means that two pathways can follow on from each of the initial, shorter term options. These are:

- continue to hold the line (representing futures where no triggers have been reached);
- managed realignment in the less developed part of the frontage, while continuing to hold the line in the other parts of the frontage (representing futures where one of the triggers has been reached and it is no longer sustainable to hold the line throughout).

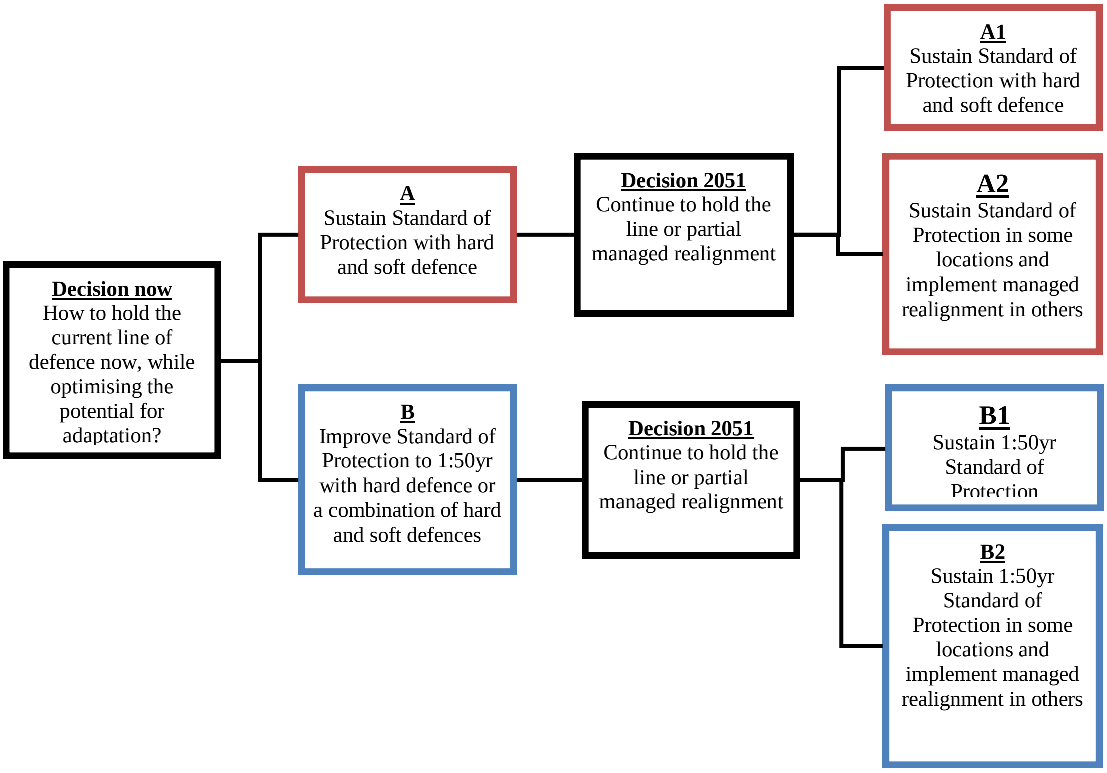


Figure 6.6 Decision tree for the coastal strategy

Finally, the key future uncertainties faced are not only climate change but also the availability of funding (and to a lesser extent the societal acceptability of environmental impacts and risk to life). This has been simplified down to only considering the impact of sea level rise on the costs and benefits of the options.

Using the costs and damages already developed by the strategy team, cost and benefit streams were developed for each of the four pathways.

Damages and benefits

Damages have been calculated for two options, 'do nothing' and 'sustain defence standard' (SDS) over the whole strategy period. Assumptions have been made regarding how these damages would change for the managed realignment and 1/50 per year SoP options:

- Tourism and recreation losses for a 1/50 per year SoP are half that of the SDS option.
- Property and agricultural damages for the 1/50 per year SoP have been calculated by assuming that no damage occurs in the events considered up to and including 1/50 per year probability. For lower probability (i.e. more extreme) events, damages are assumed to be equivalent to those in the SDS future.

- For the managed realignment options the area being realigned has been assumed to be agricultural land and this area (281 ha) would be written off in the first year of the realignment at its market value. This area would also no longer be subject to ongoing damages.
- A benefit of managed realignment is the creation of new intertidal habitat (mudflat and saltmarsh). To capture this in the analysis, the average indicative value for these two habitats from Eftec (2010) was used as a benefit in the two realignment futures. This value is £1,350 per hectare per year and was applied to the 281 ha of land which would form the realignment site.

Costs

Fully calculated damages are only provided for two of the options considered: SDS and 1/50 per year SoP. Initial costs for elements of the managed realignment options have been considered; however, some assumptions have been necessary to develop full costs for these options. These assumptions are outlined below:

- It has been assumed that the costs for soft defence measures (beach recharge and recycling) are reduced by 30% after managed realignment has been implemented, representing the section of coast for which this is no longer necessary.
- The capital cost of setback embankments to limit the extent of the realignment have been developed; however, maintenance has not been considered. A typical maintenance cost for grassed embankments of £500 per kilometre per year has been obtained from the Environment Agency's maintenance standards guidance (Enviroment Agency 2012a).
- The costs of breaching the existing defences and creating the realignment site have not been considered. An outline cost for the whole managed realignment has been obtained by considering the cost of other current schemes in the UK. This gives an average cost of managed realignments at £60,000 per hectare. This value has been used with an optimism bias of 60% to account for unforeseen risks to give a cost of £27,000,000 for the whole realignment.
- The cost of providing a hard defence 1/50 per year SoP has been developed based on the assumptions made by the strategy for new hard defences in the costs that have been calculated.

Futures

The strategy at present has only considered one future, a central estimate of climate change using the current guidance, referred to as 'change factor' in the Environment Agency advisory note (Environment Agency 2011). To apply this to the economic analysis the costs for SDS have been adjusted so that the regular and capital works would keep pace with climate change.

To account for beach management, the strategy incorporated analysis of the impact of anticipated sea level rise on wave climate and sediment transport to develop a sediment transport climate change factor for each year of the appraisal period. This factor has been applied as a cost (in practice as a reduction in benefits) for each of the futures.

This approach has been used to develop an equivalent factor for three alternative sea level rise futures; the lower estimate, upper estimate, and H++ scenarios from the Environment Agency advisory note. These new factors have been used to adjust the benefits for the change factor scenario to represent the other three sea level rise scenarios.

These four futures are referred to as follows:

- Future 1: Change factor sea level rise scenario
- Future 2: Lower estimate sea level rise scenario
- Future 3: Upper estimate sea level rise scenario
- Future 4: H++ sea level rise scenario

At present it is not appropriate to apply weightings to climate change scenarios, as both the UK Climate Impacts Programme (UK CIP) and the Intergovernmental Panel on Climate Change (IPCC) do not give any guidance on the relative confidence of different futures. For illustrative purposes all futures have been weighted equally.

Results

The results of the decision tree analysis have been analysed and compared with the conclusions that would have been reached if a more traditional approach was taken. The focus of this analysis has been to assess how far the metrics assist the decision maker in understanding how the choices made now will be affected by future variability and assist making the correct decision now.

Traditional approach

A summary of the key traditional measures that are normally used to assess the economic viability of options are given in Tables 6.8a and 6.8b – 1/50 per year SoP with mixture of hard and soft defences and 1/50 per year SoP with hard defences. This focuses on the use of the BCRs for the best estimate scenario and how these compare.

Table 6.8a Economic viability of options: 1/50 per year SoP with mixture of hard and soft defences

Option	Present value costs (£m)	Present value benefits (£m)	Benefit cost ratio	Incremental BCR (IBCR)	Option for IBCR comparison	Net present value (£m)
A1: SDS	14.92	120.25	8.06			105.33
A2 SDS then managed realignment	20.33	130.19	6.40			109.86
B1: 1:50yr SoP	17.55	147.58	8.41		A1	130.03
B2: 1:50yr SoP then managed realignment	23.52	149.39	6.35		A1	125.87

Table 6.8b Economic viability of options: 1/50 year SoP with hard defences

Option	Present value costs (£m)	Present value benefits (£m)	Benefit cost ratio	Incremental BCR (IBCR)	Option for IBCR comparison	Net present value (£m)
A1: SDS	14.92	120.25	8.06			105.33
A2 SDS then managed realignment	20.33	130.19	6.40			109.86
B1: 1:50yr SoP	56.68	147.58	2.60	0.65	A1	90.90
B2: 1:50yr SoP then managed realignment	59.76	149.39	2.50	0.65	A1	89.63

These tables show that for the (quite distinct) options considered, the choice of preferred option for the short-term decision on the basis of a traditional approach would be very clear: investment pathway B from Table 6.8a, achieve and sustain 1/50 per year SoP with the current mixture of hard and soft defences.

The following sections discuss the four different measures of performance that the tool gives to illustrate how adaptive the different options are under different futures.

Expected performance

Expected performance is weighted average NPV for an option based on the NPVs in all futures that have been considered. The analysis calculates this for all four of the pathways considered.

The results for the coastal strategy assessment are given in Table 6.9, along with the NPV for each future.

Table 6.9 Expected performance: 1/50 per year SoP with mixture of hard and soft defences

Option	Future 1 NPV (£m)	Future 2 NPV (£m)	Future 3 NPV (£m)	Future 4 NPV (£m)	Expected performance (£m)
A1	105.33	103.24	105.18	108.64	105.60
A2	109.86	107.38	109.95	114.71	110.48
B1	**130.03**	**127.39**	**129.97**	**134.69**	**130.52**
B2	125.87	123.14	125.86	130.86	126.43

As the key decision is what should be done now, this measure should be modified to become the weighted average NPV for each investment pathway over the different futures. In this case it would be the weighted average of all futures for the options in pathway A or B. The overall expected performance of investment path A is 108.04, while for investment path B it is 128.48.

The results for the coastal strategy assessment using a mixture of only hard defences are given in Table

6.10 along with the NPV for each future. This shows that over the four futures considered option A2 gives the highest expected performance, with investment path A always outperforming investment path B.

Table 6.10 Expected performance: 1/50 year SoP with hard defences

Option	Future 1 NPV (£m)	Future 2 NPV (£m)	Future 3 NPV (£m)	Future 4 NPV (£m)	Expected performance (£m)
A1	105.33	103.24	105.18	108.64	105.60
A2	**109.86**	**107.38**	**109.95**	**114.71**	**110.48**
B1	90.90	88.25	90.84	95.56	91.39
B2	89.63	86.90	89.62	94.62	90.19

In this case the overall expected performance of investment path A is 108.04, while for investment path B it is 90.79.

Robustness

This is a measure of how well a given decision pathway continues to perform under each future. A pathway is defined as one of the two branches on the decision tree, either path A or path B. This measure shows which of these pathways performs best overall in the futures considered.

In both tests a single investment path has the best performance in all four futures. In the first test considering a mixture of hard and soft defences for the 1/50 per year SoP this is path B, while when all hard defences are considered it is path A.

Adaptive capacity

In the first test with mixed defence types option B1 always has the highest NPV, while for the hard defences test option A2 always has the highest NPV. The analysis therefore suggests that for each of the two tests there is a single best sequence of choices leading to the best possible outcome irrespective of which future materialises. It is therefore not relevant to consider the value associated with the capacity to make alternative adaptive choices at the second, future, decision point.

Opportunity loss

This is a measure of the potential benefits foreclosed by a choice – reflecting the difference between the best available outcome and the best outcome from those foreclosed. This is considered at the investment path level, where opportunity is lost if one path is selected and there is the potential in the future for the alternative path to give better performance under a certain future.

In the first test considering mixed defence types the preferred investment pathway is B. There are no futures where choosing path B would lead to a lost opportunity as in all cases it performs better than path A. Alternatively if path A were chosen, the opportunity lost would be valued at £19.98m to £20.17m. This is the range of difference in NPV between the best performing option of investment path B and investment path A across the four futures.

In the second test considering hard defences only the preferred investment pathway is A. There are no futures where choosing path A would lead to a lost opportunity as in all cases it performs better than path B. Alternatively, if path B were chosen, the opportunity lost would be valued at £18.96m to £19.15m. This is the range of difference in NPV between the best performing option of investment path A and investment path B across the four futures.

Conclusions

The following sections analyse the results from a traditional approach and the decision tree analysis for the two tests.

Test 1: Mixed defence types

Based upon the decision tree analysis it is concluded that the performance measures indicate that investment pathway B is the best option for the decision that the strategy has to take now. It scores better on three metrics in all futures with the highest expected performance and robustness, and lower opportunity loss.

The traditional approach to the results suggests that, based on BCRs, investment pathway B is the correct decision now. This is the case as both options in this pathway have a higher BCR than both options in pathway A. Incremental BCRs are not relevant as the option with the highest BCRs give the highest SoP.

Test 2: Hard defence types

Based upon the decision tree analysis it would be concluded that the performance measures indicate that investment pathway A is the best option for the decision that the strategy has to take now. It scores better on three metrics in all futures with the highest expected performance and robustness, and lower opportunity loss.

The traditional approach to the results would suggest that based on BCRs, investment pathway A is the correct decision now. This is the case as pathway A has a higher BCR and the incremental BCRs to move from the options in pathway A to the higher SoP of pathway B are below 1. This is insufficient to move from pathway A to pathway B following the appraisal guidance decision rule.

Assessment of BCRs would suggest that option A1 is the best eventual outcome, while analysis based on NPV shows a preference for option A2. Although this does not affect the decision made now to opt for pathway A, it highlights the differences that can occur when using BCR or NPV.

Overall conclusions

Considering the results of the two tests, there is agreement between the decision tree analysis and the traditional approach in deciding the correct investment pathway. It is likely that this is assisted by the fact that the options considered do not vary in their relative performance between the different futures: the options are very distinctive and the preferred option stands out by such a wide margin that it is not influenced by the impact of uncertainty.

There remains a question of the timing of the decision whether or not to implement managed realignment. For the preferred option, sensitivity of the economic case to this timing decision can be explored using the methodology based on real options analysis set out in Appendix A.

Demonstration spreadsheet tool

A simple prototype spreadsheet-based tool has been developed as part of the overall project outputs. It is intended to act as a workbench tool that can be used to demonstrate how each of the recommended performance measures can be derived. It is currently limited to evaluate up to four decision pathways only but may easily be extended. The inputs required are:

- number of autonomous futures with associated weights (which can be set to be equal);
- investment costs and timings associated with each of the proposed options;
- benefits (i.e. avoided economic damages with respect to a baseline) associated with each of the proposed options, evaluated with respect to each future uncertainty.

Benefits can be entered either as an estimate of avoided annual average damages for a given future, or using a simple multiplier of the benefits in the baseline case. The tool outputs the performance metrics for each decision pathway being evaluated, and includes a brief narrative relating to each.

Lessons from case study experience

Key findings from the above case studies (Boxes 6.1 and 6.2) are summarised below. In terms of general methodology, the examples demonstrated that:

- The adaptive capacity captured through multiple decision pathways can be assessed in quantitative terms through use of metrics derived from decision analysis methods.
- The decision tree analysis and performance measures help to quantify how deferring large investments into the future may buy robustness, and that the conditions under which this is economically preferable can be explored in more detail using the approach set out in the real options example. These analytical tools can help in providing evidence to resist reactive decision making.

- The benefit multipliers approach is a useful element that allows quick sensitivity analysis to be undertaken with minimal effort.
- The approach should ensure adaptive capacity is properly considered and that appraised options can be assessed for their adaptability potential.

The case studies also identified a need for additional research:

- Further work is required to derive robust weights for alternative futures describing autonomous change. While UKCP09 (Defra 2009c) offers information for climate projections, other factors are harder to weight. In addition, there is no readily available information or guidance to offer a consistent probabilistic interpretation of combining such alternative futures and fully understanding the interdependencies between them.
- The simple demonstration spreadsheet is useful, but reality is more complicated and in the future a more flexible tool should be developed to build a more complex decision tree with the potential for more options and pathways.

