Climate adaptation:
Risk, uncertainty and decision-making

UKCIP Technical Report
May 2003

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Forewords

Climate change is one of the most significant challenges we face over the coming century. We must try to avoid the worst effects, by reducing emissions of greenhouse gases. The Environment Agency as the leading body responsible for protecting the environment in England and Wales, has a key role to play as a regulator and in partnership with others.

Yet however successful we are at reducing emissions, some climate change is already inevitable, so we will need to adapt. Climate change poses a risk to many of our policies, strategies and plans. We must learn to manage this risk, and provide appropriate climate change 'headroom' when we make decisions. The Environment Agency already takes account of climate change when planning improvements to flood protection, and as part of our water resources strategy. Our fisheries and biodiversity policies are kept under review and we are ready to respond to any future changes in industrial regulation in relation to emissions and energy efficiency.

The management of climate risk is a developing area, and one that will not go away. I encourage other decision-makers to read this report, and apply the framework for risk-based decision-making that it provides. By doing this, we can all ensure that our policies and projects will be robust enough to cope with the uncertain future climate.

Barbara Young

Barbara Young
Chief Executive, Environment Agency

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001), indicates that some signs of climate change are now detectable and that adaptation has become a necessity. Recent decisions of the Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) have raised the profile of adaptation and drawn attention to the need to incorporate adaptation into economic development and policy decisions in all countries.

The issue of how best to adapt to climate change including climate variability and extreme events is no longer a theoretical question that can be left to the research community alone. Decision-makers at all levels, and a wide array of stakeholders, now find that they are obliged to deal with the issue of climate change and how to facilitate the adaptation process. Decisions have to be made.

This new set of circumstances has generated a worldwide debate about adaptation decisions and a search is underway for the best practices for managing the risks that face individual countries and the world community as a whole. Attempts are being made within the UNFCCC process and elsewhere to develop appropriate frameworks and methods. We are both involved in this process and have an appreciation of the difficulties of handling the uncertainties with which decision-makers are faced.

This report is a substantial pioneering effort to synthesize existing knowledge and to provide guidance to help those engaged in the decision-making and policy process. It also makes creative contributions to current understanding.

Especially helpful is the clarification it brings to the distinction between climate adaptation decisions, climate influenced decisions, and climate adaptation constraining decisions, and to "no regret" climate adaptation options. The report goes on to propose a clear step-wise approach in a risk-uncertainty-decision-making framework.

While the report has been written primarily in the UK context, and includes an excellent case study on land use and forestry development in Wales, it can be expected to find a wide international readership. In many governments and research institutions, and in international agencies, people are asking for the sort of help and guidance that this report provides so well and so abundantly. We encourage all those concerned to use this publication and to draw upon it in the context of their own priorities and circumstances.

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Executive Summary

Climate change as a risk to decision-makers

1. There is now convincing evidence that our climate is changing, and that the emissions of greenhouse gases from human activities are partly responsible for the observed changes. Many activities are affected by climate, and decisions taken to manage associated risks. As climate changes so too will risk. This will have an effect on the outcome of a wide range of decisions affecting individual, societal and economic well-being. Decision-makers need to be aware of these risks when planning for the future.

2. Climate change is an additional source of uncertainty for the decision-maker. Uncertainty stems largely from limitations of our scientific knowledge of the climate system, and of how future greenhouse gas emissions will change. However, significant advances in our understanding of climate change in recent decades have enabled us to be reasonably confident about the main expected changes.

3. There is also uncertainty about the impact of future climate on society, the environment, businesses and the economy, because our knowledge of impacts is based largely on experience of past events, and this knowledge is also imperfect. **Studies that aim to understand the impacts and benefits that result from present-day variability in climate can be important in helping to reduce uncertainty surrounding the consequences of future climate change.**

4. The improved management of risk has been set as a priority by the UK Government (Cabinet Office, 2002). Climate change represents a complex, strategic risk, requiring decisions concerning policies, strategies, plans and projects that will provide benefits under future climate, that will deliver climate adaptation. This report aims to improve the decision-maker's capacity to handle risks associated with climate and a changing climate.

Climate adaptation and decision-making

5. This report recommends a structured framework and associated guidance to promote good decision-making. This should enable decision-makers to recognise and evaluate the risks posed by a changing climate, making the best use of available information about climate change, its impacts and appropriate adaptive responses. The report identifies methods and techniques for risk assessment and forecasting, options appraisal and decision analysis. Using these methods will be important in delivering policies and projects that are successful in the face of an uncertain future.

6. Many climate-sensitive decisions are directly driven by the need to reduce or otherwise manage anticipated climate risks, based on past experience of climate. Many decisions are required to manage the expected consequences of variability in climate: cold years, flood events, seasonal droughts, storm surges, extreme wind speeds, freezing conditions, heat waves. These are decision areas where climatic factors have long been acknowledged as being a primary consideration in the choice of management option. Climate change is expected to alter the choice between, and the balance of risk associated with, different options for managing the risk. In some circumstances the prospect of climate change may provide the sole reason for considering a decision. We call these **climate adaptation decisions**.

7. There are, however, many decisions where the outcomes could be affected by climate change, but where climate change is only one of a number of factors of differing importance. These are also climate-sensitive decisions. For example, an outcome may not itself be directly sensitive to climatic hazards, but may be indirectly affected by climate-dependent events or by the consequent decisions of others. We call these **climate-influenced decisions**; they include decisions that could be taken to exploit the opportunities and/or avoid the threats associated with climate change.

8. Decisions with long payback periods or with long-term consequences (decades or greater) are vulnerable to assumptions regarding both short-term variation and long-term changes in future climate. Climate-sensitive decisions with shorter payback periods are more likely to be vulnerable to short-term variations and extremes of climate. Climate surprises, with large-scale and significant consequences (such as the collapse of the Gulf Stream), represent a risk to the widest range of decisions, but have a low probability of occurrence over the next 50-100 years, according to present knowledge.

9. Decision-makers should consider identifying sets of climate conditions representing benchmark levels of climate risk, against which they can plan to manage. Such benchmarks may be based on past experience of particular, reference climate 'events' (e.g. periods of significant drought or excess rainfall), or describe particular future climates (perhaps defined relative to past climate). In either case, these benchmarks represent a defined threshold between tolerable and intolerable levels of risk, and provide a basis for developing practical risk assessments. New climate observations and updated forecasts of future climate change can then be placed in the context of these established benchmarks.

10. Adaptation to climate is itself not risk-free. Decision-makers may underestimate the risk associated with climate variability and climate change. This may lead to choices that fail to deliver appropriate levels of adaptation. Particularly for climate-influenced decisions, there is a risk that a decision-maker may tacitly assume that climate is not an important part of the decision problem. Alternatively, the climate risk may be overestimated, resulting in over-adaptation and perhaps the unnecessary use of resources. In both cases, the level of climate risk has to be determined relative to other, non-climate risk factors. Different climate adaptation options will often be associated with differing portfolios of consequent risks, even where they offer the same level of residual climate risk. There is also a risk that the adaptation option will not deliver the benefits anticipated, due to uncertainty in future climate or uncertainty in the effective performance of the option.

11. The framework and guidance aims to help decision-makers and their advisors identify the important risk factors, and to describe the uncertainty associated with each. Uncertainty analysis is a key feature of risk assessments. We recommend the use of techniques based on sensitivity and uncertainty analysis to help identify sources of uncertainty and key assumptions in general, and specifically to better understand the implications of uncertainty in future climate for decisions.

12. These techniques include the use of multiple climate and non-climate scenarios to explore uncertainty. These methods are particularly useful for complex problems involving multiple risk factors.

13. The guidance describes climate adaptation strategies that summarise the general options for managing climate change under conditions of uncertainty. **An important consideration is to keep open or increase the options that will allow climate adaptation measures to be implemented in the future, when the need for climate adaptation and the performance of different adaptation measures is less uncertain**.

14. Certain decisions may affect the ability of other decision-makers to manage the consequences of climate change; they reduce either present day and/or future climate adaptation options. Examples are inappropriate construction or development within flood risk areas. We call these **climate adaptation constraining decisions**. Decisions with these consequences should be avoided. The majority of adaptation constraining decisions will be taken to meet objectives that are not climate sensitive, or not recognised to be climate sensitive. However, climate adaptation and climate-influenced decisions might also constrain the adaptation decision-making of others, particularly where conflicts exist between climate adaptation objectives. The guidance aims to help decision-makers recognise adaptation constraining decisions.

15. An objective of climate change risk assessments should be to identify **no regret climate adaptation options**. These are climate-sensitive decision areas where no apparent uncertainty exists as to the best

adaptation option to implement. Such an option is anticipated to deliver benefits under any foreseeable climate scenario, including present day climate.

16. In many circumstances no regret options will not be available, and the choice of climate management option will be uncertain. In these cases the choice will in part be dependent on the decision-maker's attitude to climate and non-climate sources of risk, and to the risks associated with the different decision options. For example, a decision-maker may prefer adaptation decisions anticipated to have low implementation costs, or some type of precautionary approach. We recommend that decision-makers explicitly describe their attitude to risk, as part of the decision-making process.

The decision-making framework

17. There are eight stages in the framework:

- Stage 1 Identify problem and objectives
- Stage 2 Establish decision-making criteria
- Stage 3 Assess risk
- Stage 4 Identify options
- Stage 5 Appraise options
- Stage 6 Make decision
- Stage 7 Implement decision
- Stage 8 Monitor, evaluate and review.

18. The framework and stages provide a flexible approach to decision-making under climate change. The following features of the framework promote good decision-making principles:

- It is **circular** – emphasising the importance of the adaptive approach to managing climate change problems and implementing response measures. It may be that a sequential implementation of adaptation measures is most appropriate. Decisions should be revisited in the light of new information on climate change and its impacts – for instance, when new climate scenarios are published.

- **Feedback and iteration** are encouraged, so that the problem, objectives and decision-making criteria can be refined (Stages 1 and 2), and further options identified and refined

to better reduce and manage climate change risks (Stages 3, 4 and 5). Iteration is important to achieving robust decisions.

- Certain stages (3, 4 and 5) are **tiered**. This allows the decision-maker to identify, screen, prioritise and evaluate climate and non-climate risks and options, before deciding whether more detailed risk assessments and options appraisals are required.

19. The framework stresses the importance of an open approach to decision-making, which takes account of the legitimate interests of stakeholder and affected parties. Where appropriate the decision process should encourage active participation from interested groups. Among other benefits, this will help minimise the risk of overlooking potential impacts, and of failing to identify adaptation-constraining decisions. It should also ensure that differences in the perception of risks and values are fully explored within the risk assessment and decision appraisal process.

20. For each stage of the framework, there are key issues that the decision-maker should consider, and questions that should be answered. The guidance indicates tools and techniques that can be applied to inform each stage.

21. Stages 1 and 2 define the nature of the decision problem, the decision-maker's objectives and criteria that help differentiate between options. These are extremely important to avoid making poor decisions, especially those with long-term objectives or consequences (which are often associated with the greatest uncertainty). The framework emphasises the need to revisit Stages 1 and 2, following a risk-based assessment of climate change.