6.4 Summary of guidance

Key features of the approach are:

- Decision trees promote the development of adaptable strategies and should be used to allow for a structured view of the flexibility within options. The decision tree approach provides a method of representing the range of future choices and then appraising the performance of each branch of the tree in each alternative future.
- Evaluating each pathway through the decision tree enables robust choices to be made – decision pathways represent a key addition to the existing FCERM AG. Costs and benefits for each option are still evaluated as in existing guidance and entered as an annual stream of values into appraisal summary tables to generate NPVs. However, additional performance measures are introduced to value the flexibility, resilience (expected performance) and opportunity lost through making particular decisions.
- Future storylines enable alternative futures to be described (including all important drivers). Storylines enable uncertainty about the future to be represented with each associated with probabilistic weights (where information exists to support these, e.g. UKCP09 and derived products) or expert weighting, or simply used to test sensitivity to assumptions. Whichever approach is used the basis of the weighting schemes must be clearly stated and defensible – stakeholders should not, for example, create their own weighting schemes for climate projections.
- Using the existing appraisal processes to represent the performance of alternative options under a range of alternative futures is difficult. The Supplementary Appraisal Guide makes this possible by adopting a decision tree approach to represent the range of future choices and then appraises the performance of each branch of the tree under alternative futures.
- Decision trees and the supporting analysis need only be as complex as the decision demands. The concepts, methods and tools presented are scalable and have been developed in such a way that they can be applied to a wide variety of situations and plan and project scales.

6.5 Evaluating the business case for a flexible investment plan – taking the analysis further

6.5.1 Introduction

While the decision tree analysis provides some measure of the potential benefits gained by leaving future investment choices open, a more detailed analysis can be achieved through assessing the economic case using real options analysis concepts. A real option is defined in the Green Book supplementary guidance as being ‘an alternative or choice that becomes available through an investment opportunity or action’. This alternative or choice (such as the option to abandon an investment if future climate change is not as originally anticipated) has an inherent value associated with it, termed the option value.

Real options analysis has been developed in respect of various investment and business planning decisions (e.g. Dixit and Pindyck 1994, Mathews and Salmon 2007, Mathews et al. 2007). Recently, there has been an interest in applications in flood management, and the approach has been demonstrated in the context of the Thames Estuary (Woodward et al. 2011). The real options approach extends on the type of decision tree analysis discussed above by introducing a decision rule, such that future investment choices are conditional on the futures used to represent future uncertainty. This means that the costs and benefits of investment in the future are assessed under the assumption that a decision maker will adapt rationally to future change.

6.5.2 Method development

Early trials in this project considered how a tool could be developed to analyse the economic value of a plan where an upfront cost would be incurred to ‘buy the option’ to make further investments in flood management measures at a later date.

This initial work considered the future benefit streams (avoided flood damages) to be uncertain, as a function of uncertain climate futures and therefore linked to the UKCP09 climate projections. The basic cash flow analysis is illustrated in Figure 6.7.

After initial testing and consultation, it quickly became apparent that implementing the analysis could be difficult given the costs and time overhead involved in obtaining estimates of benefits for multiple alternative futures. In addition, the construction of alternative futures combining changes derived from UKCP09 with other factors (such as development or land-use plans) was identified as a complex issue that pointed to the need for a simpler approach. However, we consider that our investigations into this area provide useful intelligence and the potential foundation for a real options analysis once further research has been undertaken.

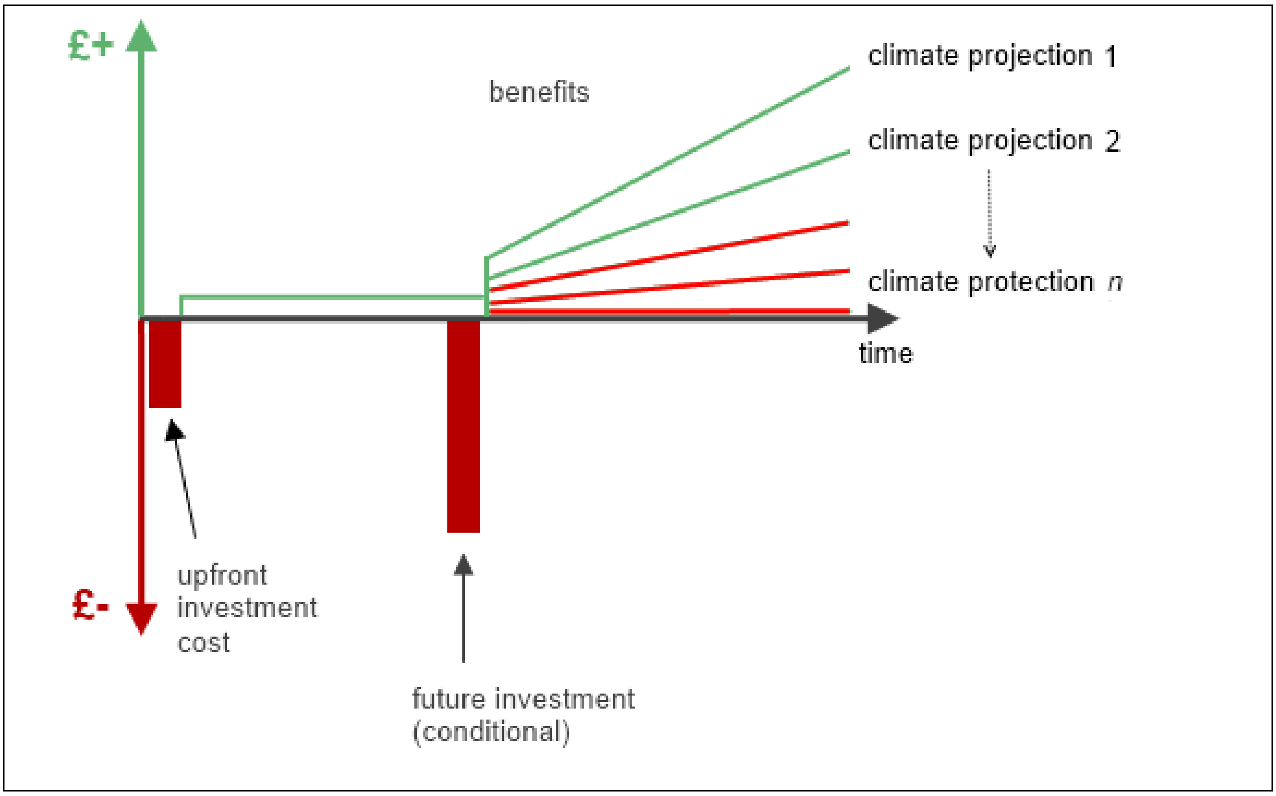


Figure 6.7 Simplified principles for cash flow analysis using multiple climate projections[5]

6.5.3 Real options analysis for a hypothetical investment case

Instead of developing a general-purpose tool the project has explored the way in which options analysis can be applied in a hypothetical case study. This has been done by defining functions based on external modelling to specify projected changes in the probability of flood flows over time and projected changes in flood damages related to increased population, changes in land use and overall economic growth. In each case the change functions are controlled by rate parameters that allow uncertainty about the future rates of change to be explored.

The case study is described in detail in Appendix A and the calculations are captured in a computer program. In effect this provides a template for analysis that could be applied to other real cases.

This case study offers insights about the conditions under which a flexible, multi-stage investment plan may be preferred to a fixed plan, or in which a fixed plan may be economically preferred, or in which no clear preference is found. In particular, it reveals how the economic case depends on the desired level of protection (a measure of risk aversion) and the desired cost-effectiveness.

A flexible plan is more advantageous:

- where a very high absolute level of protection is required;
- when the projected rate of increase in risks and the decision rule imply an upgrade midway through the design life, especially if the upgrade is to a relatively high level of protection;
- where uncertainties about the future are high and the possibility of very high or very low climate change is significant.

Flexibility is seen to be less advantageous:

- where risk only changes slowly over the design life;

[5] Red lines indicate scenarios in which the investment would under-perform and therefore be discarded under a real options analysis. (Uncertainty about benefits is ignored in the near future here for simplicity, but expands further into the future.)

- where risk changes very rapidly in the initial period;
- where the rate of growth of risk, combined with the preferences about the level of protection and desired cost-effectiveness, mean that the flexibility would be used before the middle part of the design life to attain a similar level of protection as a cost-effective fixed plan would have offered.

Although the findings are specific to the hypothetical case study, the generic conclusions are that it is not beneficial to pay for flexibility where additional investment is inevitable in the near future, or where the future option to upgrade is almost certain not to be taken up.

6.6 Summary and areas for further research

Building on the principles of HM Treasury Green Book and associated guidance, the project has developed further guidance in using decision trees and in applying economic evaluation to those decisions to include concepts of adaptive capacity within an economic appraisal. The Supplementary Appraisal Guide sets out some recommendations to assist in application of the decision tree analysis approach, which has been informed by realistic case study examples.

A further case study builds on the concepts of real options analysis to explore the economic case for flexible investment planning including decisions that can adapt to uncertain future change. This shows how real options analysis can be used to look in more detail at the circumstances in which it is economically justifiable to buy optionality (the potential to have future choices) or defer investment.

Through market testing workshops, the project has trialled the decision tree scenario testing approach, and feedback indicated that the robustness measures were seen as useful. However, there remains a need for the ongoing evolution of guidance, and provision of standardised scenario data, or approaches for developing futures consistently.

Workshop feedback indicated demand for a set of prepared benefit estimates or multipliers linked to autonomous futures so as to provide a consistent treatment of uncertainty. This would entail substantial additional work to offer national provision, for example, but would remove a significant barrier to uptake of the approach in practice.

Decision trees may need to be of varying levels of complexity for different cases. While the approaches set out in this project are capable of extension to complex decision structures, practitioners have to find a way to construct the decision tree. Although the project has offered some basic guidance, there remain currently only a few examples that users can learn from.

Finally, further guidance is required concerning the development of futures and the application of weightings to these. Stakeholders may perceive some alternative futures to be more likely than others, but may well disagree in their judgements. There is currently unlikely to be sufficient objective evidence to resolve these disagreements completely. To be meaningful, however, there must be a conclusion to this discussion and, based on best available evidence, a relative weighting should be negotiated with stakeholders.

Each future may be assigned a simple weight to reflect a degree of belief about it. However, it should not automatically be assumed that meaningful weights can be assigned. In the absence of consensus about the relative weight to attach to each future, one simple ‘lack of knowledge’ position is to assign equal weights to each future. This has been done in the example shown here, implying that we are not in a position to assert that any one future is more or less likely than the others.

Where climate change is considered, projections derived from the current UK climate projections (UKCP09) contain some information that could help in assigning weights objectively. It should be noted that these ‘probabilistic’ climate projections are correctly interpreted as subjective degrees of belief, based on evidence and judgement, and represent only the technical uncertainties surrounding the climate modelling; they do not tell us how likely a particular future change is. It is challenging to find a manageable number of alternative futures that effectively sample a much broader range of possible scenarios over several factors such as climate and economic growth. If a more detailed study is justified, then there are some examples of more formalised alternative future discovery that also, in effect, start from a sensitivity analysis (Lempert and Schlesinger 2000, Haasnoot et al. 2012).

7 Spatial planning and development management

7.1 Context

Land-use planning has a crucial role to play in managing flood risk and combating the effects of climate change, both now and in the future; land-use plans need to be informed by FCERM strategies and FCERM informs the development of plans. Land management practices which deliver flood risk management benefits are supported by *Making space for water* (Defra 2005), the *Water Framework Directive* (European Parliament, 2000), Defra's Water Strategy (Defra, 2011c) and the Pitt Review (2008). While the project is focused on promoting and valuing managed adaptive approaches, it was agreed early on in the study period that the role of land-use planning in encouraging an adaptive approach (to FCERM) should also be investigated. Research undertaken to inform the work of the Climate Change Adaptation Sub-Committee (Ranger et al. 2010b) states that 'For inland flooding, the most important near-term driver of risk is likely to be land-use change and development'. However, land-use planning should also be seen as an opportunity as well as a 'control' through the promotion of regeneration schemes and other development that actively helps to reduce the risk of flooding now and in the future.

Planning policy controls the pattern of development, including whether or not planning permission is given for development in areas at risk of flooding, identifying land to be used for flood storage, and requiring sustainable urban drainage systems (SuDS). Master-planning and good urban design play an important role in managing flood risk, as does development control through the assessment of individual applications. In addition, Compulsory Purchase Orders can be issued in situations where it is decided that it is no longer viable to protect properties from flooding or coastal erosion.

Land-use planning also has a clear role in enabling small-scale catchment management approaches that deliver flood risk management benefits through, for example, the use of farmland to store flood water and reduce downstream flood risk. Effects at a large catchment scale are more difficult to determine and continue to be the subject of research by the Environment Agency.

The degree to which land-use planning supports and encourages managed adaptive approaches has been investigated through a review of national planning guidance in England and Wales and identification of a number of local plan policies which embed an adaptive approach.

7.2 National planning policy guidance

This section refers to legislation, policy and guidance in place as as 1 January 2014 and does not cover more recent revisions to planning policy in relation to development and flood risk in England.

7.2.1 Planning policy guidance in England

The National Planning Policy Framework, 2012 (NPPF) consolidates and rationalises all previous planning policy statements and other elements of national planning policy guidance. Planning Policy Statement 25: Development and flood risk (PPS25) (DCLG, 2010)is replaced by the NPPF, but the main thrust of this PPS is taken forward in the NPPF and through its accompanying technical guidance (DCLG 2012a, 2012b; recently reviewed by Taylor 2012). The PPS25 Practice Guide (DCLG, 2009) also remains in place although this is due to be reviewed. The Environment Agency enforces this element of the NPPF and has powers to challenge the local planning authority (LPA) over development applications in the flood plain.

The NPPF makes it mandatory for the LPA to consult with the Environment Agency on planning applications for sites over one hectare in size located in Flood Zones 2 and 3.

The NPPF's overarching core planning principles include 'Support the transition to a low carbon future in a changing climate, taking full account of flood risk and coastal change, and encourage the re-use of existing resources...'. However, there is no overarching comment around the planning system dealing with uncertainty, whether this is climate change, population growth or any other long-term uncertainty that will influence and be influenced by current and future land use.

The NPPF contains a specific section 'Meeting the challenge of climate change, flooding and coastal change'. Placing flooding firmly in the wider context of climate change provides a good platform for taking forward an adaptive approach suggesting that current decisions should be made taking into account future known and unknown climate change impacts. This section states that LPAs should adopt proactive strategies to mitigate and adapt to climate change taking full account of flood risk, coastal change, and water supply and demand considerations. It also requires local plans to take account of climate change over the longer term, including factors such as flood risk, coastal change, water supply and changes to biodiversity and landscape. New development should be planned to avoid increased vulnerability to the range of impacts arising from climate change.

With regards to flooding, the NPPF states that inappropriate development should be avoided by directing development away from areas at highest risk but, where development is necessary, make it safe without increasing flood risk elsewhere. Local plans should be supported by strategic flood risk assessments (SFRAs) and apply a sequential, risk-based approach to the allocation of development.

The sequential test aims to steer development to the most sustainable locations (informed by the identification of zones with different likelihoods of flooding as set out in the supporting SFRA). The exception test is intended to ensure that development located in zones with a higher probability of flooding is only granted permission where the development provides wider sustainability benefits to the community that outweigh flood risk, and a site-specific flood risk assessment shows that the development will be safe for its lifetime taking into account the vulnerability of its users, without increasing flood risk elsewhere, and where possible will reduce flood risk overall. However, the zoning approach fails to recognise the dynamic nature of flooding, which will be impacted by climate change and other uncertain futures. This does not sit well with the overall objective of supporting the transition to a low carbon future in a changing climate.

With regards to coastal change, the NPPF requires LPAs to reduce risk from coastal change by avoiding inappropriate development in vulnerable areas or adding to the impacts of physical changes to the coast. It also reiterates the requirement to identify coastal change management areas (CCMAs), which are areas likely to be affected by physical changes to the coast. It stresses that LPAs need to be clear what type of development is appropriate in CCMAs, and in what circumstances, and make provision for development and infrastructure that needs to be developed away from CCMAs unless there are exceptional circumstances. The NPPF explicitly promotes an adaptive approach through the requirement for LPAs to 'ensure appropriate development in a CCMA is not impacted by coastal change by limiting the planned lifetime of the proposed development through temporary permission and restoration conditions where necessary to reduce the risk to people and the development'. (For example, Happisburgh on the North Norfolk cost has installed temporary toilets and a car park due to the imminent threat of coastal erosion.) Such an approach could also be extended to locations impacted by fluvial flooding.

Finally, with regards to plan-making overall, the NPPF states that local plans 'can be reviewed in whole or in part to respond flexibly to changing circumstances' and 'They should address the spatial implications of economic, social and environmental change'. Again this provides a supportive environment for the development of adaptive planning policies and the implementation of adaptive responses.

The technical guidance to the NPPF (DCLG 2012b) and the PPS25 Practice Guide (DCLG, 2009) provide additional guidance to LPAs to ensure that guidance concerning development at risk of flooding in the NPPF is effectively implemented. The PPS25 Practice Guide has been retained to support this technical guidance to the NPPF on a temporary basis. The Taylor Review of planning policy guidance which reported in December 2012 recommended that all existing guidance should be brought together into a single, coherent and up-to-date suite of only essential guidance which is easily accessible online. It also identified priorities for update which included guidance on climate change 'to bring this vital material up to date and ensure it is used effectively and proportionately' and on flooding 'to bring this key material up to date and ensure it is used effectively and proportionately'.

The PPS25 Practice Guide provides specific advice in relation to taking climate change into account in the design of flood risk management measures. This highlights the two principal approaches that can be undertaken: precautionary and managed adaptive. The managed adaptive approach is highlighted as being more flexible and it is suggested that this is appropriate where the site design takes specific account of the potential need to adapt the flood risk management measures at a future date, and ongoing responsibility can readily be assigned to tracking the change in risk, managing this and ensuring that the necessary adaptations are made over the lifetime of the development.

7.2.2 Planning policy guidance in Wales

National planning policy in Wales is set out in the Welsh Government's Planning Policy Wales (PPW, Edition 5, 2012) and a series of technical advice notes (TANs). A new Planning Bill is being prepared in Wales to take forward national legislation following devolution. This is due to be introduced to the Assembly in 2014. Following the Planning Bill, national planning policy will be amended. Therefore, the findings from this study and the Supplementary Guide have the potential to inform any changes made to national planning policy in Wales.

PPW sets out a commitment for planning to both minimise the causes of climate change and plan for the consequences of climate change by reducing the vulnerability of the natural and built environments. An adaptive approach is encouraged from the outset with the statement that:

> *Planning for climate change must be carried out in a way that is consistent with sustainability principles, and in a way which does not prejudice future action to tackle climate change, by integrating solutions to tackle the causes and consequences of climate change. This will require close co-operation across all sectors and communities*.

PPW also states that:

> *Given current uncertainty as to the precise impacts of climate change, planning authorities need to ensure that both places and the development that takes place within them remain adaptable. For example, local planning authorities should identify circumstances in which development might prevent effective management of risks in future. Where it is not possible to avoid building in areas of environmental risk, appropriate design and other adaptation responses will be necessary for both the development and local communities.*

However, there is also a strong focus on applying the precautionary principle with a clear statement that 'Cost-effective measures to prevent possibly serious environmental damage should not be postponed just because of scientific uncertainty about how serious the risk is'.

PPW is intended to take forward the Welsh Government's sustainability principles and promotes action through the planning system to move away from flood defence and the mitigation of the consequences of new development in areas of flood hazard towards a more positive avoidance of development in areas defined as being of flood hazard. It also stresses that climate change is likely to increase the risk of coastal and river flooding as a result of sea level rise and more intense rainfall, and reduced service levels provided by surface water drainage infrastructure. A sustainable approach to flooding is promoted, which involves the avoidance of development in flood hazard areas and, where possible or practical, the encouragement of managed retreat, the creation of wash-lands and flood plain restoration.

PPW requires the planning system to manage flood risk through adoption of the Precautionary Framework, which follows the principles of the English sequential test (through the identification of zones via strategic flood consequence assessments) and exception test. This is in keeping with earlier versions of Planning Policy Wales. TANs set out technical guidance which supplements the relevant policies set out in PPW.

The Welsh Assembly Government's TAN14 on coastal planning is dated 1998 and in need of review to reflect developments in understanding concerning climate change processes and their implications for projected increase in sea level. Guidance concerning appropriate development near the coast makes no reference to the need to take account of climate change and its potential future implications.

TAN15, on development and flood risk (Welsh Assembly Government 2004), advises on development and flood risk as this relates to sustainability principles (detailed in section 3.1) and provides a framework within which risks arising from both river and coastal flooding, and from additional run-off from development in any location can be assessed. The guidance states explicitly in the introductory section that 'relevant sustainable development considerations from the flooding perspective include... making provision for future changes in flood risk, for example taking account of climate change, where they can be anticipated'.

The TAN sets out a precautionary framework to guide planning decisions, which is similar to the sequential and exception tests set out in the English guidance. Advice for development plans stresses the importance of appropriate land management to reduce flood risk (as well as protecting areas from flooding) and highlights the potential for managed responses: 'The option of managed coastal alignment and floodplain restoration may be considered as a means of reducing future flood risk and protecting and enhancing natural heritage'.

Advice for new development on the flood plain does not include a requirement to assess future risks (i.e. as a result of climate change or other uncertainties). More general guidance does refer to the need to include allowances for increased flows and sea level rise provided in the latest project appraisal guidance. Appendix 2 of TAN15 focuses on flooding and climate change. The climate change information is very dated, but guidance does refer to using the most up-to-date projections. Overall, despite stressing the importance of an adaptive approach in the text, much of the specific guidance promotes a strongly precautionary approach which may, on occasion, lock out the potential to be adaptive.

7.3 Examples of good practice

A number of local authority planning documents have been analysed to identify how and where these enable adaptive approaches to FCERM. These were selected from recognised good practice and the case areas studied through the course of the project. As detailed above, all local planning policies in relation to flood risk management are required to comply with the NPPF, its technical guidance and practice guide to PPS25, all of which promote the sequential and exception tests. Plans are not considered sound unless this compliance is evident and therefore these key elements of planning policy are not investigated as they should be evident in all cases. Instead this section identifies those policies and/or supporting text that:

- highlight a strategic approach to flood risk management and climate change incorporating making space for water;
- promote adaptive schemes;
- acknowledge and seek to address multiple uncertainties;
- explicitly promote an adaptive approach.

7.3.1 Strategic approach to flood risk management and climate change

The NPPF requires that 'Local planning authorities should adopt proactive strategies to mitigate and adapt to climate change, taking full account of flood risk, coastal change and water supply and demand considerations'. All local plans are required to set out policies to adapt to climate change. The examples in Box 7.1 demonstrate policies which enable an adaptive approach through their climate change policies, but also link this to a strategic approach to flood risk management, making space for water and maximising the potential of green infrastructure and ecosystem services.

Box 7.1: Examples of policies which enable an adaptive approach and link this to a strategic approach

Derby – Local Development Framework Core Strategy: Preferred Growth Strategy Consultation Document, October 2012

Derby City Council's Core Strategy expresses commitment to tackling the causes and minimising the effects of climate change by stating that all new development will be expected to take account of the need to reduce the causes of and adapt to the effects of a changing climate and contribute to the strategic objectives of reducing carbon emissions and energy use. Approaches to achieve this include sustainable management of surface water, maintaining local flood pathways and taking opportunities to use green infrastructure to adapt to increasing flood risk.

Leeds Local Development Framework Core Strategy, February 2012

Addressing the challenge of climate change is recognised throughout the Core Strategy. The long-term vision includes the aspiration that by 2028 Leeds will be resilient to climate change through the use of innovative techniques and efficient use of natural resources. In addition, there is a clear commitment to green infrastructure (Policy G1 Enhancing and extending green infrastructure) which is stated to be 'integral to Leeds' resilience to climate change' with an intention to identify, link and extend green infrastructure and increase the amount, distribution and accessibility of greenspace.

Taunton Deane Core Strategy, September 2012

Taunton's climate change policy (Policy CP1 Climate Change) requires that development proposals should result in a sustainable environment, and will be required to demonstrate that the issue of climate change has been addressed by (among other things):

- the protection of the quality, quantity and availability of the water resource;
- incorporation of measures which promote and enhance the resilience of ecosystems and biodiversity networks within and beyond the site;
- measures to minimise and mitigate the risks to the development associated with expected climate change impact.

East Lindsey District Council Draft Core Strategy, October 2012

East Lindsey is likely to be affected more than most areas by climate change and therefore includes specific commitments to addressing this issue now and in the future as set out in the introduction to the Core Strategy.

This states that in order to support its vision of a commitment to tackling the causes and effects of global climate change through local action, East Lindsey District Council will:

- maintain and enhance the district's biodiversity;
- encourage new development to be energy-efficient and carbon neutral;
- support the economy of the coastal communities while not putting more people at risk from flooding;
- locate development to minimise traffic generation.

7.3.2 Promoting adaptive schemes

A number of local plans refer to planned or ongoing flood alleviation schemes within planning policies. Box 7.2 highlights examples where planning policies actively support schemes that take forward a managed adaptive approach.

Box 7.2: Examples where planning policies actively support schemes that take forward a managed adaptive approach

Derby – Local Development Framework Core Strategy: Preferred Growth Strategy Consultation Document, October 2012

The Preferred Growth Strategy Consultation document for Derby supports the 'Our City Our River' scheme, which aims to achieve an adaptive approach and plan for future development. The 'Our City Our River' masterplan document presents a preferred realignment route for the city's flood defences, and through this approach aims to unlock economic potential within the existing flood plain and reconnect the city and the river.

London Plan 2011

The London Plan refers to the Thames Estuary (TE2100) tidal flood risk management study and catchment management plans identifying that fluvial flood risk is likely to increase significantly through the century as a result of climate change requiring continual steering of development to places of lower flood risk and planning new development as a means of reducing flood risk by, for example, providing flood storage/conveyance or setting development back from rivers.

7.3.3 Addressing multiple uncertainties

Coastal planning authorities, in particular, are faced with competing priorities in relation to managing flood risk as a result of sea level rise, addressing economic and social regeneration requirements and managing other objectives such as protected landscapes and agriculture. This is a particular issue for the planning authorities along the North Norfolk and Lincolnshire coastline. Box 7.3 gives examples of policies aimed at managing multiple uncertainty and competing pressures.

Box 7.3: Examples of policies aimed at managing multiple uncertainty and competing pressures

Borough Council of King's Lynn and West Norfolk Core Strategy, July 2011

Policies for King's Lynn highlight the importance of regeneration within areas that are at risk of flooding. This remains a common theme throughout the Core Strategy and is reflected in strategic, spatial and thematic policies, which state that the council will 'seek to resolve the need for economic and social regeneration in those parts of the town which are at risk to flooding'.

London Plan 2011

The London Plan recognises the multiple impacts likely to result from climate change including tidal surges, fluvial flooding and surface water flooding and the effect these could have on the 1.5 million people who currently live on the flood plain of the Thames and its tributaries. It also identifies that these impacts are likely to be worst for deprived communities, many of which live in the affected areas and are unlikely to be insured. Water shortage is also identified as an ongoing challenge which is likely to increase in frequency and severity with climate change. The Plan recognises that climate change issues and their impacts on the way London 'works' are likely to dominate the policy agenda and should drive a shift to a new low carbon economy.

7.3.4 Explicitly adaptive policies

Some plans include policies and/or supporting text which is explicitly adaptive in approach by either promoting the need to be flexible in order to respond to future challenges or identifying these challenges and the changes that may be required in terms of patterns of land use and development. Examples are given in Box 7.4.

Box 7.4: Examples of explicitly adaptive policies

Taunton Deane Core Strategy, September 2012

Supporting text to Policy CP1 Climate Change states 'adapting to the effects of climate change through location and design considerations will be of increasing importance throughout the Plan period as the impacts of climate change are increasingly felt'.

Borough Council of King's Lynn and West Norfolk Core Strategy, July 2011

The impact of flooding and climate change is recognised as a threat to the distinctive villages, landscape and heritage of the area. In adapting to flooding and climate change, the Core Strategy will promote new and innovative approaches to mitigate risk which do not undermine existing coastal assets. The Sustainability Appraisal of the Core Strategy has highlighted that some land may in time be lost to the sea, therefore it is important that mitigation strategies are developed for threatened sites that may be designated of special importance, historical interest or particular landscape character.

West Lancashire District Council Core Strategy Preferred Options, May 2011

The preferred option includes a section focused on maintaining flexibility in relation to managing the risks that the Core Strategy needs to address. This highlights that the Core Strategy should be flexible enough to enable future changes in terms of patterns of development that may arise as a result of new evidence. A Plan B approach is highlighted, which essentially allows for more development on the green belt should the plan's development targets not be met. While this is not a decision that focuses on climate change, it sets out an adaptive approach and highlights how flexibility can be built into local plans.

The Council believe that the locally-determined targets that have been proposed in this Preferred Options document are fair and reasonable in light of all the available evidence at this time and it is anticipated that, if there is any change, new evidence over the Core Strategy period will actually point to the need for slightly lower targets for housing and employment, especially given the environmental and infrastructure constraints that the Borough faces. However, it is possible that targets for housing and employment will rise, meaning that new locations for development would need to be identified, and so in this situation the 'Plan B' would also provide the flexibility required to accommodate this rise.

7.4 Implications for the promotion of managed adaptive approaches

The review of guidance and consideration of good practice examples highlights a number of issues which should be taken into account in any further reviews and revisions of national planning and FCERM policy guidance:

- The NPPF contains no overarching objective or principle concerning the need for the planning system to recognise and respond to uncertainty whether this is climate change, population growth or any other long-term uncertainty. Land use is a key issue that will affect and be affected by longer term uncertainties, and adaptability should be embedded within the spatial planning and development planning system to respond to such uncertainties.

- The NPPF places flooding firmly in the wider context of climate change; this provides a good platform for taking forward an adaptive approach suggesting that current decisions should be made taking into account future known and unknown climate change impacts. However, encouragement of managed adaptive approaches is only highlighted in relation to coastal erosion and should also make reference to fluvial flooding.

- The zoning approach, promoted through the sequential and exception tests, fails to recognise the dynamic nature of flooding which will be impacted by climate change and other uncertain futures. Regular review of flood zones in strategic flood risk assessments should be required in response to identified trigger points such as new climate change information, major flooding events etc. In addition, climate change should be considered in both vertical (flood depth) and horizontal (flood extent) terms.

- The PPS25 Practice Guide (DCLG, 2009) (which will be refined and updated following the Taylor Review) provides specific advice in relation to taking climate change into account in the design of flood risk management measures and promotes the flexibility of managed adaptive approaches. However, it is recognised that in practice the Environment Agency tends to take a strongly precautionary approach with regards to new development. The need for a change in culture and mindsets as identified in section 4 applies to decision makers within the Environment Agency as well as local stakeholders and practitioners.

- Planning Policy Wales and TAN15 present the adaptive and precautionary approaches as separate options. The two are not necessarily mutually exclusive and can be combined depending on circumstances. Because of the risk aversion associated with planning for climate change and new development, it is likely that the precautionary approach will prevail. This could result in locking out adaptive solutions.

- TAN14 on coastal planning is in urgent need of review and updating; this document is more than 15 years old and considerable advances have been made in the provision of data and development of policy with regards to coastal planning over this time period.

- Enabling planning to facilitate time-limited decision making, which keeps several future options for development open, will be difficult when the precautionary approach is so well embedded in policy and practice.