22. At Stage 3, the climate change risks associated with the decision are formally identified and assessed, alongside other non-climate risks. Climate change scenarios (e.g. the UKCIP02 scenarios) are an important tool to inform this stage. The risk assessment should identify those aspects of climate that represent the greatest risk. This will require careful consideration of the definition of climate variables in relation to potential impacts.

For example, the risk assessment will need to take account of average climate changes, such as seasonal temperature increases, as well as changes in extreme climatic conditions, such as intense daily rainfall events. While extreme climatic events are by definition rare, they often have the most significant impacts. Unfortunately, they are also difficult to predict, so information on climate extremes is more uncertain.

23. At Stage 4, the decision-maker should aim to identify options that are robust to climate change, and provide the greatest likelihood of meeting the objectives and criteria defined in Stage 2. In particular, the decision-maker should try to find 'no regret' and 'low regret' options. These options are appraised against the criteria in Stage 5 to determine the 'preferred' or 'best' option. If options had not been identified previously (as part of the problem formulation, Stage 1), it may be necessary to first revisit Stages 2 and/or 3, to consider appraisal criteria.

24. This process seeks ways of refining options, to find ones with lower social, economic and environmental consequences. The 'best' option may involve a combination of elements from various options. The decision-maker will be making choices about **how much** adaptation is required – for instance, how large a safety margin or climate headroom allowance – and **when** to carry out the measures. Allowing a greater safety margin may well involve higher costs. The option chosen will therefore be determined by the decision-maker's attitude to the risks associated with over- or under-adaptation.

25. Stage 6 demands that the decision-maker forms a judgement that all issues revealed during the decision-making process have been addressed. This is particularly important if, for example, adaptation constraining decisions are to be avoided. Stage 6 is followed by implementing the preferred option (Stage 7), with a programme of monitoring, evaluation and review (Stage 8) to check whether the expected benefits of the decision are delivered. Stages 7 and 8 are not considered in detail in this guidance.

| Executive Summary

Part 1

1. Introduction

"The evaluation of uncertainty and the necessary precaution is plagued with complex pitfalls... Some of these uncertainty aspects may be irreducible in principle, and hence decision-makers will have to continue to take action under significant uncertainty so the problem of climate change evolves as a subject of risk management in which strategies are formulated as new knowledge arises."

(Toth and Mwandosya, 2001 from Moss and Schneider 2000 and Jaeger *et al* 1998.)

1.1 Context

The global science community is increasingly confident that human activities contribute to climate change, and that the absence of significant actions to reduce greenhouse gas emissions will have serious ramifications. Recently, in its Third Assessment Report, the IPCC stated that "*There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities*" (IPCC, 2001a, p.5). When it comes to future prediction, however, there are considerable uncertainties. Despite enormous improvements in our understanding of the Earth's climate, and a long history of climate monitoring and weather forecasting in the UK, the exact extent and nature of changes in our climate remains uncertain. Current information about the expected changes for the UK, together with indications of the uncertainty associated with these changes, are summarised in the UKCIP climate change scenarios report (Hulme *et al*, 2002). The changes we will experience will vary across the UK. In addition, seasonal and other types of climate variability are expected to change; these may be particularly important since it is often extremes of climate (rainfall, storm force winds, heat waves and periods of extreme cold) that are most damaging and problematic for society.

Climate therefore represents a changing source of risk. Climate adaptation is about recognising these altered risks, and taking decisions that allow the likely impacts to be reduced or managed, and the opportunities to be exploited. The necessity of adaptation to climate change, irrespective of the success of future controls on emissions of greenhouse gases, has been recognised by the UK Government (DETR, 2000a). Climate affects many aspects of economic and social endeavour and hence climate change may affect the outcomes of many decisions. Decisions taken today will have implications tomorrow in terms of the future impact of climate on society. Such decisions may need to be modified to reflect the change in risk.

The assessment of climate risks is a complex undertaking that must support judgements and decisions concerning appropriate future courses of action. It requires a combination of scientific and technical knowledge, not just from the climate sciences, but from those who understand the consequence of decisions for business and the economy, for society, institutions and individuals, and for the environment. Decision-making requires knowledge of society's tolerance and acceptance of risk, and the costs and benefits of different courses of action. However, much of this knowledge is imperfect, uncertain or unknown. Nevertheless, decisions are required. The poor handling of issues that involve judgements concerning risk has been recognised as a significant challenge to policy development, and the delivery of programmes and projects (Cabinet Office, 2002). Climate change is such a risk.

1.2 Aims and objectives

The overall objective of this report is to provide guidance that helps decision-makers and their advisors:

(i) take account of the risk and uncertainty associated with climate variability and future climate change; and

(ii) identify and appraise measures to mitigate[1] the impact or exploit the opportunities presented by future climate – that is, to identify good adaptation options.

The report provides guidance to help decision-makers answer the questions:

(i) What are the climate and climate change risks that could affect my decision?

(ii) Should climate change influence my decision?

(iii) What adaptation measures are required, and when?

(iv) What adaptation measures would be most appropriate?

Decisions involving climate adaptation may be required of a very wide variety of institutions and associated decision-makers. These include:

(i) National, regional and local government and their departments;

(ii) Regulatory bodies (such as the Environment Agency and Office of Water Services);

(iii) Executives and managers in a wide variety of national and international corporations, including non-governmental organisations, and small and medium-sized enterprises; and

(iv) Individual citizens.

This report will be particularly relevant to decision-makers and their advisors:

(i) who are responsible for business areas that are known to be sensitive to changes in climate;

(ii) who are responsible for managing the consequences of present-day variability in weather or climate;

(iii) who make decisions with long-term consequences for the use of extensive areas of land, nationally important sites, or population groups within society and their prosperity;

(iv) whose decisions could be vulnerable to assumptions about the risks associated with future climate;

(v) who are responsible for commissioning or overseeing technical assessments of climate change vulnerability, impacts and associated adaptation options; or

(vi) who need to assess the robustness of a proposed decision to assumptions associated with the nature of the future climate.

Within each institution, relevant decisions are taken at a variety of structural and functional levels, and using a variety of different criteria, reflecting the importance of the decision to the institution concerned, and established management structures and procedures that govern decision-making. This report acknowledges the need to take account of, and recognises the constraints imposed by, existing institutional decision-making structures.

At its core, the report presents an eight-stage decision-making framework. Given the broad audience and diversity of applications, the framework and supporting guidance are inevitably rather generic. There are questions for the decision-maker to apply at each stage, and tools that may help. Guidance is provided for any decision that is likely to be influenced by climate, and decisions being made specifically in response to climate. The report does not aim to provide specific guidance on particular climate hazards, their probabilities, uncertainties, or possible impacts, as the role of a risk assessment is to assemble such information appropriate to the problem in hand. Nor does the report aim to address decisions about the mitigation of greenhouse gas emissions.

1.3 Structure of the report

Part 1 lays out the eight stages of the decision-making framework, provides guidance on its use, and recommends tools and techniques that may be applied at each stage. A case study example is described in Appendix 1, demonstrating the application of the framework to a decision within the forestry sector.

Part 2 provides framework-supporting material that will be needed by those unfamiliar with aspects of risk assessment in general, or risk-based climate change impact assessments in particular.

[1] In the context of this report, the term 'mitigate' is used to describe any action to reduce unwanted consequences.

This information will help decision-makers (and their analysts) reach robust decisions. Part 2 includes the following chapters:

Chapter 1, providing an overview of the concepts of risk and uncertainty.

Chapter 2, providing an overview of considerations for taking decisions in the light of risk and uncertainty, and providing an overview of generic climate adaptation strategies.

Chapter 3, providing information on the key aspects of climate change risk assessment.
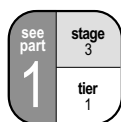
To assist with navigation through the document, icons are provided, linking relevant sections of Parts 1 and 2. An example of the icons is shown in the margin.

see part **1** stage 3 tier 1

2. Climate change risk-uncertainty-decision-making framework

2.1 Introduction

In this chapter, the key stages of the framework are described. For each stage, we:

- **introduce** the stage;
- outline the **key issues** to be considered and the types of activities to be undertaken;
- identify a **series of questions** that the decision-maker should endeavour to answer; and
- indicate appropriate **tools and techniques** that can be used.

2.2 An introduction to the framework: a structure for good decision-making

2.2.1 EIGHT KEY STAGES

The decision-making framework is illustrated overleaf in Figure 1. It identifies the key stages comprising 'good practice' in decision-making. It covers the whole decision-making process, from problem identification through to implementation and monitoring of the decision. As shown in the figure, these are:

Structuring the problem:
- Stage 1 Identify problem and objectives;
- Stage 2 Establish decision-making criteria, receptors, exposure units and risk assessment endpoints;

Analysing the problem: (tiered stages)
- Stage 3 Assess risk;
- Stage 4 Identify options;
- Stage 5 Appraise options;

Decision-making:
- Stage 6 Make decision;

Post-decision actions:
- Stage 7 Implement decision;
- Stage 8 Monitor, evaluate and review.

The focus of this report is upon identifying and treating the risk and uncertainty associated with decisions where climate change may be a significant factor. This emphasis is reflected in the level of detail with which the individual stages in the framework are described. For example, the options appraisal and decision-making stages require the use of a variety of standard techniques, and these stages are therefore described more briefly, although we emphasise the treatment of uncertainty.

The aim of using the framework is for the decision-maker to identify where climate change is a material consideration. Where climate or climate change are significant, the decision-maker should aim to identify adaptation options for the decision (such as no regret options) that are robust to the key sources of uncertainty. At each stage of the framework, it is important that a balanced approach is taken to both the climate and non-climate factors that represent sources of risk and uncertainty. The framework aims to deliver a decision-making process that allows decision-makers and other stakeholders to define and refine their attitude to risk. This can include precautionary approaches (Green Alliance, 2002).