- Further guidance needs to be provided regarding the types of conditions that could accompany planning permission to ensure developments remain adaptable in the context of a changing climate.

- The NPPF should be a sufficient trigger for spatial plans to consider and start the debate at a local level about the adaptive choices that should be considered and ultimately feed through into FCERM scheme appraisals. Further reinforcement, through initiatives such as Climate Local and the Environment Agency's Climate Change e-learning module and support tools is, however, essential to ensure that a joined up and strategic approach is being taken. The direction of travel is set out, the question is whether amid the current pressure on growth, sufficient time and inspiration is available to look at forward planning in a longer term holistic manner. This cannot be done in a vacuum and the risk management authorities must be heavily involved in bringing the debate into the important area of how to sustain existing communities through new development or regeneration. An integration of the work of the lead local flood authority, the planning authority and the Environment Agency in seeking an adaptive future, will require the tools associated with options appraisal. Scenario development and Partnership Funding will be an obvious area that is required. These plan-based triggers will need alternative routes and direction in Wales, where TAN15 remains the prime but limited lever to prompt a change in approach.

- With every consultation regarding planning policy, there are constant calls for the planning system to provide greater certainty for developers, planning officers and communities. This must be balanced with the need to accept uncertainty which is the basis of an adaptive approach.

- Guidance that refers to allowing development in flood risk areas if it is safe over its planned lifetime is a difficult guarantee to make, particularly with regards to climate change.

- At the workshop held to review the various tools that have been produced through the project, there was discussion about the development of 'adaptive' objectives which was relevant to the identification of planning policies that embed an adaptive approach. The general view was that objectives do not necessarily need to explicitly promote an adaptive approach, provided that they do not rule out the potential for future flexibility, which can be achieved through a broader focus on sustainability. Objectives and planning policies that focus on responding to and being resilient to future uncertainties, should engender an adaptive approach.

8 Conclusions and recommendations for further research

8.1 Conclusions

Understanding and managing future uncertainty is complex and therefore developing the approaches to assess the value of responses to such uncertainty requires a clear and structured approach. This project and its resulting outputs have made significant progress in providing approaches which assist decision makers and practitioners in developing and appraising managed adaptive approaches. In particular, these provide an approach which:

- Supplements existing appraisal guidance, such as FCERM AG. The Guide is intended to provide advice on how to take forward the approaches set out in the climate change supplementary advice to the Green Book and the Environment Agency's (2010c) climate change advice.
- Provides clear guidance on where there is a need to fully value adaptive approaches (i.e. where significant change is likely and substantial uncertainty is faced). Where the situation is less uncertain and damages are smaller, such a full analysis is not necessarily required.
- Offers a measured step forward in illustrating how strategies can be expressed as decision trees and facilitating the development of multiple futures.
- Supports both probabilistic and non-probabilistic analysis. The Green Book supplementary guidance motivates us to consider how practitioners can make the decision tree and real options analysis work in practice. A fully probabilistic analysis developing the Green Book advice remains challenging, hence the probabilistic and non-probabilistic analysis approach set out in section 6.
- Identifies situations where climate uncertainties can be given probability weightings based on (arguably) objective science and also deep uncertainties where this may not be appropriate.
- Improves the ability to value managed adaptive approaches in appraisal. This does not necessarily require complex analysis, but means that the realities of an uncertain future can be acknowledged and reflected in the appraisal process.

8.2 Recommendations

There remains a need for the ongoing evolution of guidance, building on future research and practical experience. Specifically, further work is required in relation to:

- The development of decision trees in order to assist with the appraisal of more complex decision structures. The project has offered some basic guidance, but currently there are only a few examples of more complex situations that users can learn from.
- The development of futures and the application of weightings to these. There remains work to be done to derive weights for alternative futures when robust evidence becomes available to do so. While UKCP09 offers information for climate projections, other factors are harder to weight. Stakeholders may perceive some futures to be more likely than others, but may well disagree in their judgements. There is currently unlikely to be sufficient objective evidence to resolve these

disagreements completely. In those circumstances, it will be necessary to explore decision sensitivity to a range of plausible weights.

- The development of a set of prepared benefit estimates or multipliers linked to autonomous futures so as to provide a consistent treatment of uncertainty. This would entail substantial additional work to offer national provision, for example, but would remove a significant barrier to uptake of the approach in practice. It should be noted that this is a very ambitious objective and may not be practically achievable, but the potential should be investigated further.
- The provision of additional guidance concerning the scoring and weighting of individual variables in the supporting option screening multi-criteria decision analysis (MCDA) tool.
- The development of a dedicated Outcome Measure for Flood and Coastal Resilience Partnership Funding concerning adaptability.

Recommendations for future reviews of national planning policy guidance:

- National planning policy statements should contain an overarching objective or principle concerning the need for the planning system to recognise and respond to uncertainty, whether this is climate change, population growth or any other long-term uncertainty.
- The NPPF should explicitly encourage managed adaptive approaches with regards to all forms of flooding, not just coastal flooding and erosion.
- Regular review of flood zones in strategic flood risk assessments should be required in response to identified trigger points such as new climate change information, major flooding events etc. In addition, climate change should be considered in both vertical (flood depth) and horizontal (flood extent) terms.
- Precautionary and managed adaptive approaches should not be presented as alternatives. Managed adaptive approaches should be highlighted within the context of their potential to be precautionary. The prevailing imperative for precautionary approaches will remain until decision making at all levels – Environment Agency nationally and regionally, and local stakeholders – embraces adaptive approaches.
- TAN14 on coastal planning was published in 1998 and is therefore in urgent need of review and updating.
- Further guidance needs to be provided regarding the types of conditions that could accompany planning permission to ensure developments remain adaptable in the context of a changing climate.
- The NPPF should be a sufficient trigger for spatial plans to consider and start the debate at a local level about the adaptive choices that should be considered and ultimately feed through into FCERM scheme appraisals. Further reinforcement, through initiatives such as Climate Local, and the Environment Agency's Climate Change e-learning module and support tools is, however, essential to ensure that a joined up and strategic approach is being taken. An integration of the work of the lead local flood authority, the local planning authority and the Environment Agency in seeking an adaptive future, will require the tools associated with options appraisal. Alternative future development and Partnership Funding will be an obvious area that is required. These plan-based triggers will need alternative routes and direction in Wales, where TAN15 remains the prime but limited lever to prompt a change in approach.
- Objectives, and planning policies, which focus on responding to and being resilient to future uncertainties, should engender an adaptive approach.

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Glossary

Adaptability	Those characteristics of a FCERM plan that sustain and enhance the function of a system in the face of continuing change or uncertainty. Adaptability is about incorporating flexibility, not closing off future options prematurely but enabling evolution of the FCERM plan, and also the function of the system.
Adaptation	The ongoing adjustment in natural, engineered or human systems in response to actual or changing expectations in climate or other drivers of risk. Adaptation may be either autonomous (and achieved through natural change) or planned (and achieved through purposefully adaptation planning; replacing the reactive adaptation often seen in response to an extreme flood that has invariably been characteristic of traditional flood control approaches).
Adaptive capacity	The general ability of institutions, management systems and individuals to adjust to future change in order to take advantage of opportunities that arise and appropriately manage additional risks that are presented with minimum use of resources (social, financial and ecological).
Alternative, autonomous futures	Futures which are not purposefully influenced by flood risk management measures and related policy instruments and, as far as possible, are independent of one another.
Appraisal	The process of defining objectives, examining options and weighing up the costs, benefits, risks and uncertainties of those options before a decision is made.
Benefit cost ratio	An indicator, used in the formal discipline of cost-benefit analysis that attempts to summarise the overall value for money of a project or proposal. A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. All benefits and costs should be expressed in discounted present values.
Decision pathway	A sequence of decisions that can be regarded as a 'unique route' through the options in a decision tree. A decision pathway is the result of applying a strategy in a given future.
Decision strategy	A set of rules which define how a portfolio of measures will be put together and how decisions will be taken in order to lead to a defined outcome.
Decision tree	A graph that sets out present and future options in a tree-like structure based on nodes (decisions) and branches (measures).
Decision tree analysis	A method of analysing the possible economic consequences of choosing a particular option, based on quantifiable performance measures.

Expected performance	An average of the economic performance of an option over all defined futures.
Flexibility	The ability of a given FCERM measure, option or plan to be changed as the reality of the future unfolds and/or projections of the future change.
Flood and Coastal Erosion Risk Management (FCERM) measure	Any physical construction (structural measure) to reduce the chance or severity of the flood waters reaching a receptor, or any measure not involving physical construction (non-structural measure) that uses knowledge, practice or agreement to reduce risks and impacts (in particular through policies and regulatory instruments, forecasting and warning, public awareness raising, training and education).
Flood and Coastal Erosion Risk Management (FCERM) option	An accepted set of measures and instruments that may be implemented from now into the future and seeks to achieve a given set of objectives. The preferred FCERM option(s), once selected, are then implemented through the FCERM plan.
Flood and Coastal Erosion Risk Management (FCERM) plan	A coherent plan(s) that set out goals, specific targets, decision points and the mix and performance of both structural and non-structural measures to be employed. Flood risk measures within the plan are then grouped into coherent packages (here termed FCERM option(s)) as the basis for further development and implementation (asset management, flood warning, development control etc).
Future scenario	Internally consistent verbal picture of a future phenomenon, sequence of events, or situation, based on certain assumptions and factors (variables) chosen by its creator. In this study we have used scenario to describe the future according to one variable (e.g. climate change projections). Alternative futures represent the future storylines that may result from a combination of scenarios (e.g. climate change and economic growth).
Future uncertainty	Conditions that may occur in the future, the exact scale, composition and impact of which are currently uncertain, such as climate change, economic growth and population change.
Investment plan	A single investment pathway with known costs and potential benefits – either fixed (no future intervention allowed) or flexible (intervention allowed).
Low regrets option	Adaptive measures which have relatively low associated costs and relatively large benefits, although these will primarily be realised under projected future climate change or the realisation of other future uncertainties.
Managed adaptive approaches	Flexible approaches that are capable of addressing future challenges and opportunities (which are currently uncertain or unknown) as they arise.

Managed realignment	This approach allows an area that was not previously exposed to flooding by the sea to become flooded by removing coastal protection. This process is usually in low-lying estuarine areas and almost always involves flooding of land that has at some point in the past been claimed from the sea.
Measures	Actions that can be taken to alleviate the impacts of flooding or coastal erosion (e.g. construction of a sea wall, development of a storage pond etc.).
Maximin	A decision method which seeks an option that has the best 'worst case' performance.
Minimax	A decision method which seeks an option that minimises the lost opportunity, or regret, should a worst case scenario materialise.
Net present value	The 'difference amount' between the sums of discounted: cash inflows and cash outflows. It compares the present value of money today to the present value of money in the future, taking inflation and returns into account.
Objectives	Specific goals that a particular project or plan is aiming to achieve.
Opportunity loss	A measure of the potential benefits foreclosed by a choice, also known as **regret**, defined here by a comparison, in a given future, between the best outcome attainable from a chosen option and the best outcome attainable from any option.
Option	A choice that is available at some time in the future.
Precautionary approach	Acting as early as possible to manage potential risks, where upfront costs are likely to be high.
Probability weight	A measure of belief that a particular future (climate or otherwise) is realistic.
Quality criteria	Criteria that will be used to assess whether the final outputs from the appraisal have achieved their goals and why those goals are important.
Resilience	The ability of an individual, community, city or nation to resist, absorb or recover from a shock (e.g. an extreme flood), and/or successfully adapt to adversity or a change in conditions (e.g. climate change, economy turn down) in a timely and efficient manner.
Robustness	The ability of a given FCERM measure, option or plan to perform adequately across a wide variety of possible futures.
Win–win option	Adaptive measures that have the desired result in terms of minimising the climate risks or exploiting potential opportunities, but also have additional social, environmental or economic benefits.

Abbreviations

AST	appraisal summary tables
BCR	benefit cost ratio
CFMP	Catchment Flow Management Plan
CCMA	Coastal Change Management Area
Defra	Department for the Environment, Food and Rural Affairs
FCERM	Flood and Coastal Erosion Risk Management
FCERM AG	Flood and Coastal Erosion Risk Management appraisal guidance
IPCC	Intergovernmental Panel on Climate Change
LPA	local planning authority
MCDA	multi-criteria decision analysis
NCPMS	National Capital Programme Management Service (Environment Agency)
NPPF	National Planning Policy Framework
NPV	net present value
PAR	project appraisal report
PLP	property level protection
PPS	Planning Policy Statement (England)
PPW	Planning Policy Wales
RMA	Risk Management Authority
SDS	sustain defence standard
SEA	strategic environmental assessment
SFRA	strategic flood risk assessment
SoP	standard of protection
SMP	Shoreline Management Plan
SoS	standard of service
SuDS	Sustainable Urban Drainage Systems
SWMP	Surface Water Management Plan
TAN	Technical Advice Note (Wales)
TE2100	Thames Estuary 2100 Plan
UK CIP	UK Climate Impacts Programme
UKCP09	UK climate projections

Appendix A

Real Options Analysis of Adaptation to Changing Flood Risk: Structural and Non-Structural Measures - Miyuki Hino and Jim Hall, Environmental Change Institute, University of Oxford, UK

ABSTRACT

Real options analysis provides a means of appraising the benefits of introducing or preserving flexibility in flood risk management decisions. Building in optionality can help to create flood risk management strategies that are robust to a range of possible future conditions. Real options analysis has therefore been attracting increasing attention as an approach to climate change adaptation decision making, and in particular for adapting flood protection infrastructure to the uncertain impacts of climate change. Further to recent studies, here we present methodology where future decision makers are taken to be rational optimizers who benefit from improved information compared to the present day. We demonstrate the sensitivity of two archetypical flood risk management decisions to uncertainty both in future river flows and to socio-economic change. In the first, a flood protection dike can be built with a widened base, providing the option to heighten it at a later date, or it can be built to a fixed height with no further options apart from costly reconstruction. In the second problem, a portion of undeveloped, flood-prone land separates an existing development from the river. A decision can be made to purchase the land and forgo development. A real options analysis is used to identify the circumstances in which it is cost-beneficial to purchase the land, which depends on the value of existing assets exposed to flooding and how that value would change were development to take place.

1. Introduction

Potential losses due to flooding are projected to rise as a result of more frequent extreme weather events and greater value of assets exposed to such disasters (Evans et al., 2006, Wilby et al., 2008, Botzen and Van Den Bergh, 2008). However, the nature and magnitude of this increase depend on a number of uncertain factors including effects of climate change on precipitation and river flows, adaptation measures, and socio-economic development. These inherent uncertainties complicate the high-cost, high-consequence question of how to manage flood risk.

In recent decades, quantified risk analysis has replaced deterministic engineering standards as the basis for flood management decisions (Sayers et al., 2002, Sayers, 2012). Risk is defined as the product of probability of a given flood event and the consequences of the flood event (USACE, 2006). The benefit of an intervention designed to reduce flood risk is measured as the difference in risk before and after the intervention (the 'residual' risk) (Hall and Solomatine, 2008). This beneficial risk reduction can be compared with the cost in order to compare alternative interventions. The approach provides a rational basis for decision making, but is limited by (i) the difficulties of fully valuing and comparing all costs and benefits and (ii) the uncertainties, in particular in projections of future risks and costs.

There are multiple sources of uncertainty in flood risk management decisions (Hall and Solomatine, 2008, Merz et al., 2010), associated with changing environmental and socio-economic conditions. Changing environmental conditions may be associated with climatic or catchment land use changes and alter the frequency of hazardous events such as extreme flows. Socio-economic changes can influence the vulnerability and exposure of people and property located in floodplains. In this study we address the uncertain effect of climate change on river flows and the potential effects of economic development and growth on floodplain vulnerability.