The decision process should, in general, involve all stakeholders. Nevertheless not all stakeholders may agree with the objectives and criteria defined by the primary decision-maker. This framework may be useful to those stakeholders excluded from or peripheral to certain decisions, aiding the examination or review of the decision-making process adopted by the primary decision-maker.

see part 2 | section 2.7.2

see part 2 | section 2.5 & 2.6
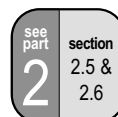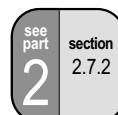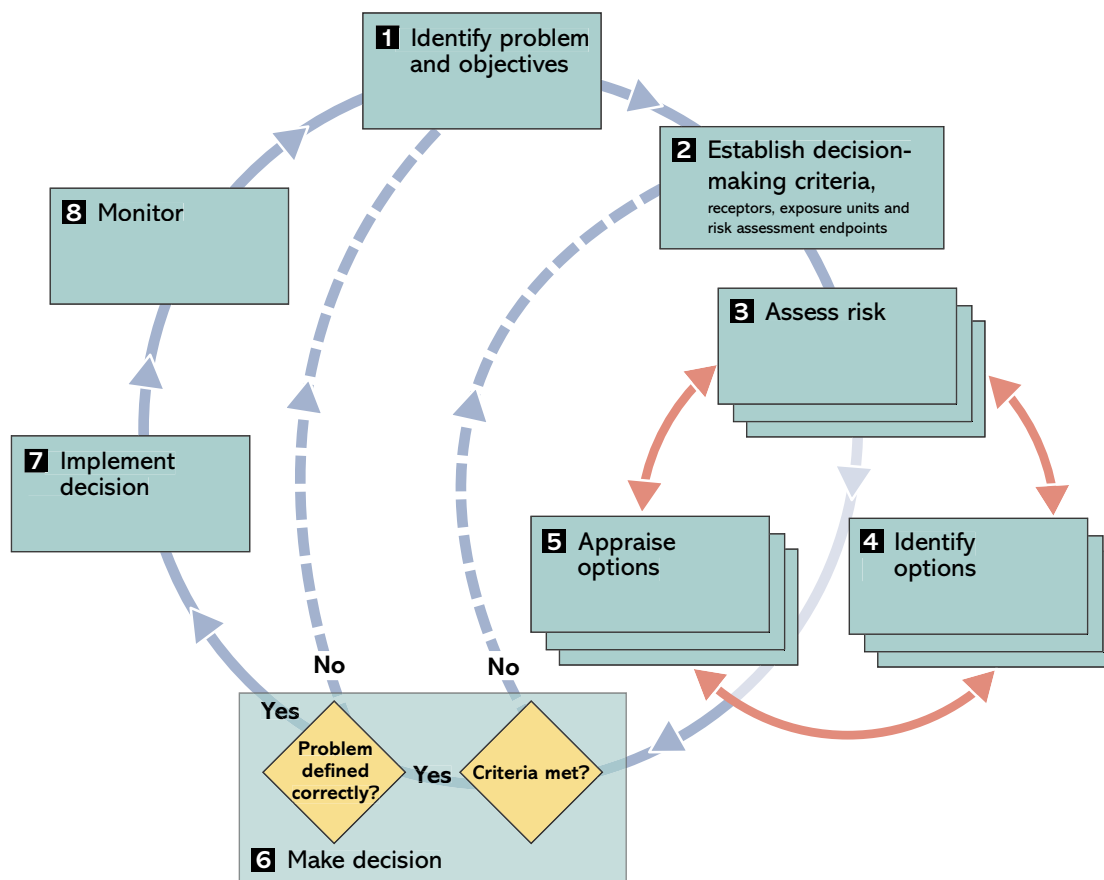
Figure 1: A framework to support good decision-making in the face of climate change risk

This framework was purposely developed to be flexible, allowing it to be applied to the wide range of decisions that may potentially be affected by climate change. This means it can be applied to many different types of decisions across a wide variety of sectors, and including commercial and public decisions concerning policy, programmes and projects.

2.2.2 AN ITERATIVE PROCESS

Note that there are three separate aspects to the process represented by the framework:

• First, it is **circular**, allowing the **performance** of decisions taken to be reviewed, and decisions revisited through time, in light of new information on climate change and its impacts. Existing climate change policies, as

well as adaptation strategies that have resulted from previous iterations of the framework, can be regarded either as inputs to the process or constraints upon it.

• Second, it is **iterative**, allowing the problem, decision-making criteria, risk assessment and options to be refined as a result of previous analyses, prior to any decision being implemented.

• Third, certain stages within the framework are **tiered**, allowing the decision-maker to undertake screening, **evaluation** and prioritisation of climate risks and options for the decision which promote adaptation to climate change, before moving on to more detailed risk assessments and options appraisals (DETR, 2000b).

In practice, the stages in decision-making will not always follow on from one another. It is often necessary to return to a previous step, for example to take into account a new option that has only been identified as a result of a first round of risk assessment or options appraisal. In Figure 1 frequently needed reiteration routes are indicated by dotted lines. In particular, the difficulty and importance of problem formulation must be recognised. In a climate change context, many adaptation issues have probably not yet been recognised – and problems that may require adaptation remain ill defined. In other cases the problem will have to be redefined in order to open a practical set of options. It is widely recognised that good problem definition can be critical to a useful analysis and to the generation of a wide range of options for the decision-maker.

Good decision-making also involves revisiting a decision as new information becomes available. This is especially true for climate change issues, where research is ongoing – for example, the UKCIP02 climate change scenarios have replaced the previous UKCIP98 scenarios.

The need for a decision will not always be driven by a problem that explicitly identifies climate change as a factor (i.e. a climate adaptation problem). For example, a decision may be part of an ongoing process, such as a periodic review of land use plans. The risk represented by climate change, relative to other risk factors, may be recognised only once decision-making criteria have been set and initial options identified. The forestry case study (see Appendix 1) provides an example of this type of decision problem. In all cases, awareness of the preceding and following stages in the framework should help to make the decision process more robust.

2.2.3 ANSWERING THE QUESTIONS

At each stage of the framework, a set of questions is provided for the decision-maker to answer. These aim to help the decision-maker to understand the key issues at each stage, and thus make a better decision overall. In general, the answers to the questions should be as complete as possible – simple 'Yes' or 'No' answers should be avoided.

The decision-maker should:

- provide clear reasoning for each answer;
- state any significant assumptions;
- be explicit about the choice of decision criteria and policy strategies;
- where appropriate state the degree of confidence in the answer (see Table 10);
- identify any major uncertainties; and
- state any information sources, literature, methods and tools used in arriving at the answer.

The answers to the questions should form part of a formal process or audit record of the decision-making process, so that it can be reviewed and revisited at a later date by other stakeholders.

2.2.4 TIME AND RESOURCES NEEDED FOR DECISION-MAKING

Formally allowing for risk and uncertainty in decision-making will almost inevitably mean that additional time and resources will be required for the decision-making process. However, the use of **risk screening** and a tiered approach to assessment can help prevent unnecessary costs by avoiding the immediate use of complicated decision-making and quantitative assessment methods. Preliminary assessments also provide a basis for assessing the costs and benefits of more sophisticated assessments.

Clearly, though, when making a decision that will involve significant investment or with potentially significant consequences, the decision-maker will want to be well informed. In these cases, he will need to ensure that he has sought out and used the best available information and data, and is likely to spend longer reaching his decision.

2.3 An introduction to the use of tools and techniques

Decision-making may be assisted by the use of a wide variety of analytical tools and techniques, varying from the simple to the sophisticated. Many of the tools can be applied within more than one stage of the framework, but some are more specific. At the simplest level '**brainstorming**' constitutes a straight-

see part **2** section 3.6.3

forward technique with established protocols describing good practice. At the other end of the spectrum, there are complex tools such as climate impact modelling, cost-benefit analysis and risk forecasting. Certain techniques, such as **uncertainty analysis** and **multi-criteria analysis**, describe general approaches that can be undertaken using a variety of tools. The choice of particular tool will depend on the problem. Although it can be difficult to specify which tool should be adopted for a particular decision, there are some questions to be considered by the decision-maker before a tool or technique is selected, and these are outlined in the box below.

Background information and a brief description of the tools and techniques are provided in Appendix 3. Some of the more important ones are described in further detail in the web-based resources on the UKCIP website.[2] Websites describing software applications of particular tools are indicated in Appendix 4.

Questions to consider when choosing a tool/technique

1. **How much will it cost?**
   - ➤ **Applying certain types of tools, particularly those involving the extensive collection of data or the development of quantitative assessment models, can be costly.**
   - ➤ **Inexpensive off-the-shelf computer packages are available that can facilitate model development (see Appendix 4).**
   - ➤ **However, expert assistance will still be required, particularly in understanding the underlying assumptions of the tools.**

2. **How long will it take?**
   - ➤ **The timescale involved in applying tools can often be longer than decision-makers (and sometimes their analysts) realise. Timescales for decision-making may be much shorter. No matter how useful a tool might potentially be, it is of little use if it cannot meet the decision deadline.[3]**
   - ➤ **The decision-maker will need to judge the risk involved in taking a decision in the absence of the benefits that a more detailed analysis might bring.**

3. **To what extent will the analysis improve the decision?**
   - ➤ **There is little point in undertaking sophisticated analysis, at a potentially high cost, if it adds little to the quality of decision-making. Nevertheless, decision-makers may feel less vulnerable if their decision is based on the best available data and science.**

4. **Can appropriate data and information be obtained?**
   - ➤ **If not, the preceding criteria will need to be considered.**

5. **Who will undertake the analysis?**
   - ➤ **If the use of particular tools requires specialist input, can that input be provided in-house or will it be necessary to seek (and, perhaps, pay for) external advice?**

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[2] See www.ukcip.org.uk/risk_uncert/risk_uncert.html

[3] Although such tools might be useful for a forensic analysis of decision already made.

Stage 1: Identify problem and objectives
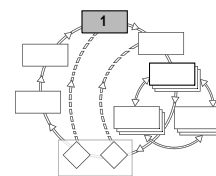
Introduction

Formulating the issue represents a critical stage for the decision-maker. Before embarking on a decision-making process, it is essential to understand the reasons for the decision being made, the decision-maker's broad objectives, and the wider context for the decision. The way an issue arises is likely to affect the approach to decision-making and the associated analysis. It may well be necessary to revisit this stage further on during the decision-making process, to ensure that the problem has been correctly defined and is being addressed properly.

The need to make a decision may arise from a range of factors, including:

- development of a new policy or project;
- changes in legislation, government or other policy, or regulatory guidance;
- regular reviews of ongoing programmes of activity;
- public concerns (possibly reflected by the media);
- pressure from interest groups;
- new scientific information on present day or future climate risk; or
- new technologies.

The factors that have led to a decision being required will also affect the extent to which climate change has been considered. While both knowledge and awareness of climate change have improved in recent years, many decisions will be taken without considering the potential effects of climate change on the decision, or in ignorance of the **sensitivity** of the decision to assumptions regarding future climate. Hence consideration of climate change may mean that a problem needs to be re-framed. For example, a problem that is defined as *'How do we protect a community from coastal flooding over the next 100 years?'* may, in the light of anticipated increases in sea level rise, need rethinking, so that a broader range

of options can be considered at the options identification stage. The problem could usefully be re-framed as: *'How do we manage the consequences of sea level rise for the community at risk over the next 100 years?'* For some decisions, however, there may be policies in place to guide the decision-maker towards a set of appropriate adaptation options.

Where there is uncertainty, a well-defined problem should be as open as possible, so that options for the decision are not cut off at an early stage.

Key issues

TYPES OF CLIMATE SENSITIVE DECISION

see part 2 section 2.3

It is important to recognise where decisions need to take account of climate change. These are called climate-sensitive decisions. This framework also recognises that it is useful to determine the circumstances (decisions) where climate change risks may be ignored, because they are not relevant to the decision being considered. In practice there will be many decisions whose outcomes could be affected directly or indirectly by climate change, but where climate change is one of a number of important factors. The degree of importance of climate change may vary from negligible to moderate, in which case some climate adaptation may be appropriate. These we term **climate-influenced decisions**, and it is essential that decision-makers are able to recognise these decisions. Many long-term business decisions may fall into this class, where, for instance, climate change could indirectly affect supply lines, customer demand or insurance costs.