Studies have identified a variety of methods of analysing changing flood risks (Merz et al., 2010). One such method is scenario analysis, in which flood risk projections are developed under various climatic and socioeconomic futures and potential responses are tested in each scenario (Hall et al., 2003, Evans et al., 2006). Hine and Hall (2010) employ info-gap theory to test for sensitivity to uncertainty in cost, rate of increase in vulnerability, and rate of sea level change and identify robust options that perform well over a wide range of conditions.

One possible way of helping to ensure that options perform well over a range of future conditions is by building in flexibility, so that the decision can be adapted or modified in future. Flexibility can seldom be achieved without incurring additional cost. The decision problem then becomes one of weighing up the costs of introducing flexibility with the benefits that flexibility provides by possibly enhancing performance in some future conditions. Real options analysis provides methodology for valuing the benefits of flexibility , and has been advocated by HM Treasury (2009) for appraisal of capital investment decisions that are sensitive to the impacts of climate change.

Similar to a financial option, a real option is the opportunity, not obligation, to take future action if it will reduce cost or increase benefit (Dixit and Pindyck, 1994). The initial investment is a sunk cost, but as time passes and uncertainty over future benefit is reduced, the value of further investment can be ascertained with greater confidence. Real options methodology considers the value added by the temporal flexibility of the second investment. Unlike financial stocks, real options represent irreversible investments such as infrastructure.

Real options theory has in recent years been applied to flood risk management decisions, with an emphasis upon the benefits of providing flexibility in the design of flood walls. In some situations, the embedded flexibility provides a cost-effective means of coping with an uncertain future; in others, the additional upfront cost makes the real option prohibitively expensive. Linquiti and Vonortas (2012) model how two different real option frameworks for coastal protection systems perform in comparison to an inflexible strategy. In the first real option strategy, titled “Sense & Respond,” planners use local observations about changing conditions to determine the appropriate protection level. This retroactively adaptive model allows building to take place as frequently or infrequently as needed. In the second, “Predict & Respond,” extrapolations of observed changes are used to forecast risk over the next 20 years. The flood protection is then optimised using the sum of protection costs and residual damage as the performance metric. Results from the Monte Carlo simulations demonstrate that the inflexible strategy is preferred to the Sense & Respond retroactive approach. However, depending on the vulnerability of the coastal area, the Predict & Respond strategy reduced costs by up to 28% in comparison to the conventional flood protection.

In a case study applying real options methodology to flood risk management in the Thames Estuary, Woodward et al. (2011) compared the performance of flexible and inflexible strategies under three different emissions scenarios and two different discounting systems. In the flexible strategy, the foundation of a flood dike is widened in 2010, with the option to raise it to an appropriate height in 2040. Two different traditional strategies are evaluated: in the first, the dike is both widened and raised in 2010 to meet the medium emissions scenario with no further action, and in the second, the dike is only refurbished in 2010, with widening and raising according to sea level rise in 2040. The results illustrate that while real options solutions provide significantly higher NPVs and BCRs across many emissions scenarios, they are not preferred universally. Using the same case study, in subsequent work, Woodward et al. (2013) used a multi-objective optimisation method to sample a large space of possible intervention strategies, separating minimisation of cost and maximisation of economic benefit as two separate objectives. Options were evaluated over a range of probability weighted sea level rise scenarios, with future options being exercised based on whether or not sea level exceeded a pre-specified threshold.

We argue that future decision makers are more likely to themselves be applying benefit-cost criteria, rather than adopting sea level thresholds that were set in the past, which doubtless will have become obsolete thanks to new information that has emerged in the meantime. In this paper, at any time-point in the future the decision maker evaluates the options at their disposal. We also embed an optimisation process for choosing the protection level, based on benefit-cost ratio. By incorporating two layers of flexibility for the real option (timing and protection level), we ensure that the option value is more fully captured. Moreover, whilst previous studies have dwelt upon potential future modifications to flood dikes, here we also address optionality in land use planning decisions.

In the following section we set out the risk analysis and options appraisal framework that has been used throughout the study. We then apply it to two decision problems (1) appraising the benefits of building in flexibility in the design of a flood dike and (2) appraising the decision of whether to permit of forego development on a plot of riverside land. The former case is novel in the nested optimisation procedure that we propose whilst the latter is the first example that the authors are aware of using real options analysis to appraise a non-structural flood protection decision.

2. Risk-based appraisal framework

Our simulation study of the decision problem conform to the layered architecture introduced by Harvey et al. (2012). At the core of the analysis is a deterministic calculation of flood impacts (damages). An estimate of risk is built up by sampling probability distribution of environmental conditions (e.g. river flows) at any given time in future, and integrating to obtain the expected damage. Risks are aggregated through time by discounting to Present Value. Risk can be reduced by deliberate interventions in the system, which incur some cost. The performance metric for any given decision is the (discounted) Benefit-Cost Ratio (BCR) or the Net Present Value (NPV) relative to the ‘do nothing’ base case. The risk at any instance in time is conditional upon an assumption about the exogenous future changes in environmental conditions and socio-economic vulnerability. These uncertainties are analysed through the use of scenarios as the outer layer in the appraisal framework. We now describe each layer in this framework.

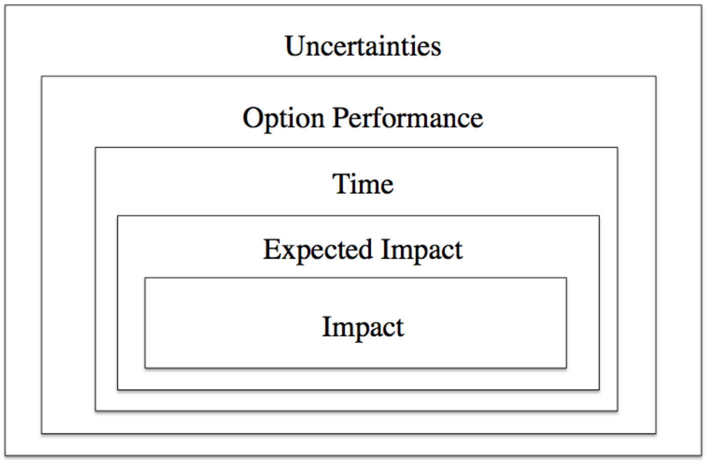

Figure A.1 Overview of the option performance calculation

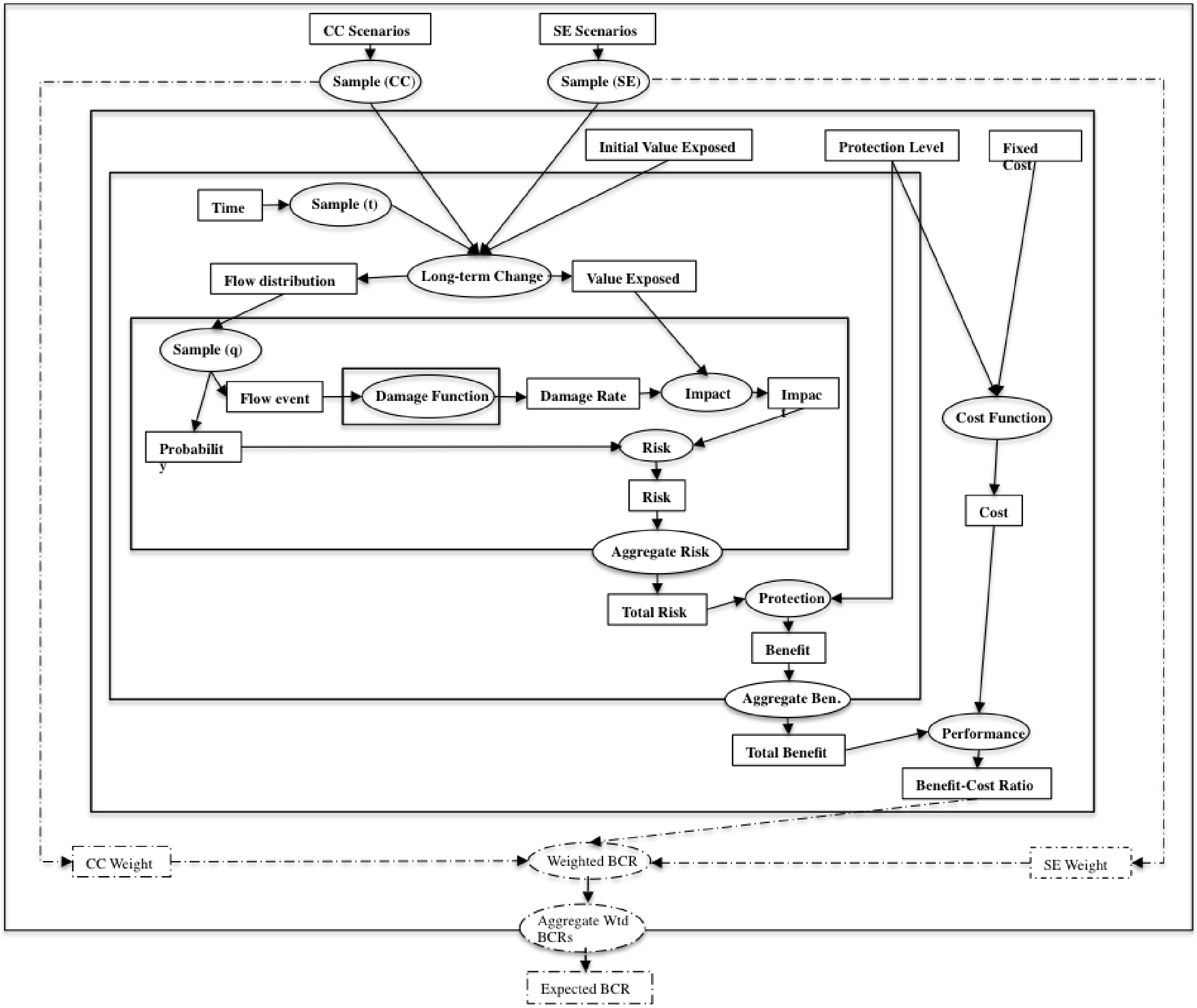

Figure A.2 The option performance calculation. Rectangles denote data sets and ovals denote transformations between them. The dashed lines indicate calculations that are optional and necessary only when calculating a single BCR for the option.

2.1 Flood damage calculation

The economic damage that occurs during a flood event is computed by consideration of the damage to properties located in the floodplain. In practice this is represented by a function that relates river flow, q, to the proportion, e, of potential damage, up to a total possible damage of 1. Up to a certain threshold flow rate, q0, no damage is incurred (either no flooding occurs, or the flooding does not affect the community). Damage increases as flow rate exceeds that threshold. Here a damage of 1 is assigned to the flow rate corresponding to the 1:500 year flow. The intermediate values scale quadratically such that:

$$e(q) = \frac{(q-q_0)^2}{(q_{500}-q_0)^2}.$$

2.2 Flood impact

The impact of the flood event is calculated as the product of the damage rate, e, and the value of assets exposed (v) in the community: $d(q) = v.e(q)$. The value exposed depends on the number of assets as well as the value of those assets. In the examples presented here, we do not distinguish between the two components, but vary v from 1,000 to 15,000 to test for sensitivity.

2.3 Flood risk

In situations of a risk-neutral decision maker, decisions can be made on the basis of expected damage, which we use here as the metric of flood risk. Flood risk is computed by integrating the probability density function f(q) of flow with the flow-damage function (Dawson et al., 2005):

$$r = \int_{q_0}^{q_{500}} f(q)d(q)dq \qquad (1)$$

The exceedance distribution of damage $1 - F_D(q)$ is illustrated in Figure A.3.

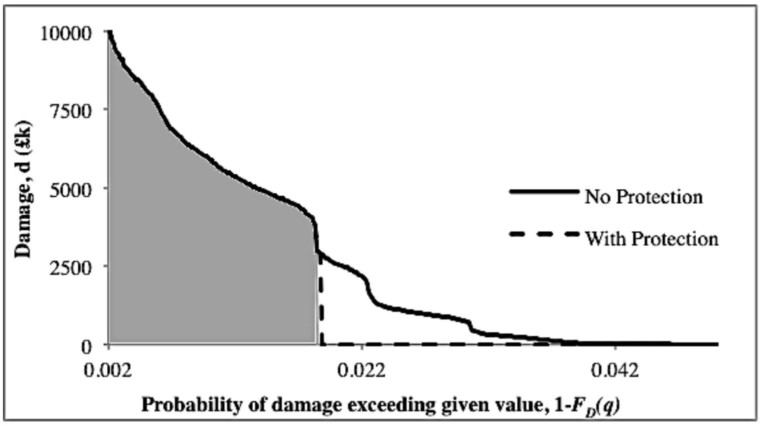

Figure A.3 Damage-exceedance plot for defended (grey shaded) and undefended locations

2.4 Reducing risk with flood dikes

Construction of a flood dike will reduce the risk of flooding by protecting the vulnerable area from flooding up to the flow, qp, for which the dike has been designed. There is also a small but finite probability that the flood dike will breach at lesser flows, but here we neglect that probability, and we also assume that the dike provides no protection for flows greater than its protection level. There remains a residual risk, r', associated with those conditions in which the flow exceeds the protection level of the flood dike:

$$r' = \int_{q_p}^{q_{500}} f(q)d(q)dq \quad (2)$$

The protection level range tested begins at 150 and ends at 700.

2.5 Cost of flood protection

The cost of building a flood protection includes a variety of costs such as land acquisition, materials, labour, management, and maintenance. In this study, the total cost is broken down into a fixed cost and a height-dependent variable cost. The flow rate, qp, represents the greatest flow against which the dike provides protection. Following Al-Futaisi and Stedinger (1999) we take the cost function to be of the form:

$$c(q_p) = c_f + \alpha_c({q_p}^{0.6} - q_0^{0.6})^{\beta_c} \quad (3)$$

where c_f is the fixed cost. We select the scaling constant, α_c, to be equal to 1 and take $\beta_c = 2.3$ which is in the middle of the range quoted by Al-Futaisi and Stedinger.
An adaptive flood protection has a higher up-front fixed cost $c_{f,Adapt1}$. Any subsequent upgrade has a fixed cost $c_{f,Adapt2}$, and the variable cost depends on the difference in protection level between the existing and final situations:

$$c_{Adapt2}(q_{p2}) = c_{f,Adapt2} + [({q_{p2}}^{0.6} - {q_0}^{0.6})^{2.3} - ({q_{p1}}^{0.6} - {q_0}^{0.6})^{2.3}] \quad (4)$$

where q_{p1} is the Phase 1 protection level and q_{p2} is the protection level of the Phase 2 upgrade.

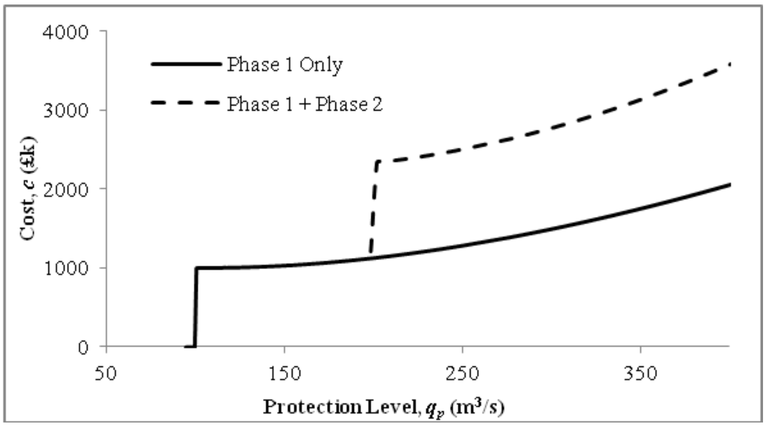

Figure A.4 Cost functions. Phase 1 q_p = 200, c_{f1} =1000 and c_{f2} = 1200

For a given flow distribution, damage function and cost function, the protection level of a flood dike can be optimized by discounting costs and benefits over a time horizon T at a discount rate s:

$$q_{p,opt} = \max_{q_p} \sum_{t=0}^{T} \frac{1}{(1+s)^t} \left[\frac{r_t - r'_t(q_{dp})}{c_t(q_p)} \right] \quad (5)$$

where subscript t denotes that a cost or risk is incurred in year t (Figure A.5). The discount rates employed here closely follow HM Treasury guidance: 3.5% for years 0-29, 3.0% from 30-69, and 2.5% thereafter (HM Treasury, 2003).