In some cases the intended benefits of a decision will be determined to be at significant risk due to climate change, perhaps as a result of a risk assessment. In other cases a decision may be made explicitly to address issues or risks associated with present or future levels of climate variability, climate extremes and/or future climate change. Alternatively, the cli-

mate change 'issue' may be driving the need for new decision, or a review of past decisions. Such decisions are then identified as problems of **climate adaptation**. Many areas of decision-making (e.g. future coastal flood protection, flood-plain development, nature conservation management) fall into this category.
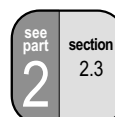
The distinction between these decision types is not absolute. Analysis may reveal that a climate-influenced decision is sufficiently sensitive to climate change that satisfactory climate adaptation may be the key component of a successful outcome.

A final decision type is identified: **adaptation constraining decisions**. The IPCC call these maladaptations (IPCC, 2001b). Maladaptations result from decisions that prevent or constrain the ability of others to manage, reduce or otherwise adapt to the effects of climate change (see Table 1). Those dealing with these negative consequences will in most cases not be those responsible for the original decision, but will be stakeholders with an interest in the outcome of the decision-making process. Decisions that constrain future adaptation, or reduce climate headroom, are decisions that may be regretted by future decision-makers.

MAKING MISTAKES UNDER UNCERTAINTY: OTHER MAL-ADAPTIVE DECISIONS

In anticipating an uncertain future climate, even well-informed decision-makers will make mistakes.

Uncertainty can make even the best decision-making process look foolish in retrospect. However, decision-makers have a responsibility to be aware of the risks associated with the future being different to that anticipated, or the chosen decision option performing less well than expected. In addition to maladaptation decisions described above, two broad types of mistakes or decision errors are possible, resulting from four different causes. These are outlined in Table 1 and dicussed further in Part 2, Section 2.3.2.

LEVELS OF DECISION-MAKING

Decision-making takes place at many different levels within a wide range of different organisations. The decision-makers and decisions in question can have differing characteristics and needs, and will certainly have different types of objectives. Broadly speaking, decisions can normally be described as being policy-, programme- or project-level decisions. Associated with these will be a range of different objectives. These objectives may be financial (e.g. minimise costs, maximise return), commercial, economic, public policy and welfare, utilitarian or environmental. In many cases decisions will aim to achieve and balance a number of different objectives. The different levels and types of decision-making will require different types of appraisals and techniques.[4] In many cases there will be multiple objectives and/or constraints, and these may benefit from techniques such as multi-criteria analysis
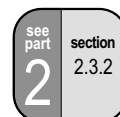
Table 1: Maladaptation and other climate change decision errors	
Consequence of poor decision	**Description of cause of poor decision**
Under-adaptation – 1	Where adaptation to climate change is or should be an essential component of the decision, but it is either ignored, or insufficient actions are taken to adapt.
Under-adaptation – 2	Where non-climate factors are perceived as having greater importance to the decision than climate change factors, the result may be that insufficient **weight** is attached to the need for adaptation. This may tend to lead to under-adaptation.
Over-adaptation – 1	Actions taken where climate change is considered to be a significant factor on the decision to be taken, but where it will have or should have little or no influence on that decision.
Over-adaptation – 2	Actions taken where non-climate factors that should have a significant influence on the decision are ignored or given insufficient weight compared to climate change factors. This may tend to lead to over-adaptation.
Maladaptation	Actions taken that reduce the options or ability of decision-makers now or in the future to manage the impacts of climate change. Such actions are sometimes described as reducing climate headroom.

[4] For instance, best-practice advice on how to take account of climate change in planning is being prepared through the Office of the Deputy Prime Minister. It draws upon guidance in this report, and makes use of this decision-making framework.

Table 2: Examples of different levels of decisions

	Policy or policy review	Programme	Project – example 1	Project – example 2 (see Appendix 1)
Example	National Park Management Strategy	Programme of Catchment Flood Management Plans	Individual coastal flood defence scheme	Forestry development in an upland catchment
Broad decision objective	To conserve and enhance the National Park's particular qualities and to provide opportunities for their enjoyment. (More specific objectives, aimed to achieving this high level objective, can also be formulated.)	To improve the overall level of flood protection provided within river catchments.	To reduce risk of flood damage by 20% by 2050 at a particular location.	A sustainable forestry, with long-term environmental and social benefits, qualifying for grant-aid.
Some characteristics of decision	May be a multi-faceted problem with multiple specific objectives. Climate change may affect these objectives in different ways.	Range of objectives: public safety, protection of private and commercial, property, promotion of local development, including some environmental improvement. Trade-offs between objectives dependent on particular decision options. Decision is subject to local planning and national policy constraints.	Effects of the decision may be limited to a specific area.	Wide range of stakeholders. Choice of option, and decision to proceed, constrained by need to obtain grant-in-aid funding. Success of forestry options and consequences are long-term (> 50 years), so likely to be influenced by climate change.
Treatment of climate change risks and uncertainties	Undertake a broad brush analysis of uncertainty – orders of magnitude, estimates of risks and costs of options.	Allowance for climate change may already have been considered and policy level guidance provided. If not, treatment may proceed as for policy review opposite (see also DETR 1998a), or be developed based on case studies.	Risks associated with climate change may be realised at this level. Assessments of probabilities, impacts and costs of options may be based on expert and subjective judgement, informed by available climate scenarios and historical data on impacts. Key sources of uncertainty could be range of future climate scenarios used, the choice of downscaling to allow them to be applied to a specific location, and the availability or otherwise of historical flood risk data.	Wide range of potential receptors and risk assessment endpoints determined by need for Environmental Impact Assessment, extending exposure unit beyond the boundary of the land proposed for afforestation. Risk determined in terms of the possible impact of changes in specific climate variables on the likely (i) success of different forestry options meeting the decision-maker's objectives and (ii) on the environmental consequences of each option determined as part of the EIA.
Timescale for decision-making/ implementation	Timescale established by decision-makers, and similar to other planning timescales.		Timescale established by the decision-maker but linked to the expected design life of the component defence works (decades).	Timescale for making and implementing decision linked to the approval of grant-in-aid by the component authority.
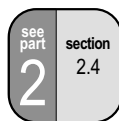
(DTLR, 2001a). Examples of these decision types and some associated objectives are provided in Table 2. Some general guidance on the treatment of risk and uncertainty for the various levels is provided in Part 2, Section 2.4.

Addressing questions such as those given in the box below should help in the understanding of how important climate change is to making the decision. It will also help to focus on how climate change-related risks and uncertainties should be taken into account within later stages of the appraisal.

Questions

Key questions for Stage 1
1. **Where does the need to make the decision come from? What are the main drivers behind the decision? What beneficial objectives are intended?**
2. **Is the problem explicitly one of managing present-day climate or adapting to future climate change?** ➤ **i.e. Is the problem perceived to be a climate adaptation decision problem?**
3. **If the main driver is not related to climate or climate change, is climate change believed to be a factor in the problem?** ➤ **If so, how important is climate change believed to be, relative to other factors?** ➤ **i.e. Is the problem perceived to be a climate-influenced decision problem?**
4. **Is it a policy-, programme- or project-level decision?**
5. **Who or what will benefit or suffer as a consequence of the problem being addressed?** ➤ **Who are the key stakeholders representing these interests?**
6. **Have timescales been established for making and/or implementing a decision?** ➤ **Do these timescales constrain the time available for the decision appraisal, or vice versa?**
7. **Is the decision expected to provide benefits in the long-term (> 10 years) or have other long-term consequences?** ➤ **Describe what they are, the likely time period, and to whom they may be important.** ➤ **Decisions with long-term consequences are likely to be more sensitive to climate change.**

Tools and techniques

Features to consider when deciding which tool to adopt at this stage (see Table 3) include familiarity with the problem area, and numbers of stakeholders involved in the decision. Some tools are useful for indentifying other decisions that could be affected by the decision under consideration (i.e. potential 'knock-on' effects) and could therefore assist in recognising potential adaptation constraining decisions.

Table 3: Tools and techniques for Stage 1			
Tool/technique	Familiarity with problem area	Number of stakeholders	Identify related decisions?
Brainstorming	little/some/great	few/some	potentially
Consultation Exercises	great	many	potentially
Focus Groups	some/great	some/many	no
Analysis of Interconnected Decision Areas (AIDA)	some/great	few/some	yes
Problem Mapping Tools	little/some/great	few/some/many	potentially
Free-form Gaming	some/great	some/many	yes
Policy Exercise	some/great	some/many	yes

Stage 2: Establish decision-making criteria
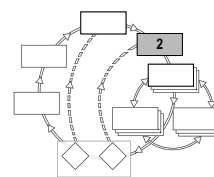
Introduction

This stage sets out the establishment of criteria for decision-making. The broad objectives of the decision-maker, set out under Stage 1, need to be translated into operational criteria that can be used in a formal risk assessment, and against which the performance of different options and the subsequent decision can be appraised. It prompts the decision-maker to consider the context for the decision-making process. These criteria should reflect uncertainty about the future and future climate, and will be influenced by the organisation's decision-making culture and attitude to risk.

see part 2 | **section 2.6**

Key issues

CONSTRAINTS

In many cases, the criteria for decision-making will be constrained, for example by the legislative and regulatory environment, by other stakeholders and decision-makers, budgets, etc. Different overall criteria for decision-making are described in Part 2, Section 2.5. Stakeholders may have different, and sometimes conflicting, decision-making criteria.

see part 2 | **section 2.5**

The decision-maker needs to recognise these constraints at an early stage in the decision-making process, as they may provide a focus for any decision. Such constraints should have arisen, or had their appropriateness examined, through a risk-based decision process such as that advocated here. The constraints can be different for climate adaptation and climate-influenced decisions, as follows:

- For **climate adaptation decisions**, the decision-maker may be informed or constrained by policies formulated specifically to guide him towards a portfolio of appropriate climate adaptation options.

- For **climate-influenced decisions**, climate adaptation may be peripheral to the decision-maker's initial objectives. In these cases, climate change may represent a risk or constraint on these objectives. The purpose of the **decision analysis** is then to recognise the nature and significance of these climatic risks and constraints, and identify modified objectives that can be achieved.

At this stage, the decision-maker may only be aware of some of the possible decision options, and may wish to consider other decision criteria as a result of further analysis of the problem. As with Stage 1, it may be necessary to revisit this stage further on during the decision-making process, to ensure that the criteria chosen are correct.

ESTABLISH EXPOSURE UNITS, RECEPTORS AND RISK ASSESSMENT ENDPOINTS

see part 2 | **section 3.3**

Before commencing Stage 3, it is essential for decision-makers and risk analysts together to consider the **exposure unit**(s) and **receptors** at risk, and agree preliminary risk assessment endpoints that relate to the decision criteria. In the context of climate change impact studies, risk assessment endpoints are sometimes known as 'climate thresholds' (Jones, 2001). This process represents an important link between the objectives in Stage 1, criteria established by the decision-maker in Stage 2, and the subsequent risk assessment and options appraisal activities in Stages 3 and 5.