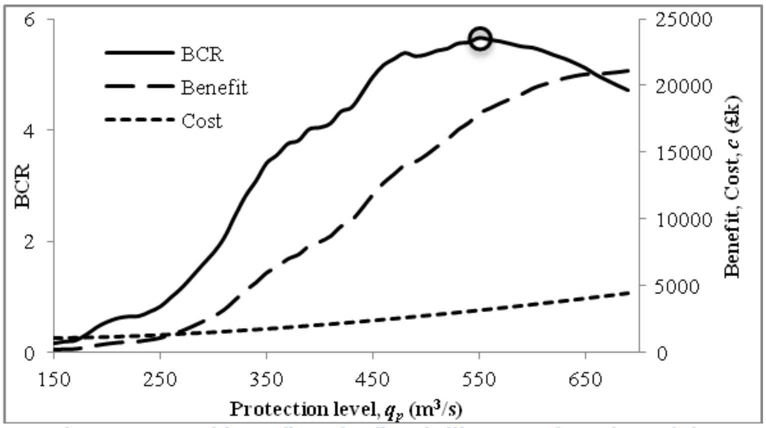

Figure A.5 Present Value costs and benefits of a flood dike, as a function of the protection level, illustrating the optimum protection level (circled)

2.6 Future Scenarios

All of the calculations outlined above are conditional upon an assumed set of future changes in flood hazard and potential flood damages. In the outermost layer of the risk calculation, a range of future flow distributions (attributed to changing climatic conditions) and socio-economic changes are sampled.

2.6.1 Climate change

The projected changes to future flows are based upon the UKCP09 climate projections (Murphy et al., 2009). A sample of 6 representative changes in future flows that span the range of future changes was obtained by propagating the precipitation scenarios through a rainfall-runoff model (Reynard et al., 2009). Each climate change scenario consists of nine decadal flow distributions, for the decades 2010s (t=10) to 2090s (t=90). The baseline flow distribution is generated from 1961-1990 data (t=0). The change factor CC1 features a steady increase in average flow rate over time, while the average flow rate in CC6 decreases from the 1961-1990 baseline. The four middle change factors were chosen as roughly equally spaced intermediate scenarios.

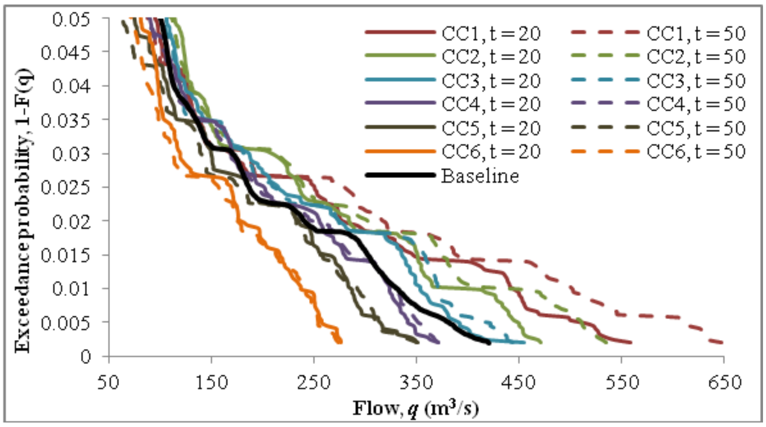

Figure A.6 Changing flow distribution for six climate change scenarios.

Where required in the decision analysis, the scenarios are weighted based on the corresponding probability distribution of UKCP09 change factors (
Table A.1), which are obtained by using these representative scenarios to partition the full Monte Carlo distribution of 10,000 change factors provided by UKCP09 and

allocating weights according to the relative count of change factors that fall into each set in the partition.

Climate change scenario	Weight
CC1	0.1
CC2	0.15
CC3	0.3
CC4	0.2
CC5	0.15
CC6	0.1

Table A.1 Weightings used for the climate change scenarios

2.6.2 Socio-economic changes

The socioeconomic growth scenarios represent different annual rates at which the value of existing assets increases. Bouwer et al. (2010) define the factor f_s, which is applied to the damage to floodplain properties:

$$f_s = \left(\frac{I_{gdp}}{(I_h + I_i + I_o)/3}\right)^t \qquad (6)$$

where I_{gdp} is the index for annual change in GDP, I_h is the index for number of change in households, Ii is the index for surface area occupied by industry, and I_o is the index for surface area occupied by offices. Here, we use values of f_c in the range 0.7% to 1.7%. The different growth rates are illustrated in Figure A.7.

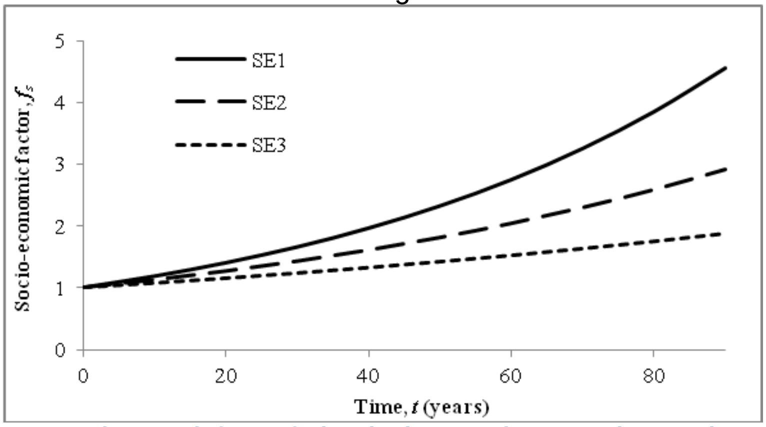

Figure A.7 Socio-economic growth factor f_s time in three socioeconomic growth scenarios

Where weights are required in the analysis, these socio-economic scenarios are equally weighted and are taken as being independent of the climate change scenario. It should be stressed that in the cases of both the climate change scenarios (which include implicit assumptions about emissions scenarios) and socio-economic scenarios, the use of probability weights could be taking as mis-representing severe uncertainties (Hall and Solomatine, 2008, Hall, 2007). Here we only apply weights where the real options methodology requires the calculation of expectations, and seek to demonstrate how the decision analysis can be used to identify options that are robust with respect to a range of uncertainties.

The probability-damage curve depends on the climate change scenario, socioeconomic scenario, and time period
Figure A.8. As time passes in the CC1/SE1 scenario, the probability-damage curve rises and shifts to the right, therefore increasing the expected annual damages. On the other hand, the CC6/SE3 scenario exhibits relatively little change from t = 10 to t = 90. The curve rises slightly and shifts to the left due to decreased flow rates.

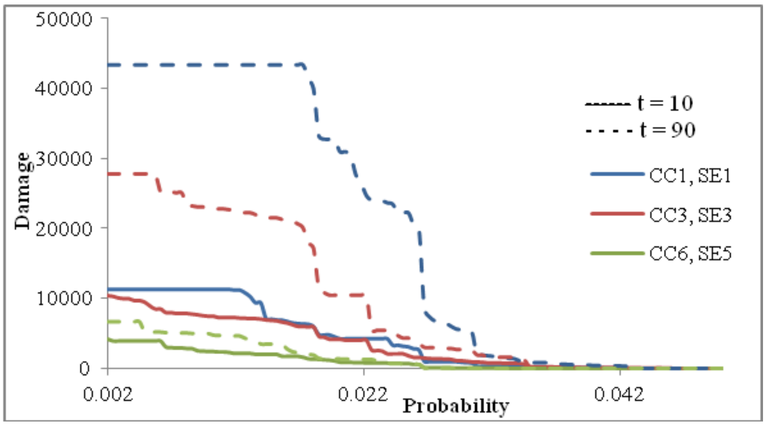

Figure A.8 Probability-damage curves (undiscounted) of different scenarios at t = 10 and t = 90

2.7 Decision making under uncertainty

While uncertainty can never be eliminated, the passage of time will lead to greater knowledge and confidence regarding the impacts of climate and socioeconomic growth. It is impossible to know how quickly or to what degree our uncertainty will be reduced. Here we allow for an initial 15-year period to elapse, after which we assume that we know with confidence which scenario will materialise. As this study is based on a decadal time scale, the earliest that any intervention can take effect is at $t = 20$. This five-year delay also provides a window for construction to take place if necessary.

From $t = 20$ onward, the timing of any construction will be determined by benefit-cost ratio such that building will occur if and when the BCR of doing so exceeds a certain trigger value. This condition will not necessarily lead to the highest overall BCR when considering the entire project, but future generations will not consider past costs when evaluating whether or not to proceed with construction. In theory, the trigger BCR should be unity to justify spending, but in a resource-constrained reality the BCR of most flood protection schemes is much higher. We vary the trigger BCR value from 3 to 8 in order to evaluate its effect on our results.

The assumption of uncertainty becoming completely resolved in 15 years' time is clearly a simplification, which has been made in order to avoid the need to make difficult assumptions about the rate at which uncertainty will be reduced. The assumption will tend to over-value the benefits of delaying decision making to acquire more information, as it is assumed that an unrealistic amount of information will be forthcoming in future.

3. Case study 1: appraising flexibility in flood dikes

Here we consider the option value of building a flood dike that may be adapted in future if it becomes economically beneficial to do so. The protection levels are selected based on an optimization process. Moreover, the timing of future interventions is not pre-specified but occurs when it is cost-beneficial to do so. The decision strategies are characterised in Figure A.9.

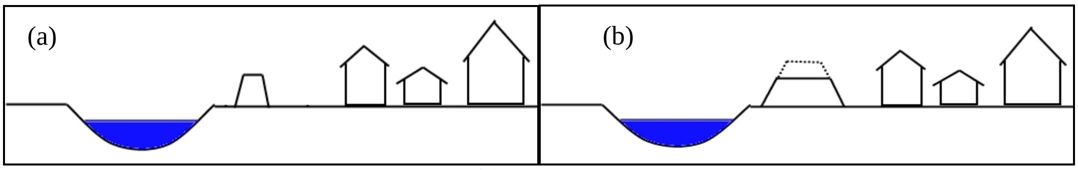

Figure A.9 (a) "Fixed" and (b) "Adaptive" flood protection options, where the dashed line in (b) represents the second building phase

"Fixed" design: This flood risk management strategy consists of building a dike at t = 0, with no option for subsequent raising of the flood protection. The protection level is determined by optimising the BCR. This requires applying weights over the climate change and socio-economic scenarios and finding the crest level that maximises the expected BCR with respect to these weights (Figure A.10).

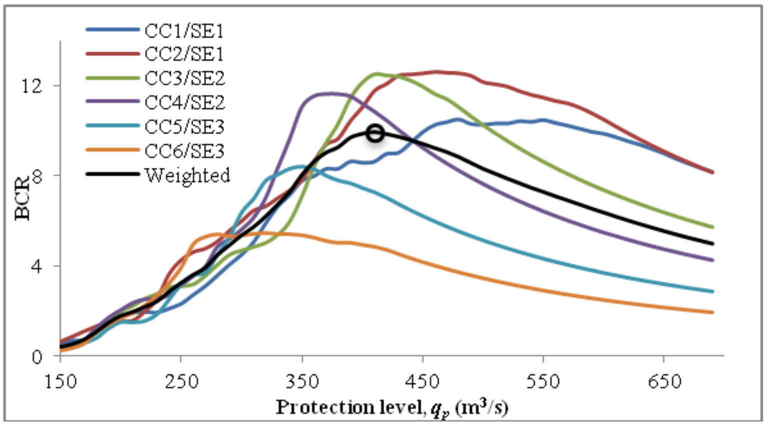

Figure A.10 BCRs for the Fixed design in different scenarios. The optimal protection level is circled

The optimal protection level is sensitive to the climate change scenario, but not to the socio-economic scenario, which influences the damages in the 'with' and 'without' protection cases uniformly (
Figure A.11). However, the BCR that is achieved is sensitive to both the socio-economic and the climate change scenario (Figure A.12). Regardless of the climate change future, the BCRs are greatest in SE1 futures and lowest in SE3 futures.

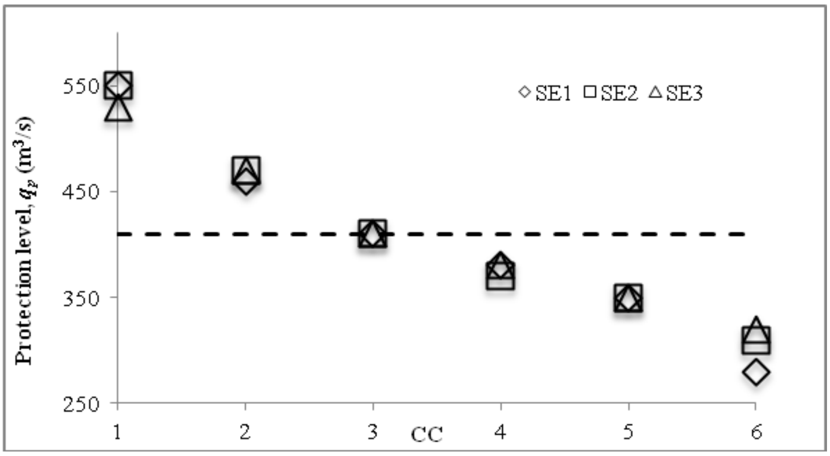

Figure A.11 Optimal protection level for each scenario. The dashed line indicates the protection level chosen based on maximum weighted BCR.

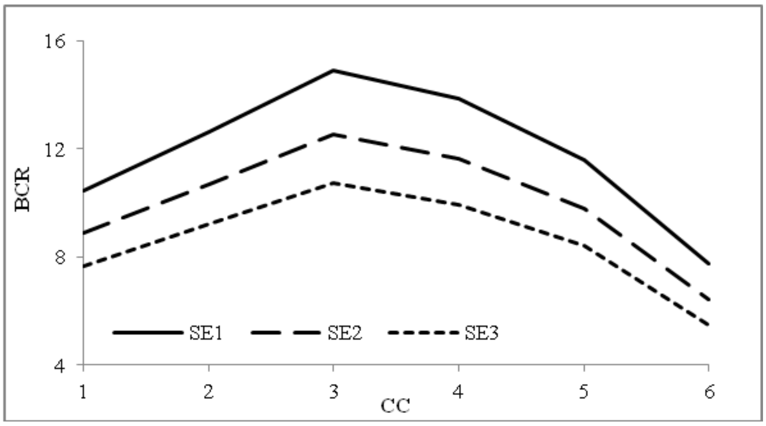

Figure A.12 BCR of the optimal protection level

"Adaptable" design: In Phase 1 the flood protection is built with a widened base at t = 0 in order to allow for future heightening. This involves selecting two protection levels. At t = 0, a specific protection level must be selected in the context of uncertain future changes. For Phase 2 the uncertainty regarding the future is assumed to be resolved so the final protection level is optimised to suit the known future. The adaptive Phase 2 can take place at t = 20, 30, 40, 50, or 60. The precise timing is determined by when the trigger BCR is reached. The overall benefit-cost ratio depends not only on the protection level of Phase 1 and the scenario-specific adaptations that take place later. The process of selecting the optimal Phase 1 protection level proceeds as follows:

1) For each future scenario, all Phase 1 protection levels are tested.
2) For each Phase 1 protection level and each time step t = 20, 30, 40, 50, or 60, the protection level of Phase 2 is optimised to maximise BCR.
3) On the first occasion that the BCR exceeds the trigger value, Phase 2 is implemented
4) The benefits and costs of the combined Phases 1 and 2 investments are calculated for each scenario.
5) These costs and benefits are weighted by the 18 scenario weights.
6) The Phase 1 protection level that maximises expected BCR across all scenarios is chosen.