The exposure unit represents the **system** considered to be at risk, and will often be defined in terms of geographical extent, location and distribution of a variety population of **receptors** at risk. These receptors are selected to represent important aspects of the exposure unit, particularly those of significance to the decision-making process. In some cases the exposure unit and receptor may be synonymous. Assessment endpoints are chosen to

help establish the acceptability of the risk posed to the exposure unit(s) by future circumstances and decisions, including those regarding climate change **risk management**. The exposure unit, receptors and assessment endpoints will all be determined by the nature of the decision problem. The choice of risk assessment endpoints therefore requires judgements concerning tolerable or intolerable levels of risk posed to receptors. Risk assessment endpoints will often be an explicit outcome of policy development. In these cases, risk assessment will be used to inform decisions regarding tolerable risk and guidance on the choice of risk assessment endpoints. Such guidance may specify quite precisely the **risk assessment endpoint** to be used as part of project design criteria (e.g. a 1:200 annual **probability** of sea level exceeding a particular

height). Policy problems, where future climate risk is a concern, will in general encompass larger exposure units and greater potential numbers of receptors and assessment endpoints. Examples of exposure units, receptors and risk assessment endpoints are given in Table 4.

The exposure unit and receptors may need to be redefined following initial risk assessments undertaken as part of Stage 3 Tier 1 and Tier 2 (see later). Risk assessment endpoints will also need to be revised where risk assessments need to become more complex or quantitative (e.g. towards Tier 3 assessments). The choice of receptors and risk assessment endpoints will often be determined by the availability of relevant data, scenarios, and tools.

Table 4: An example of a possible policy objective, relating to health outcomes, to demonstrate the relationship between the objectives, assessment criteria, receptors, exposure unit, and risk assessment endpoints. Factors contributing to the risk assessment are also identified. These factors should be chosen in such a way that informed decisions might be taken that would help the policy objectives to be achieved.	
Policy objective	Reduce the frequency of winter fracture injuries in the elderly population
Criteria	20% reduction in hospital in-patient elderly admissions and attendance at outpatient clinics for fracture injuries by 2025.
Receptors and exposure units	(i) Population of people aged over 60 years within health authority districts throughout England and Wales. (ii) Hospitals providing inpatient and outpatient orthopaedic services in England and Wales. (Additional aspects of the exposure unit may be included as factors contributing to the risk assessment. Importantly this might include significant variability in climate across the exposure unit.)

Assessment endpoints	(i) 90% confidence that the risk of
	             (a) collis wrist fracture and
	             (b) hip fracture
	 (expressed as rates per 10,000 population) can be reduced by 20% by 2025, compared to 2000.
	 (ii) Probable impact on the total level of A&E presentations, hospital admissions and outpatient clinic attendance due to all fractures that may result from falls.

Factors (to be considered in terms of assessment endpoints)	Months (September to March) Weather (perhaps including consideration of freezing conditions, presence of snow, wind speed, prolonged wet periods) Mobility (pre-injury) Gender Social status Disability Domestic situation (living alone, partner/family, sheltered accommodation, etc.) Car ownership Income Age group (60-70, 70-80, 80+) Provision of advice to help minimise risk of falling, etc.

Questions

There are two sets of questions for Stage 2. The first set is primarily the responsibility of the decision-maker. The second set will require liaison between decision-makers and their risk analysts.

Key questions for decision-makers at Stage 2

1. **What makes the correct decision? In other words, what are the criteria against which your options will be appraised in Stage 5?**
   - ➤ Criteria might include the risk of the option not succeeding, ease of implementation, cost, equity, public approval, public acceptability, etc.

2. **What are the legislative requirements or constraints?**
   - ➤ For Government agencies, does the decision require an appraisal that explicitly considers both costs and benefits (as, for example, required by the Environment Act 1995)?
   - ➤ Do guidelines exist that set out the approach that should be taken to the appraisal (e.g. DTLR, 2001b, HM Treasury, 2001 & 2003)?

3. **What are the rules for making the decision, given the uncertainty in climate change?**
   - ➤ For instance, is your organisation risk averse or focused on maximising benefit, or minimising cost?
   - ➤ If risk averse, minimum (no or low) regret and precautionary approaches to decision rules should be considered.

4. **What is the decision-making culture of your organisation?**
   - ➤ Is the culture one of open and explicit decision-making?
   - ➤ Do different stakeholders need to be involved in the decision-making process? If so, how?
   - ➤ Is the goal consensus, or a demonstrably 'rational', if not consensual, choice?

5. **Could the decision being considered possibly constrain other decision-makers' ability to adapt to climate change (i.e. contribute to climate maladaptation)?**
   - ➤ Options or decisions that may constrain climate adaptation can be difficult to identify at this stage. They may be only apparent after Stage 5.
   - ➤ If it is believed that the decision being considered may adversely affect the ability of other decision-makers or stakeholders to manage climate change risks in the future, their interests and involvement in the decision-making process should be considered.

6. **Who is the ultimate decision-maker?**

7. **Has climate change already been accounted for at a strategic level? If so, was consideration of climate change at the strategic level adequate? Does the strategy take account of all possible climate change outcomes?**

8. **What resources are available to help you make the decision?**
   - ➤ This will help determine how in-depth your decision-making process can be, and what tools are appropriate to assist in the process.

Key questions for decision-makers and risk analysts at Stage 2

1. **Have receptors at risk and the exposure unit been defined?**

2. **Have assessment endpoints or thresholds been identified as a basis for assessing risk to the exposure unit and receptors?**
   ➤ **Assessment endpoints should be directly relevant to the problem, useful to the decision-maker, and amenable to risk analysis.**
   ➤ **One or more assessment endpoint may be required, dependent on the complexity of the problem.**
   ➤ **Can assessment endpoints be analysed in terms of:**
   a) **past records and future scenarios of climate variability?**
   b) **other non-climate factors?**
   ➤ **Can assessment endpoints be developed to provide a basis of quantitative (Tier 3) risk assessments (Stage 3) if required?**

3. **Have assessment endpoints and timescales over which they will be assessed been agreed between decision-makers (policy-lead, programme officer or project manager), stakeholders, and risk assessors?**
   ➤ **If there are consequences beyond this time frame, e.g. to future stakeholders ('sustainability'), it may be beneficial to consider longer timeframes.**

4. **Have all project management issues been agreed? For example:**
   ➤ **Are the resources and time allocated to undertake the risk assessment reasonable and proportionate to the importance and urgency (see Stage 1) of the decision problem?**
   ➤ **Are the objectives clearly defined and achievable?**
   ➤ **Are the necessary expertise and data accessible?**

Tools and techniques

Key features to consider when choosing a tool are how familiar decision-makers are with the problem area, and the number and range of stakeholders involved (see IEMA, 2002). Table 5 indicates tools that are likely to be useful for identifying other decisions that could be affected by the decision under consideration (i.e. potential 'knock-on' effects) and could therefore assist in avoiding adaptation constraining decisons.

Table 5: Tools and techniques for Stage 2			
Tool/technique	Familiarity with problem area	Number of stakeholders	Identify related decisions?
Brainstorming	little/some/great	few/some	potentially
Consultation Exercises	great	many	potentially
Focus Groups	some/great	some/many	no
Analysis of Interconnected Decision Areas (AIDA)	some/great	few/some	yes
Problem Mapping Tools	little/some/great	few/some/many	potentially

Stage 3: Assess risk (tiered)
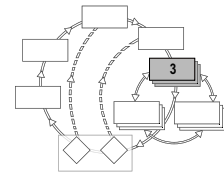
Introduction

The primary purpose of undertaking risk assessments is to:

- characterise the nature of the risk;
- provide qualitative or quantitative estimates of the risk;
- assess the consequences of uncertainty for decision options; and
- compare sources of risk, including climate risks.

The final objective is an important aspect of this approach. Risk assessment allows different sources of future risk, from both climate and non-climate sources to be compared and prioritised, prior to undertaking what may prove to be costly, detailed, quantitative assessments of climate risk. It also allows different options for the management of specific risks to be identified and examined at an early stage (under Stages 4 and 5).

Key issues

USING TIERED RISK ASSESSMENT

The decision-maker will undertake a different level (tier) of analysis at Stage 3, depending on:

- the level of decision (i.e. policy, programme or project);
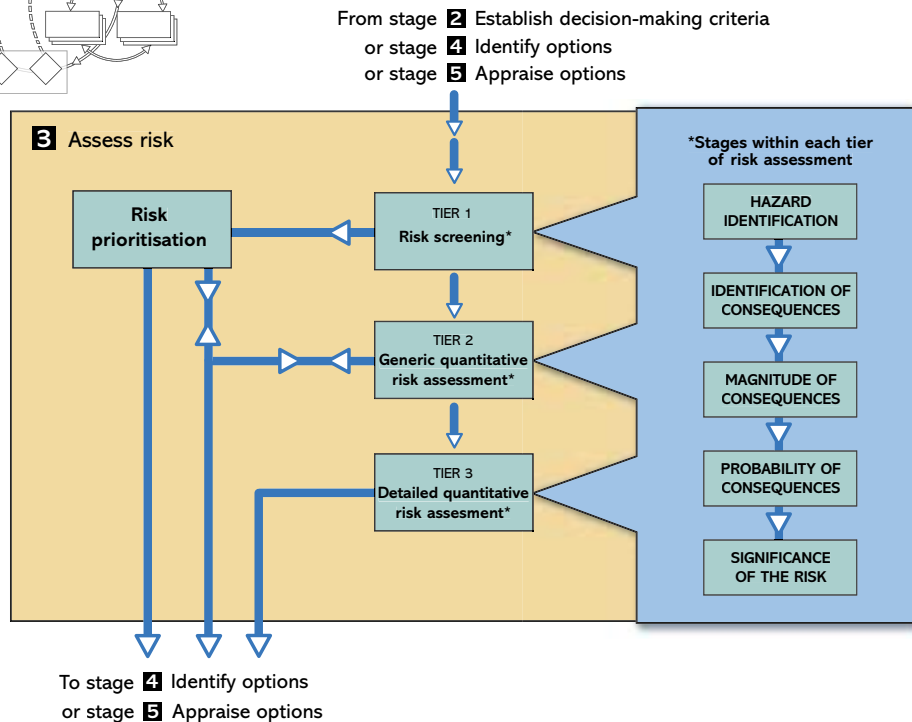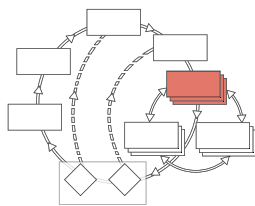
Figure 2: Overview of the stages within, and purpose of, each tier of risk assessment (DETR, 2000b)

- the level of understanding he has about how climate change will affect his decision, which will be determined in part by previous assessment iterations; and
- whether he is making a climate adaptation decision (in which case he will have already identified climate change as a significant risk as part of a Tier 1 assessment) or a climate-influenced decision (in which case he will be less certain of the implications of climate change).