Combinations of Phase 1 and Phase 2 protection levels for the CC1/SE2 scenario are show in Figure A.13. Low Phase 1 protection levels favour early (t = 20) construction of Phase 2. Between Phase 1 protection levels of 550 to 600, Phase 2 does not reach the trigger BCR until later years. The risk does not get high enough to justify an increased protection standard until more climatic change has taken place. Relatively small increases in protection are implemented at Phase 2 (for example, from 550 to 570) because major raises are not cost-beneficial. In the meantime, the expected damage is higher, so the BCR is lower. For Phase 1 protection levels beyond about 600, Phase 2 never exceeds the BCR trigger. In this case Phase 2 is never built, even though an up-front investment has been made at t=0 to allow the option to build Phase 2. The overall BCR for these combinations is illustrated in the black line, and is fairly flat, tailing off beyond 450.

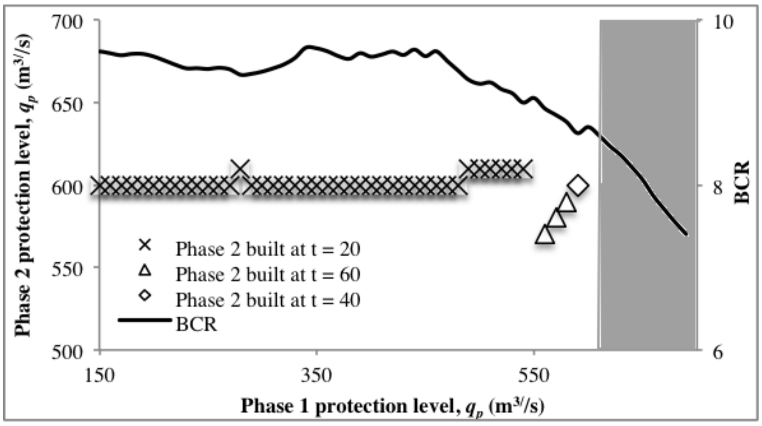

Figure A.13 Protection level combinations for Phase 1 and Phase 2 and corresponding BCR. The shaded region signifies the Phase 1 protection levels for which no Phase 2 is built. Scenario CC1/SE1 and trigger BCR = 5

Figure A.14 shows the case for lower climate change and socio-economic change. The optimum has a clearer peak at $q_p \approx 430\text{m}^3/\text{s}$. This actually corresponds to the situation in which Phase 2 is never built.

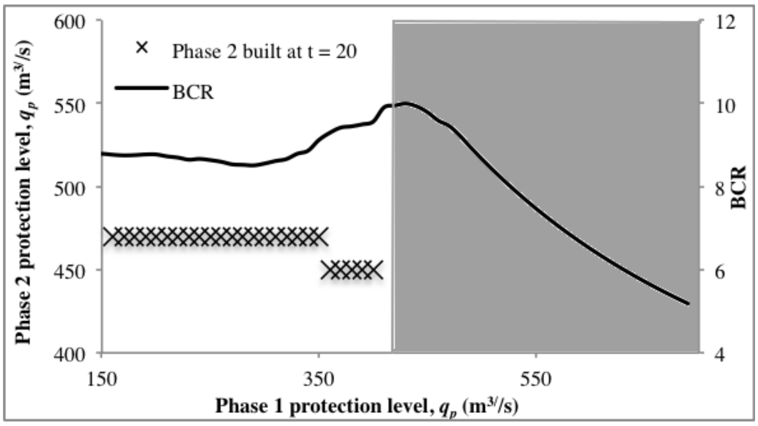

Figure A.14 Protection level combinations for Phase 1 and Phase 2 and corresponding BCR. The shaded region signifies the Phase 1 protection levels for which no Phase 2 is built. Scenario CC3/SE2 and trigger BCR = 5

Figure A.15 illustrates how the optimal Phase 1 protection level varies in different scenarios. We observer the two modes of behaviour illustrated in Figures 13 and 14: one in which a low Phase 1 protection level (and hence early implementation of Phase 2) is preferred, and one in which an intermediate Phase 1 protection level is preferred. Weighting across the scenarios, the intermediate protection level is optimal, but the objective function of expected BCR across the different scenarios is rather flat. Similarly to the Fixed design, the socio-economic scenario bears little influence on the optimal Phase 2 protection level in comparison to the climate change effects. While the cost of building a flood dike does not vary between scenarios, the benefits of flood protection do.

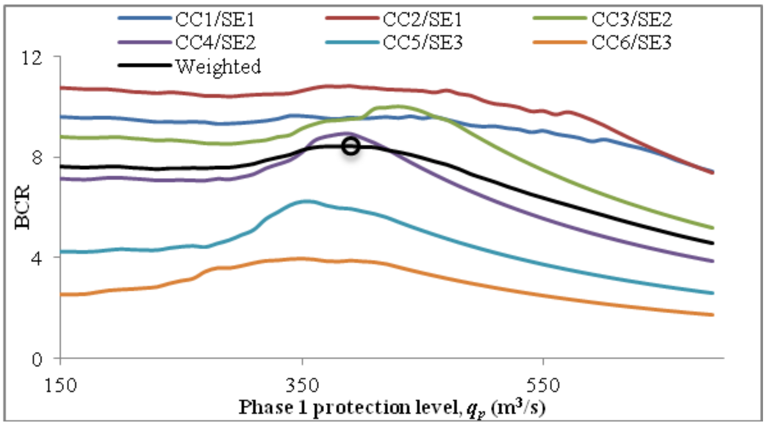

Figure A.15 BCRs for a range of Phase 1 protection levels for different CC/SE scenarios. The selected $q_{p,1}$ is marked with a circle

The risk plots in Figure A.16 depict how the difference between these two categories is attributable to the climate change scenario. The flow distribution in CC1/SE1 increases significantly faster than in CC3/SE3 so that by t = 90, the total risk values differ £19,355k to £8,962k. The Fixed design illustrates the change in risk when a flood dike with protection level = 450 is constructed immediately. On the left, the residual risk initially drops to zero, but steadily increases over time to £10,913k as the standard of the fixed dike reduces relative to the growing flow rates. On the right, the residual risk of the identical dike rises at a much slower rate, ending at £3,842k.

Two different Adaptable design strategies are shown in Figure A.16. In Figure A.16a, the initial protection level is 150 m^3/s, so risk is barely affected. At t = 20, the dike is heightened to a protection level of 630 m^3/s. This marks the steep decrease, after which risk increases because of CC1's increasing flow rates. In Figure A.16b, the initial protection level is 410m^3/s, so risk is immediately lowered to 0. The residual risk climbs slowly as flow rates only increase a little bit under CC3. At t = 60, where Phase 2 is built to q_{p2} = 480m^3/s and residual risk is eliminated for the remainder of the appraisal period.

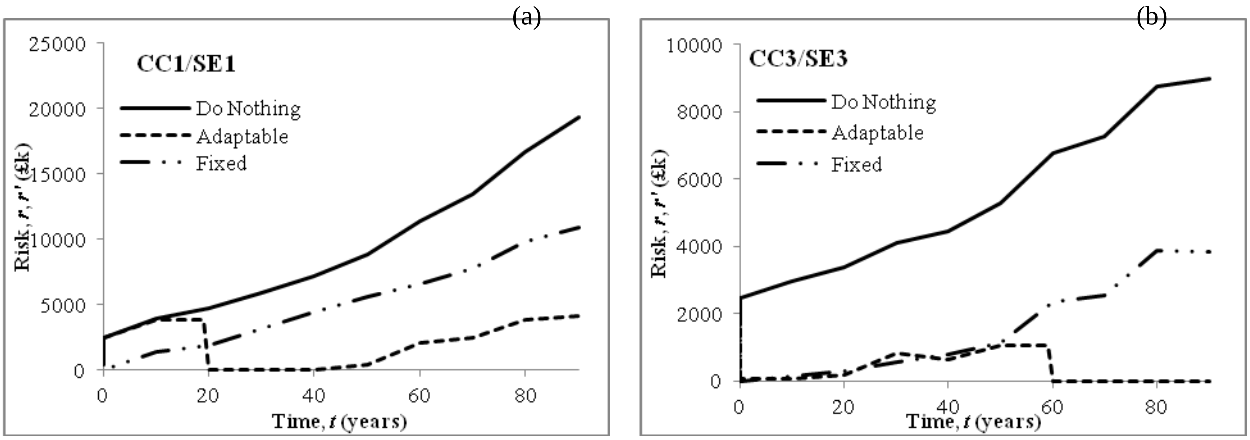

Figure A.16 Risk and residual risk over time (a) q_{p1} = 150m^3/s and Phase 2 is built at t = 20. (b) q_{p1} = 410m^3/s and Phase 2 is built at t = 60.

Comparing the plots of BCR versus qp for the Fixed option (Figure A.10) and BCR versus $qp1$ for the Adaptable design (Figure A.15), it is clear that the Fixed strategy is much more sensitive to the protection level chosen at t = 0 than the Adaptable strategy. The red dashed CC2/SE1 line, for instance, varies between 0 and 9 in the Fixed design but only between 5 and 6 with the Adaptable design. The option to select q_{p2} effectively insulates the overall performance from the initial decision because it provides the opportunity to improve the strategy later.

The Fixed option is preferred if there is confidence in an intermediate future (TableA. 2), while the Adapt option copes better with the high-risk scenarios. There are two primary exceptions to this: situations in which Phase 2 is never built and those in which Phase 2 is always built. The Fixed option offers preferable benefit-cost ratios when Phase 2 is never built (why pay more for flexibility if the option is never exercised?). The Adaptable option is typically preferred when Phase 2 is always built because of the tailored protection that it can provide.

BCR_A - BCR_F		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	1.35	0.54	-0.54	-0.20	-0.16	-0.16
	SE2	0.92	0.29	-0.57	-0.18	-0.16	-0.15
	SE3	0.61	0.11	-0.57	-0.17	-0.16	-0.15

TableA. 2 BCR of Adaptable design – BCR of Fixed design. Shaded cells indicate cases in which Phase 2 is built in the Adaptable strategy

Finally, we calculate the value of the real option based on net present benefit:

$$Option\ Value = \sum_{CC=1}^{6}\sum_{SE=1}^{3} w_{CC,SE}\sum_{t=0}^{T}\frac{1}{(1+s)^t}\left((B_{Adapt}-C_{Adapt})-(B_{Fixed}-C_{Fixed})\right)$$

where B represents benefit, C is cost, and w is the probabilistic weight of the given scenario. The unweighted net discounted benefits of the Adaptable design compared to the Fixed design are presented in
Table A.3. When multiplied by probabilistic weight and summed, the value of the real option is calculated as £1,480k.

Notably, Tables A.2 and A.3 do not always agree on which option is preferred. While the option value is positive in CC3/SE3 (indicating a preference for the Adaptable design), the BCR of the Fixed design is almost 0.5 greater than that of the Adaptable design. The net benefit valuation occasionally conflicts with the benefit-cost ratio comparison, demonstrating that utilising the option can at times improve net benefit without improving benefit-cost ratio.

Option Value		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	8462	6469	1369	-395	-321	-321
	SE2	6306	4719	845	-371	-321	-321
	SE3	4903	3636	166	-354	-321	-321

Table A.3 Option value (£k). Shaded cells indicate cases in which Phase 2 is built in the Adaptable strategy

4. Case study 2: preventing floodplain development

In this case we consider the option to permit or prevent construction of buildings (e.g. houses or industry) on a plot of land adjacent to a river (Figure A.17). If construction were to be permitted then it would need to be protected from flooding by a new flood dike. If risks increase in the future, then the dike would need to be raised, potentially incurring considerable additional cost given that by then the available land will have been built upon. Alternatively the plot of land may be purchased, which retains the option to raise the dike in future at much lower cost, and reduces the build-up of economic vulnerability in the floodplain.

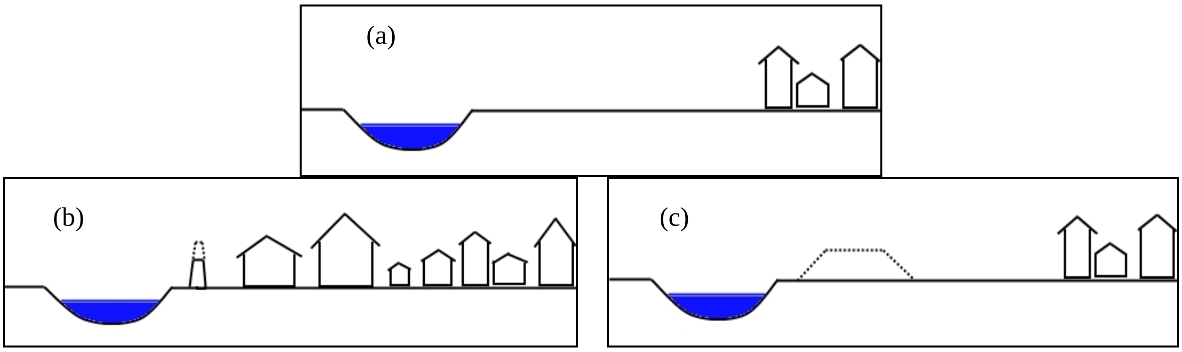

Figure A.17 The land use option decision (a) the plot of land before any action is taken, (b) the "Develop" option, with properties in the floodplain, narrow wall, and an option to raise the protection level at considerable future cost, and (c) the "Buy" option, with no development in the floodplain and a lower cost option for a flood protection in future.

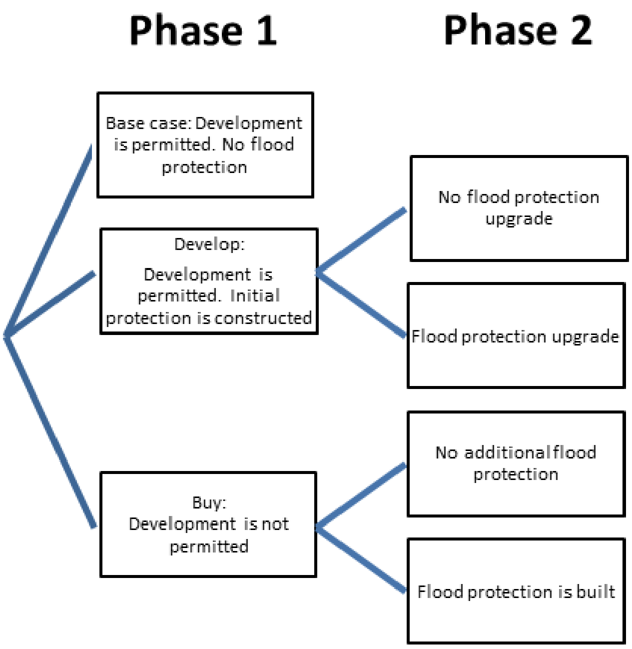

Figure A.18 Structure of the decision problem for Case Study 2

"Buy" Option: Under this strategy, floodplain development is forgone while preserving the option to build a flood protection at a later date. In order to prevent development from taking place, the community must incur the cost of purchasing land in order to reduce the growth in vulnerability to flooding and preserve space for an affordable flood protection in future. We treat the cost as a one-time payment to compensate existing land owners with development rights. That is, the community buys back the permits in order to prevent development from taking place on that land. The fair buy-back price is the market value of the land (with a permit for development), which reflects the present value of the future benefits that a developer might expect to incur net of the costs of building the development and net of taxes.

Having bought the land, the community then has the option to build a dike on the preserved land at a relatively low cost in the future (Phase 2, Figure A.18). The protection level will be scenario-specific, and the decision will be made with more information regarding the climate change and socioeconomic future scenarios. The decision of whether to build a flood protection depends upon the usual benefit-cost criteria, the benefit being the risk reduction to the existing development (whose value increases in future with the factor f_s). We ignore physical benefits that the undeveloped floodplain would provide as a flood storage and recreation area and only consider the economic benefits of damage avoided.