Guidance on which tier to use is provided in Table 6.

The purpose of risk assessment for each tier is as follows (see Figure 2 and bottom row, Table 6):

- Tier 1 – risk screening;
- Tier 2 – qualitative, and generic quantitative risk assessment;
- Tier 3 – specific quantitative risk assessment.

If the decision-maker is not sure how, or if, his decision could be affected by climate change, a broad **preliminary climate change risk assessment**, as outlined in Tier 1, should be undertaken. These Tier 1 assessments apply particularly to a decision-maker trying to decide, perhaps for the first time, whether a problem or decision may be **climate-influenced**. Decision-makers dealing with **climate adaptation** decisions may move directly to Tiers 2 or 3.

An immediate progression to potentially complex and data intensive quantitative techniques of risk assessment (Tier 3) is not recommended. Tier 2 includes a range of risk assessment techniques that may progress from the qualitative, through semi-quantitative to simple quantitative risk assessments where suitable data are readily available.

STEPS IN A RISK ASSESSMENT

see part 2 chapter 3

see part 2 section 3.4 & 3.5

A climate change risk assessment has the following key steps:

- Identify and define a set of climate and non-climate variables or factors for the exposure unit and for which the receptors may be sensitive;

see part 2 section 3.6

see part 2 section 3.7

see part 2 section 3.5.2

- Use climate scenarios to help determine the climate change dependent risk to the receptors; and
- Use non-climate forecasts or scenarios to help determine the nature of the non-climate-dependent risk.

The assessment will need to consider how the characteristics of the climate variables of concern will change over the defined temporal and spatial domain. Assumptions concerning changes in the mean and variance of the climate **variable** statistics will be particularly important, especially where impacts are associated with lower probability extremes of climate (e.g. changes in numbers of frost days or the **return period** of high magnitude rainfall events). Forecasting risk associated with extreme values may require, as part of a Tier 3 assessment, the application of specialist statistical modelling techniques (e.g. using generalised extreme value distributions; see Coles, 2001). These might be applied to scenario-based climate ensembles or forecasts based on historical time series data.

An effective assessment can be accomplished by a variety of mechanisms, including participatory workshops, specific R&D or the use of consultancy support, etc. Whatever mechanism is chosen, it should involve a full range of stakeholders, including the decision-makers effecting or affected by the decision (see IEMA, 2002). There should be recourse to a range of experts. These should include those with expertise in climate science, those with particular knowledge of the exposure unit(s) and how they may be affected by climate and other factors (including the consequences and effectiveness of any decision) and experts in the application of the analytical techniques to help decision-makers assess options.
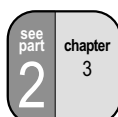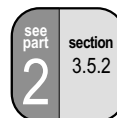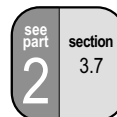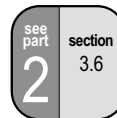
Table 6: Key to selecting the appropriate tier of risk assessment. The table emphasises climate risk, but we emphasise that risk assessments need to determine the balance of risk due to climate change with that due to other non-climate factors.

Tier	Tier 1 – preliminary climate change risk assessment	Tier 2 – qualitative, semi-quantitative and generic quantitative risk assessment	Tier 3 – specific quantitative risk assessment
Decision level	Policy Programme Project	Programme Project	Project
Understanding of climate change importance to decision	Start at this tier if unsure about how, or if, climate change could affect your decision	Start at this tier if already confident that climate variables are/are not important for your decision	Use this tier if available data exist to support quantitative assessments including climate variables and impacts
Decision type	Start at this tier for decisions that may be influenced by climate change	May start at this tier for climate adaptation decisions, or following Tier 1	For climate-influenced and climate adaptation decisions, once a range of adaptation options has been identified through previous circuits round 'assess risk/identify options/appraise options' loop
Purpose of risk assessment	For preliminary risk screening, in particular: • identifying potential factors that might represent a present or future climate hazard within the exposure unit, (associated level of confidence might be low, medium or high); • excluding potential factors that do not represent a present or future climate hazard, (associated level of confidence should be high); • identifying potential receptors at risk within the exposure unit, (associated level of confidence might be low, medium or high); • excluding potential receptors not at significant risk, (associated level of confidence should be high); • helping to identify, in broad terms, potential climate risk management options under Stage 4.	For risk characterisation, prioritisation and ranking, in particular: • identifying the influence, dependencies and causal pathways linking climate hazard to receptors; • assessing the (relative) sensitivity of a receptor to climate (and non-climate) hazards, based on agreed assessment endpoints; • characterising the nature of the risk posed to the receptor; • prioritisation and ranking of climate and non-climate risks; • helping to identify or refine options under Stage 4, including those for climate adaptation and climate change risk management; • helping to appraise options under Stage 5, including options for climate adaptation and climate change risk management; • forming reasoned judgements regarding the level of confidence (or uncertainty) associated with risk assessment, and the performance of risk management options; • identifying important assumptions.	Essential where the choice between options, or the effective management of the risk, will be improved by detailed quantitative assessment of the risk or uncertainties, including exploring the sensitivity of the assessment to key assumptions.

Stage 3 – Tier 1: Preliminary climate change risk assessment

see part 2   chapter 3
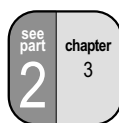
Key issues

A preliminary climate change risk assessment can be helpful in ensuring that all potentially significant climate-related hazards that may affect or impact a decision are identified at an early stage. This provides better understanding, when identifying options (see Stage 4), of the factors that may affect their consequences.

Completing a preliminary climate change risk assessment may usually benefit from some degree of information gathering. However, the intention should be to limit the time and effort spent on data collection at this time. The intention is to provide an indication (not involving quantification) of the areas where climate change risk could significantly influence the final decision.

Completing a checklist will help identify whether or not climate change related impacts may be important to the selection of options (at Stage 5) – a task which will be facilitated by consideration of the questions in the box below.

Questions

Key questions for Stage 3, Tier 1

1. **What is the lifetime of your decision? Over what period are the benefits of the decision expected to be realised?**
    ➤ This will inform the choice of climate scenarios to be used in future analysis, and how they are interpreted.

2. **Which climate variables are likely to be significant in relation to meeting your decision criteria?**
    ➤ Does information on past variability in climate or past extremes of weather indicate potential vulnerability to climate change?
    ➤ Vulnerability to changes in mean climate may be less obvious, and therefore more difficult to foresee than vulnerability to changes in climate extremes.

3. **How might future changes in these climate variables affect your decision and ability to meet your decision criteria?**
    ➤ Are certain climate variables likely to be of greater significance than others?
    ➤ Judgements should be based on information contained within the latest UKCIP climate change scenarios. Climate analogues may also be helpful.
    ➤ Changes in the frequency and magnitude of extreme values of climate variables are more difficult to predict, and more uncertain, than changes in mean values.

4. **If an initial portfolio of options exists, is it possible at this stage to judge the potential significance of the impacts of climate change to the options?**
    ➤ Is the risk posed to certain receptors likely to be of key importance to the choice of option?

5. **Is there uncertainty regarding forecasts of particular climatic hazards, or their associated impacts?**
    ➤ Can the level of confidence associated with particular hazards and their impacts be determined?

6. **Can any climatic variables, or impacts be screened out at this stage?**
    ➤ For example, because they are not likely to affect the choice of option or would apply equally to all possible options.

7. **What other (non-climate) factors could also be relevant in relation to meeting your criteria?**

Tools and techniques

Table 7 opposite provides an example of a **checklist** that can be used in preliminary climate change risk assessments. The rows and columns of the table together provide an overall checklist of climate variables and their associated characteristics, which can be used to help describe potential climate pressures or hazards. (Further information about the variables in Table 7 is provided is Part 2, Table 3.1 and explanations for the other column headings are provided in Table 3.2).

Using this checklist should make possible a comprehensive identification and screening of potential future climate hazards on receptors, and facilitate the definition of climate variables for consideration in more formal Tier 2 and 3 risk assessments (including the development of impact assessment models). The outcome of applying the checklist in Table 7 should be a well-reasoned description of those climate variables to which different receptors may be sensitive.

Table 8 provides an example of an application of a risk assessment checklist, for a National Park Management Strategy. The overall objective for the strategy was provided in Table 2. Table 8 outlines specific objectives aimed at achieving this overall objective, and describes some of the climate and non-climate factors that could affect them.

Climate scenarios can also be used at this stage to provide the basis of a list of potentially significant climate variables, together with a range of anticipated future values. While future climate scenarios include an increasing number of potentially important climate variables, they may not be presented in a form, or at a level of detail, most relevant to certain problems. It is important not to constrain the preliminary climate change risk assessment because a potentially relevant variable is not included in a particular **scenario** or report. Hence it is recommended that **checklists** should either precede or accompany consideration of the climate variables and changes described in climate scenarios.

Often **brainstorming** can give a good initial overview of impacts. A key technique that can also assist at this stage is the use of **process influence diagrams**, which help identify the causal pathways that link the impacts of both climatic and non-climatic factors to the receptors that form the important components of the decision. Further tools that may help are shown in Table 9.

The decision-maker may have greater or lesser confidence in his knowledge of how each climate variable affects his decision criteria. It is important that a systematic approach is adopted to describing the knowledge on which the assessment is based. Table 10 provides some qualitative terms, which can be used within Stage 3 risk assessments and Stage 5 options appraisal to describe different types of knowledge and the associated probability, uncertainty and confidence of that knowledge.

see part **2** tables 3.1 & 3.2

see part **2** section 3.4

see part **2** section 3.6

see part **2** section 3.8

Table 7: Summary matrix of climate variables and characteristics for use in preliminary climate change risk assessments (PCCRA).

Variable	Characteristics of variable				Sensitivity of decision criteria/ system to changes in variable	Confidence in assessment of link between variable and decision criteria/ system
	Magnitude (M) and Direction (D) of change	**Statistical basis of change**	**Averaging or sampling period**	**Joint probability events and variables**		
	No Change Change (M&D) Decrease (M only) Increase (M only) Rate of change	Average value Cumulative value Variability in values Frequency of values (incl. percentiles, extreme values, maxima & minima)	Instantaneous Hourly or sub-hourly 'Day' or 'Night' Daily Monthly Seasonal Annual Decadal or longer	Not consecutive Consecutive occurrence Coincident or joint occurrence	Not sensitive Low sensitivity Medium sensitivity High sensitivity	Known, established Reliable Extremely doubtful (see Table 10)
PRIMARY						
Carbon dioxide						
Sea level						
Temperature						
Precipitation						
Wind						
Cloud cover						
SYNOPTIC						
Weather types						
Pressure						
Pressure gradient						
Storm tracks						
Ocean climatology						
Lightning						
COMPOUND						
Humidity						
Evapo-transpiration						
Mist, fog						
sea level						
Growing season						
PROXY						
Soil moisture						
Water run-off						
Wave climate						

Table 8: Example checklist for a preliminary climate change risk assessment of a National Park Management Strategy

Objective	Criteria	Examples of potential climate change impacts on the criteria	Examples of potential non-climate impacts on the criteria
To increase the number of visitors to the park all year round	Increase number of summer visitors by 20% by 2015 (compared to 2000). Increase number of winter visitors by 30% by 2015 (compared to 2000).	Higher average summer temperatures and reduced summer rainfall could lead to increased visitor numbers in summer. Visitor numbers are sensitive to frequency and duration of higher summer temperatures and reduced rainfall. Reduced average summer and autumn rainfall will reduce the available water resources, and may constrain the park's ability to increase visitor numbers. Warmer winters and less snowfall could encourage more visitors in winter, but increased average winter rainfall, and more rainy days, may put them off. More frequent and intense winter rainfall events may lead to localised flooding on routes in to the park, affecting visitor numbers.	A new wildlife centre is opening in 2005, close to the park. Potential day visitors to the park may choose to go there instead.
To promote sustainable tourism: encouraging visitors but not cars, and promoting use of public transport	50% of visitors to travel to the park by public transport by 2015. Four new Park and Ride schemes to be introduced by 2010.	Increased average and extreme winter rainfall is likely to discourage visitors from using public transport. Reduced summer rainfall (average and frequency distribution) may mean that more summer visitors use public transport.	Any new Park and Ride schemes are likely to be opposed by local businesses, who say that they reduce trade.
To conserve landscapes and biodiversity: reversing the 75% decline in flower-rich meadows which occurred between 1990 and 2000	By 2010, increase the area of flower-rich meadows by 50% (compared to 2000).	Climate changes – e.g. higher average carbon dioxide concentrations, higher seasonal average temperatures, higher average winter rainfall, reduced average summer rainfall, more growing degree days, less snow – could affect the distributions of some of the plant species occurring in the flower-rich meadows. Some species are likely to benefit, while others may suffer. Increased frequency of above average, intense periods of winter rainfall may increase soil erosion on steep slopes in some meadows. Pests and diseases which are killed off when temperature falls below freezing may increase in numbers, as the annual number of cold/frost days falls, causing knock-on effects on some plant species.	The amount of flower-rich meadowland will depend on the types of agricultural activities undertaken. Moves to more intensive agriculture were the main cause of the decline in the meadows between 1990 and 2000. The economic viability of traditional farming, which allows the meadows to flourish, is uncertain.

Table 9: Tools and techniques for Stage 3, Tier 1				
Tool/technique	**Qualitative and/ or quantitative**	**Complexity**	**Data requirements**	**Comment**
Checklists	qualitative	easy to use	minimal	Table 7 is a checklist
Brainstorming	usually qualitative	may require specialists	minimal	
Problem Mapping Tools	usually qualitative	may require specialists	minimal	
Process Influence Diagrams	qualitative	easy to use may require specialists with expertise	minimal	
Consultation Exercises	either	may require inputs from experts	low	
Fault/Event Trees	either	requires specialists	potentially high	Data requirements high to inform precise estimates of probabilities
Expert Judgement and Elicitation	either	requires inputs from experts	low	Various methodological approaches, including: Structured questionnaires and encoding methods Facilitated workshops Delphi technique
Scenario Analysis	either	easy to use with guidance	medium	See Part 2, Sections 3.6 and 3.7
Climate Change Scenarios	either	easy to complex	medium to high	See Part 2, Section 3.6
Cross-Impact Analysis	either	easy to use with guidance	medium for simpler versions	Both formal and modified/ versions in use
Deliberate Imprecision	qualitative	easy to use with guidance	minimal	
Pedigree Analysis	qualitative	easy to complex	low	Supports interpretation of expert judgement

see part 2 sections 3.6 & 3.7

see part 2 section 3.6

Table 10: Qualitative classified descriptions of probability, risk, confidence, uncertainty, pedigree of knowledge and information, and acceptability, together with indicative quantitative probabilities. Classifications should be agreed in the context of a particular study and applied consistently. Based partly on IPCC (2001a), Moss & Schneider (2000) and others. Pedigree scores can be used within a decision analysis framework to assist the decision-maker in accounting for different qualities and certainties associated with different types of knowledge.

Quantitative descriptor	Subjective descriptor			Pedigree and acceptability				
Probability of event or outcome, Confidence or Relative frequency	**Probability of event or outcome**	**Risk[5] (including hazard consequence, sensitivity)**	**Confidence or Uncertainty**	**Theoretical basis or model**	**Information or data**	**Acceptance by peers**	**Acceptance by colleagues**	**Acceptance by stakeholders**
Greater than 99%	Virtually certain to certain	Extremely high	Extremely confident Virtually certain Known, established	Established Validated model	Experimental	Absolute, universal	All but cranks	Universal support Almost total support
90 - 99% chance	Highly probable Very likely	Very high	Very confident Highly certain Very reliable	Proven				
66 - 90% chance	Likely Probable	High	Confident Quite certain Reliable	Process-based model, underpinned by some theory	Historical experience or Observational data	High	All but rebels	Widely supported Largely supported
33 - 66% chance	Possible	Moderately high	Plausible Debatable Medium confidence Unreliable	Black box and Simulation models	Calculated	Medium	Different schools	Majority (>55%) to minority (<45%) support
10 - 33% chance	Unlikely	Moderate	Low confidence Uncertain Not reliable	Statistical models Fuzzy models	Educated or expert guess	Low	New field	Little support or local support
1 - 10% chance	Very unlikely Improbable	Low/ Small	Very uncertain Very unreliable Doubtful Very low confidence	Concepts and definitions unproven	Uneducated or non-expert guess	Very low to none	No opinion	Widely unsupported or rejected to absolute rejection
Less than 1%	Virtually impossible to impossible	Very small to negligible	No confidence Extremely doubtful					

[5] The tolerable level risk will normally be set towards the bottom of the scale.

Stage 3 – Tier 2 and Tier 3: Qualitative and quantitative climate change risk assessment
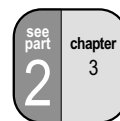
Key issues

As outlined in Table 6, a Tier 2 or 3 assessment can be undertaken by:

- a decision-maker addressing a climate adaptation decision problem; and
- a decision-maker who has already identified a range of options, and is interested to know how climate change might influence the choice between them, whether the options need to be amended, or new options considered.

Quantitative climate change risk/impact assessments (Tier 3) enable the decision-maker to evaluate risk quantitatively, including sources of uncertainty, and the influence of factors on the probability and magnitude of the risk. This tier of analysis also allows a more detailed, quantitative assessment of the prospective performance of a particular well-defined portfolio of options under the range of uncertainty concerning future climate, as well as non-climate factors.

As with other steps in the decision-making process, the outputs of risk assessment may require other stages to be revisited. Similarly, risk assessments may need to be reviewed in the light of outputs from options appraisal.

Questions

The selection of the appropriate risk assessment tool for a particular circumstance is not always straightforward but consideration of the questions in the box below should provide some assistance.

Key questions for Stage 3, Tiers 2 and 3 (in addition to those key questions in Stage 3, Tier 1)

1. Given the various options identified previously, what are the risks of failing to meet your criteria:
   a) posed by climate change?
   b) posed by non-climate factors?
   ➤ Forecasts of both future climate, and non-climate futures, will be required. In most cases these forecasts will be scenario-based in order to account for sources of uncertainty.
   ➤ Criteria will be represented by a number of defined receptors and assessment endpoints (refer to Stage 2).

2. What are the most important consequences? Which are the key hazard factors? How are the consequences dependent upon the hazards?
   ➤ Risk assessments, including estimates of probability, will be contingent on the particular scenario or scenarios upon which they are based.

3. Are some of the options more vulnerable to these factors others?

4. What tools should be used to analyse risks? Do these reflect the scale of the problem, its complexity and data availability?

5. Could other tools be adopted which would allow more explicit consideration of climate change risk, including estimates of probability, analyses of uncertainties and the significance of key assumptions?
   ➤ In-depth detailed quantitative studies (Tier 3) will usually be dependent on further data collection and the development of risk assessment models.
   ➤ What would be the advantages or disadvantages of adopting alternative risk assessment tools?

Tools and techniques

Some of the relevant tools and techniques and their characteristics are listed in Table 11.

Statistical models may be of considerable value within risk assessments, but results need to be interpreted with care. Potential applications include: models based on empirical relationships between past variations in climate and impacts on the exposure unit; relationships between **forecast** and observed climate variables at different spatial scales (e.g. statistical downscaling methods); and forecasting the historical or prospective return periods of low probability events, such as intense rainfall events or extreme river levels, using generalised extreme value distributions (e.g. Coles, 2001).

There are often a further three considerations to take into account when selecting a tool for risk assessment:

- Regret, or the consequences and costs of being wrong (see Stage 1 on decision errors). The more that is at stake, the more important it is to reach a decision which is robust, and thus greater care should be taken in selecting the best tool or, possibly, combination of tools.

- The complexity of the problem. The ability of mathematical risk models to handle a large number of complex interrelated issues is well tested. However, problems may be so large and complex that they cannot be resolved through the use of sophisticated models, although such models can still be of help in understanding the problem. In principle simple models may provide a better basis for forecasting and assessing the level of confidence associated with the forecast.

- The adequacy of the data. The output from any assessment tool will always be constrained by the quality of the available data. Where it is possible to estimate the uncertainty in the input data, this can be propagated through an assessment **model** and the consequences for the assessment examined.

Table 11: Tools and techniques for Stage 3, Tiers 2 and 3

Tool/technique	Complexity	Data requirements	Comment
Uncertainty Radial Charts	easy to use	low	
Fault/Event Trees	may require specialists	high	Also suitable for Stage 3, Tier 1
Decision and Probability Trees	may require specialists	high	
Expert Judgement and Elicitation	requires inputs from experts	low	Various methodological approaches, including: Structured questionnaires and encoding methods Facilitated workshops Delphi technique
Scenario Analysis	easy to use if appropriate scenarios are available	medium	Also suitable for Stage 3, Tier 1 See Part 2, Sections 3.6 and 3.7
Climate Change Scenarios	easy to complex	medium to high	See Part 2, Section 3.6
Cross-Impact Analysis	easy to use with guidance	medium for simpler version	Also suitable for Stage 3, Tier 1 Both formal and modified/simpler versions in use
Monte Carlo Techniques	easy to use with guidance	high	
Modelling Tools: Process Response Models Statistical Models	requires specialists	low, medium or high	Deterministic or stochastic models may be used, but methods for sensitivity and uncertainty analysis will be needed to provide estimates of risk
Development and use of Specific Sophisticated Modelling Tools	requires specialists	high	
Climate Typing	requires specialists	high	
Downscaling	requires specialists	high	Precise methods depend on available environmental or climate data, and temporal and spatial scale of the exposure unit and receptors. See Part 2, Section 3.6.7
Bayesian Methods	requires specialists	high	Can be used to determine the value of additional data or alternative models, and for reviewing risk assessments
Markov Chain Modelling	requires specialists	medium to high	Can be applied to event and fault trees and similar models to examine propagation of uncertainty
Interval Analysis	requires specialists	low, medium or high	

see part 2 sections 3.6 & 3.7

see part 2 section 3.6

see part 2 section 3.8

see part 2 section 3.6.7

Stage 4: Identify options (tiered)
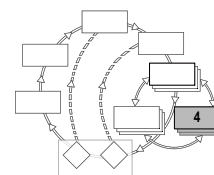
Introduction

For any particular problem, there is likely to be a number of different options that will meet the decision-maker's criteria. Initially, it is important that a wide range of potential options is considered to avoid the premature rejection of viable options. This will include options ranging from 'do-nothing' to 'do a little' to 'do a lot'. In terms of options that are robust to future climate change, and will help manage the consequences of climate change, the decision-maker should attempt to identify **No regret** and **Low Regret** options at the outset.