"Develop" Option: If the land is not purchased and development occurs, the value of property exposed to flooding increases. A flood dike is constructed on a narrow footprint within the floodplain (Phase 1, Figure A.18) and development occurs (immediately) behind this dike. Consequently, the value of the assets exposed increases by the "value of new development" (VND). The total amount of value exposed is the sum of the values of existing and new developments (i.e. VED+VND), and that value continues to increase with the factor fs associated with each socio-economic scenario. In some scenarios the risk become unacceptably high and the flood protection level has to be heightened (Phase 2, Figure A.18), but the new water-front development means that the cost of increasing the protection level is very high. The structure of this option is identical to the Adaptable design described above, so optimisation follows the same process.

The fixed costs can be organized as $c_{f,Develop2} >> c_{f,Develop1} > c_{f,Buy}$, where $c_{f,Develop2}$ is the cost of the Phase 2 dike raising in the case when development has taken place, $c_{f,Develop1}$ is the cost of the constructing the Phase 1 dike to protect the new development, $c_{f,Buy}$ is the construction cost if a new dike is require (at Phase 2) after the land has been bought. In the "do-nothing" baseline case, which is used to evaluate the benefits of risk reduction, we assume that development in the floodplain would take place, but that no flood protection would be constructed. The baseline probability-damage curve takes the total value exposed as the sum of the existing and new development values (VED + VND).

Inputs to the analysis consist of the value of the existing development (VED), the cost of compensating permit-holders for the land (Compensation), the value of the new development (VND), fixed costs (for Phases 1 and 2 of the Develop option, and for the building Phase 2 of the Buy option), and the trigger benefit-cost ratio. For the Buy option, the outputs are an overall BCR and scenario-specific protection levels for Phase 2, building years, and BCRs. For the Develop option, the analysis returns an optimal protection level for Phase 1, an overall BCR, and scenario-specific Phase 2 protection levels, building years, and BCRs.

The Develop strategy reduces risk relative to the baseline case through construction of a flood protection. The Develop option closely mirrors the Adapt option, as illustrated by the resemblance between the Adaptable plot in Figure A.16 and those in Figure A.16. Here, however, the fixed cost of Phase 2 is greater than that of Phase 1. The higher cost makes it less likely that Phase 2 will be built.

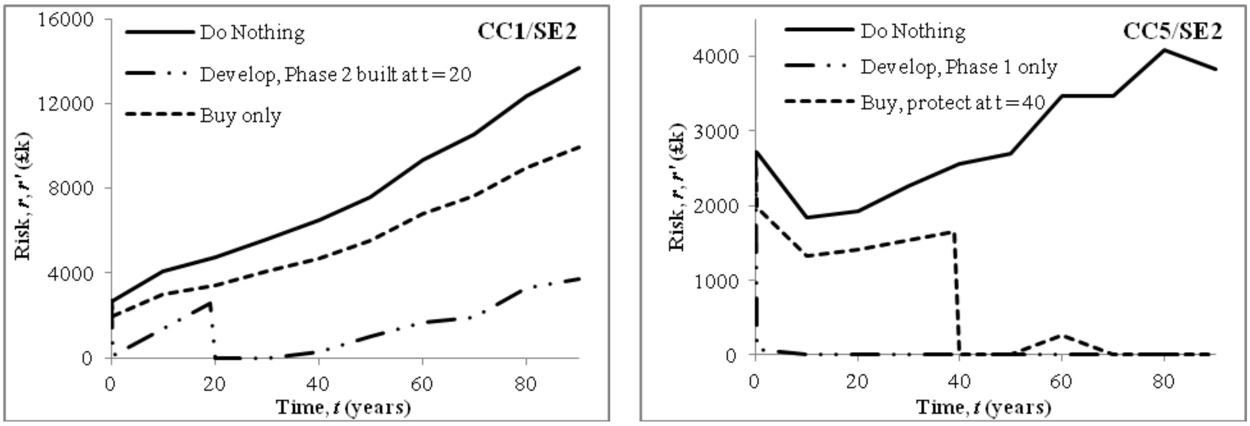

Figure A.19 Risk over time in the land use case with the Develop and Buy strategies

Because Phase 2 is triggered less frequently in the Develop strategy, the Phase 1 protection level tends to be higher. While Phase 1 in the Adaptable design ranges from 370 m^3/s to 410 m^3/s, Phase 1 in the Develop strategy, the protection level is in the range 410 m^3/s to 450 m^3/s.
Table 4 illustrates the differences between the Develop and Adaptable strategies when Value of Existing Development is equal to Value Exposed and the trigger BCR is the same. While Phase 2 is built in half of the scenarios under the Adaptable design, it is only built in two scenarios with the Develop strategy. In CC3/SE1, for example, Phase 2 is triggered with the Adaptable design only, resulting in the difference between Figure 20a and Figure 20b.

Phase 2		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	Both	Adaptable	Adaptable	None	None	None
	SE2	Both	Adaptable	Adaptable	None	None	None
	SE3	Adaptable	Adaptable	Adaptable	None	None	None

Table A.4 Phase two decision, comparing Case Studies 1 and 2. Value Exposed (VED) = 10,000, VND = 1,000, $c_{f,Adapt1}$ = 1200, $c_{f,Adapt2}$ = 400, $c_{f,Develop1}$ =800, $c_{f,Develop2}$ = 1200

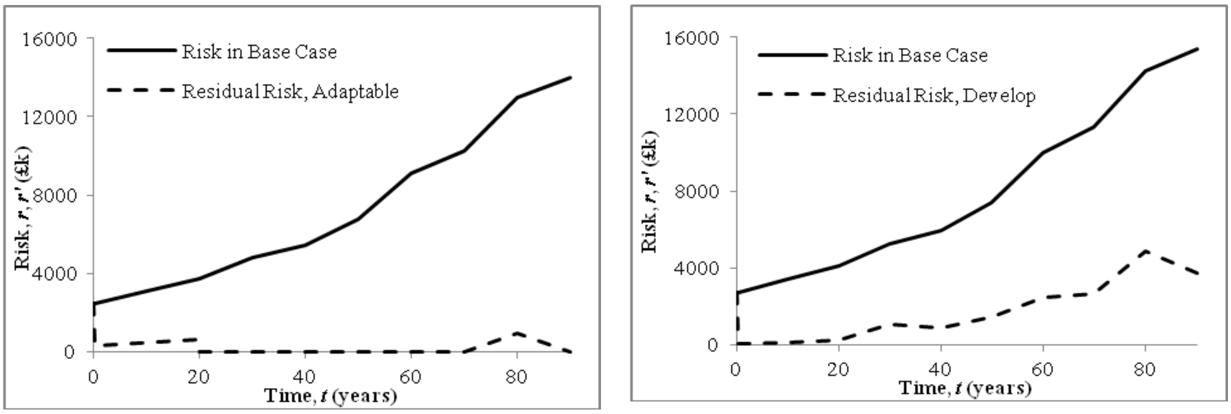

Figure A.20 Risk over time in CC3/SE1 in a) the Adaptable strategy and b) the Develop strategy

The Buy strategy moderates risk through lowering the amount of value exposed to flood events, so the VED and VND values influence whether it is justifiable to buy the land. Once the land has been bought, no development takes place, so only the VED and the accompanying CC/SE scenario influence whether the option to construct a flood protection is exercised in future; it is not influenced by the VND. For each scenario, the earliest year in which the flood protection is triggered (if at all) is computed. When protection is triggered, the discounted costs and benefits of that protection are incorporated in the decision whether to buy.

The tipping compensation for the Buy option is the compensation cost at which the benefit-cost ratio of buying the land is 1. It is a function of the socioeconomic and climatic change scenario, VED, VND, and $c_{f,Buy}$. When no future flood protection in constructed, the tipping compensation is equal to the benefit from only purchasing the land. When flood protection is expected to be subsequently built, the tipping compensation also reflects the expected net benefit of that flood protection. Higher values of VND increase the tipping compensation because the amount of benefit derived from purchasing the land depends directly on how much risk is avoided from forgoing development. If VND is expected to be high, then buying the land significantly lowers the total value subject to flood damage, yielding more benefit. By the same logic, tipping compensations are also higher in the scenarios of greater climatic and socioeconomic change and their higher risk levels. In Tables A.5 and A.6, the prohibitively expensive $c_{f,Buy}$ prevents flood protection from being built in any scenario, so the tipping compensations reflect the benefit of purchasing the land only. The VND is doubled from Table A.5 to Table A.6, resulting in the greater tipping compensations.

Tipping Compensation		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	2,236	2,106	1,794	1,300	988	624
	SE2	1,820	1,742	1,482	1,092	858	546
	SE3	1,534	1,456	1,248	936	754	494

Table A.5 Tipping compensation for Buy option. VED = 7,500, VND = 1,000, $c_{f,Buy}$ = 4,200

Tipping Compensation		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	4,452	4,200	3,584	2,604	1,988	1,260
	SE2	3,640	3,472	2,968	2,184	1,708	1,092
	SE3	3,052	2,912	2,492	1,876	1,484	980

Table A.6 Tipping compensation for Buy option. VED = 7,500, VND = 2,000, $c_{f,Buy}$ = 4,200

If flood protection is constructed in the future, the tipping compensation increases significantly because the act of building the flood protection must meet the trigger BCR (between 3 and 8); that is, the additional benefit derived from building the protection must be 3-8 times the additional cost. Since the benefit of construction outweighs the cost so significantly, the scenario's BCR can remain above 1 even with a significantly more expensive compensation cost. In Table A.6, all of the tipping compensations shaded yellow correspond to scenarios in which flood protection was constructed.

Tipping Compensation		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	14,035	14,210	12,086	8,263	5,007	1,265
	SE2	3,630	10,770	9,273	4,946	1,705	1,100
	SE3	3,025	2,915	2,475	1,870	1,485	990

Table A.7 Tipping compensation for Buy option. VED = 7,500, VND = 2,000, $c_{f,Buy}$ = 1,100. Scenarios in which flood protection is constructed are shaded

The overall tipping compensation for a given set of VED, VND, and $c_{f,Buy}$ is clearly influenced by the number of scenarios that build flood protection. The more scenarios that build in the future, the more cost-beneficial it is to buy. For the set of inputs presented in Table A.6, in which no scenarios involve future flood protection, the expected tipping compensation was 2600. For those of Table A.7, the expected tipping compensation was 5500.

The difference between VED and VND strongly influences the decision whether or not to protect, having bought the land. When the VED is high, the Phase 2 dike construction is cost-beneficial and takes place early (Table A.8). When the VND is higher, relative to the VED (Table A.9), then the VND provides the justification to buy the land, and Phase 2 protection is only required in the higher scenarios of climatic and socio-economic change.

Year of Protection		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	20	20	20	20	20	60
	SE2	40	20	20	20	60	none
	SE3	none	none	20	none	none	none

Table A.8 Phase 2 year of construction for Buy option. VED = 7,500, VND = 1,000, Compensation = 1,000, $c_{f,Buy}$ = 830

Year of Protection		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	40	20	20	20	40	none
	SE2	none	50	20	50	none	none
	SE3	none	none	none	none	none	none

Table A.9 Phase 2 year of construction for Buy option. VED = 6,000, VND = 1,500, Compensation = 1,000, $c_{f,Buy}$ = 830

Table A.10 retains the same VED and VND as Table A.9, but increases $c_{f,Buy}$ from 830 to 1,200. The increased cost has less impact than the VED-VND shift: it changes the building year in several scenarios and changes the decision in three. While changing the fixed costs do affect the overall BCRs, the decisions regarding Phase 2 in the Buy strategy depend more strongly on the difference between VED and VND.

Year of Protection		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	50	40	20	30	none	none
	SE2	none	none	50	none	none	none
	SE3	none	none	none	none	none	none

Table A.10 Phase 2 year of construction for Buy option. VED = 6,000, VND = 1,500, Compensation = 1,000, $c_{f,Buy}$ = 1,200

When the BCRs for Buy versus Develop are compared (Table A.11), the Buy option is generally preferred in the high-risk futures (CC1 and CC2). The preference for the Buy option is strongest with large values of new development. The preference for the Develop strategy is strongest in CC3, CC4, and CC5, while CC6 is typically closer to neutral. Even with a Phase 2 option, the Develop strategy cannot compete with the Buy option when the value of new development is high, illustrating that forgoing development in the floodplain can at times be the most economically efficient flood risk management strategy.

$BCR_{Develop} - BCR_{Buy}$		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	-4.68	-4.01	-3.06	-2.69	-1.84	-0.89
	SE2	-3.22	-2.56	-1.83	-1.66	-1.04	-0.35
	SE3	-2.13	-1.50	-0.94	-0.89	-0.45	0.04

Table A.11 BCR of Develop design – BCR of Buy design

The two strategies can also be compared based on net benefit. However, as observed in the first case study, preference based on benefit-cost ratio does not always agree with preference based on net benefit. In Table A.11, the Buy option is preferred in all but one scenario. The expected BCR is 6.72 in the Develop strategy and 8.59 in the Buy strategy. Comparison based on net benefit (Table A.12) reveals a very different picture. This apparent contradiction is a consequence of the increased value exposed under the Develop option, and hence large benefits that are achieved by the Phase 2 protection. The nature of the net benefit metric creates a perverse incentive for development to take place in order to acquire more benefit from building protection.

Net $Benefit_{Develop}$ – Net $Benefit_{Buy}$		Climate change scenario					
		CC1	CC2	CC3	CC4	CC5	CC6
Socio-economic scenario	SE1	-7559	-2772	6244	6316	5510	3862
	SE2	-4173	-38	6445	6109	5354	3807
	SE3	-2013	1535	7025	5941	5208	3763

Table A.12 Net Benefit of Develop design – Net Benefit of Buy design

5. Conclusions

Methodology has been presented for the appraisal of the benefits of providing flexibility in flood risk management. The problem has been formulated in terms of conventional benefit-cost criteria, which future decision makers will apply based on the information available to them at the time. This leads to a two-stage optimisation problem. By exploring two major future uncertainties (climate change influencing future river flows, and socio-economic change influencing development in the floodplain), we have been able to identify the situations in which different decision strategies are adopted.
In analysis of the benefits of incorporating flexibility in the design of a flood protection we observe situations in which:

- A low initial protection level is preferred, with rapid upgrading when uncertainty about future scenarios is resolved
- An intermediate initial protection level is preferred, in which case the option for a subsequent upgrade may or may not be exercised in future.

We find that the socioeconomic scenario bears little influence on the optimal protection level at the upgrade, whilst the climate change scenario is strongly influential. The socio-economic scenario does influence the benefit-cost ratio of the investment decision. Applying typical weights across the scenarios prefers the intermediate protection level, but the objective function of the optimisation is rather flat, so the result is sensitive to the chosen weights.

We find that the benefit-cost ratio of the fixed design is much more sensitive than the flexible design to the climate change / socio-economic scenario that actually materialises. The fixed design can yield higher benefit-cost ratios (because its cost is lower), but can also yield much lower BCRs. For the flood protection costs and benefits adopted in this study, we have calculated a positive option value for the flexible design, which justifies the up-front investment.

We have also demonstrated methodology for evaluating the benefits of foregoing development and setting aside land that may be occupied by a flood protection in future. The benefits of incurring cost now to avoid the build-up of damage potential, or costly dike upgrades, in future are greatest in scenarios of more severe climate change. The compensation that it is justified to spend to buy back the land is sensitive to the assumed climate change and socio-economic scenarios and the anticipated value of the foregone development. From a risk reduction perspective it makes sense to pay more to forego major development opportunities, though this will have to be weighed against wider economic benefits that may be incurred due to that development. Foregoing development also leaves room for the construction of less costly flood protection in future, and if it is likely that such protection is going to be cost-beneficial then the compensation it is justified to spend to buy back the land is significantly higher. Using a net benefit metric rather than a benefit-cost ratio metric creates a perverse incentive to allow development to take place in order to acquire more benefit from building protection in future.

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