Adaptive management – the sequential and continual process of making the best decision at each decision point and reviewing the performance of previous decisions – is an important strategy for handling uncertainties, including those associated with climate change. Sequential adaptive management should be directed towards an overall strategic objective. In all cases an objective must be to keep open possible future options, that is, avoid decisions that constrain future options for adaptation.

Key issues

If a **climate adaptation** decision is being made, there are a range of generic adaptation strategies that can be considered in response to climate change risk and uncertainty. Examples of the types of strategies are shown in Table 2.3 in Part 2. For a decision identified at Stage 3 as being **climate-influenced**, the information provided in Part 2, Table 2.3 should be useful in stimulating the decision-maker's thinking on appropriate options.

Which options are most appropriate will depend on a range of factors, including:

- whether the decision is operating at the policy, programme or project level;

- the non-climate impacts of concern;
- the relevant climate change impacts;
- the decision-maker's attitude to risk; and
- the degree of risk and uncertainty surrounding the decision.

As some of these factors may only become clear following further iterations round the risk assessment, options identification and appraisal loop, there is likely to be a need to revisit the options under investigation. New options may emerge which provide a more appropriate means of managing risk and uncertainty for a given decision. For example, if the objective were to build 1,000 houses, one option would be to build them at Site A. However, if the preliminary climate change risk assessment suggests that Site A may be subject to an increased risk of future flooding as a result of climate change, two options could be taken forward: A1, build the houses with integral flood-proofing, and A2, build the houses with a two metre embankment around the site perimeter.

Questions

The types of questions that may assist in identifying options in a manner that takes into account climate change risk and uncertainty are outlined in the box below. Given the wide range of possible options which could be devised under the headings in Part 2, Table 2.3, it will be important to use appropriate tools to reduce to a manageable set the number of options examined within Tier 2 and Tier 3 risk assessment and options appraisal stages. This is the role of the Stage 5 Tier 1 options appraisal (see opposite).

Key questions for Stage 4

1. **What type of options should be considered? What are the likely consequences of the 'do nothing' option, or of not adjusting existing options to take account of forecast changes in climate?**

2. **If the risk assessment stage has identified climate change as a significant factor for your decision, then can options be identified that are more robust to climate change?**
   ➤ **Generic climate adaptation strategies may help identify specific options appropriate to the particular problem.**

3. **Can 'no regret' and 'low regret' options be identified?**
   ➤ **Potential no regret options would perform well under present-day climate, and under all future climate scenarios.**

4. **Can the options be defined in a flexible manner to allow for sources of uncertainty?**
   ➤ **e.g. Can adaptation options be identified that could be increased at a later date, or implemented separately or in combination or in sequence to provide flexible levels of response to risk? For example, could staged options be appropriate?**

5. **Delay is a possible option. Would it be feasible or advisable to delay making a decision until further information is available? Consider:**
   ➤ **the rate of climate change vs. the timescale for implementing the decision;**
   ➤ **the magnitude and nature of the risk (especially in relation to low probability high consequence events that are also highly uncertain);**
   ➤ **the value (reduction in uncertainty) to be gained from improved monitoring or research to better characterise the climate hazard (including climate scenarios and ensembles), exposure pathways, impacts and costs, and the effectiveness of risk reduction and management options.**

Tools and techniques

Table 12: Tools and techniques for Stage 4			
Tool/technique	**Familiarity with issues**	**Number of stakeholders**	**Comment**
Brainstorming	little/some/great	few/some	These tools have already been outlined for Stages 1 & 2
Consultation Exercises	great	many	
Focus Groups	some/great	some/many	
AIDA	some/great	few/some	
Problem Mapping Tools	little/some/great	few/some/many	
Checklists	some	not applicable	
Screening	some	few/some	
Free-form gaming	some/great	some/many	Identify conflicts and other decision-making strategies
Policy exercise	some/great	some/many	

Stage 5: Appraise options (tiered)
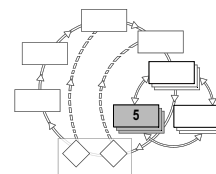
Introduction

Options appraisal is closely linked with risk assessment and comprises evaluation of the options against the criteria established in Stage 2. The prime purpose of the options appraisal stage is to provide a robust basis upon which to recommend the 'best' way (the preferred option) to meet the overall decision criteria. Options appraisal informs the decision; making the decision is within Stage 6.

Key issues

Many of the options considered in an assessment will concern choices regarding **how much** (including, if any) adaptation (e.g. how large a safety margin or headroom allowance) and **when** to carry out such measures. Such choices are therefore dependent on changes in the probability and magnitude of the significant climate variables identified by the risk assessments under Stage 3. The choices between options can involve significant costs and environmental and social impacts. Consequently, decision-making on climate change adaptation may often involve important trade-offs between the environmental, economic and social implications of such options. These need to be considered with care. Allowing a greater safety margin may entail higher costs – for example, a greater security of water resource supply could entail the high costs and environmental impacts of providing a reservoir. Which option is chosen will therefore be determined by the decision-maker's attitude to the risks associated with over- or under-adaptation.

The UKCIP report "Costing the impacts of climate change in the UK" (Metroeconomica, 2003) provides a standard methodology for undertaking the options appraisal process.

Although each of the options identified should contribute to meeting the decision-maker's objectives (e.g. the reduction and improved management of

climate risk), each option may be associated with other risks. These may be related to the inputs on which the options are based (for example, whether the demand for 1,000 houses in a particular area will be realised) or to the outputs (the risk that the houses cannot be built within the planned time-scale or that the budget is exceeded). The risks associated with each option, and the assessment of their significance, should be undertaken under Stage 3 as part of the iterative process.

SCREENING OPTIONS

A further key purpose of the options appraisal is to seek ways of refining the options so as to **seek better options** with lower environmental, social and economic impacts. The 'best' option may involve a combination of elements of the options appraised that exploits strengths identified for specific options. Hence the appraisal should analyse differences between the effectiveness of the different options. Moreover, it should focus on specific important elements of the options and identify the key determinants of these impacts so as to identify ways of ameliorating them. Such insights can be much more useful than any specific numbers (or conclusions) that the appraisal generates. Orders of magnitude estimates may often be sufficient to identify the best option. It is more important that the appraisal covers comprehensively all the major impacts and considerations than provides a precise estimate on just part of the problem.

The tiered approach to risk assessment recommended in Stage 3 also applies within the options appraisal stage, which should start with the application of qualitative assessment tools. Semi-quantitative or more fully quantitative tools are then applied if warranted by the importance of the decision (in social, environmental as well as economic terms) and the anticipated difference in performance between the available options. For many

see part **2** section 2.6

decision problems, the combined use of a number of approaches may prove the most valuable. Hence the approach could be as follows:

- **Tier 1** – a systematic qualitative analysis, where the size, significance and relative importance of the risks, costs and benefits for each option are described. There should be an emphasis on **ranking** the options in terms of costs and benefits, but this may not involve quantification.
- **Tier 2** – a semi-quantitative analysis, where some aspects of the risks, costs and benefits are assessed in quantitative terms while others are assessed qualitatively; the assessment would aim to assess uncertainty by placing upper and lower bounds on the risks, costs and benefits.
- **Tier 3** – a fully quantitative analysis, where the probable performance of each option in managing the risk is quantified in terms of costs and benefits and, in some cases or where possible (e.g. HM Treasury, 2003), converted into monetary terms.

At Tier 1, it should be possible to reduce a 'long-list' of options down to a 'short-list' to take forward for further in-depth appraisal, taking account of aspects such as vulnerability to climate change, technical feasibility, economic impacts, environmental impacts, and likely **stakeholder** acceptability.

In a few cases, screening tools may indicate that one option is likely to perform better than the others against the screening criteria. Where there is general agreement amongst stakeholders that this option is 'best', it may be the case that no further analysis is required (unless there are legal requirements or other drivers underlying the need for a fuller appraisal). Some form of uncertainty analysis may be used to determine that a particular option is indeed likely to perform better than other options. Justification for the rejection of options must be provided. In the majority of cases, however, the information developed through a screening exercise should make it possible to reduce the initial, wide-ranging set of options to a smaller number for more detailed (Tier 2 or 3) analysis. In so doing, however, it should be remembered that no option that is

technically feasible, and performs better than all of the other options on at least one important **criterion**, should be eliminated at this tier.

The form of more detailed analyses will depend upon the importance of the decision, the range of options identified and the data available. In general, quantitative analysis will provide more information to decision-makers, for example, on the trade-offs between options and their relative costs and benefits. However, quantitative approaches require more resources and more detailed data, together with the use of informed professional judgement to handle uncertainties. A balance will therefore need to be struck between the thoroughness of the analysis and the constraints in terms of data, budget and time-scale. Achieving this balance will require consideration of the questions in the box overleaf.

The approach taken to options appraisal will determine how the data are analysed, the way in which the alternative options are compared, and the criteria that are used in decision-making itself.

For example, where **cost-benefit analysis** is required of a public policy, the aim is to compare estimates of the costs to society of taking action (e.g. managing a climate change risk) with the anticipated benefit or reduced disbenefit to particular receptors. If sufficient data are available, it may be possible to place a monetary value on the economic, environmental, human health and social benefits and costs. Where such valuation is feasible, expressing the benefits in the same units (money) as the costs allows the direct comparison of alternative measures. In risk terms, the aim should be to provide the decision-maker with an estimate of the confidence associated with the determination of the cost-benefit ratio.

In many cases, however, it can be difficult, impossible or misleading to undertake an appraisal in monetary terms. In such cases non-monetary, or a mix of monetary and non-monetary appraisal methods, allow alternative options to be compared. For public sector decisions in the UK, monetary values should be attributed wherever feasible (HM Treasury, 2003).

Questions

Key questions for Stage 5
1. **How do these options rate in relation to the criteria and risk assessment endpoints established at Stage 2, and as informed by the Stage 3 risk assessment?** ➤ **Where there are multiple criteria, MCA techniques may be used.** ➤ **Can different levels of confidence be attached to the likely performance of different options? If so, what are they?** ➤ **Can particular options be confidently excluded because they are unlikely to meet the acceptability criteria?** 2. **Do you need more precise definitions (operational definitions) of these criteria to appraise the options?** 3. **Would other criteria have led to a different form of options appraisal?** 4. **Would further, more detailed Stage 3, 4 or 5 (Tier 2 or Tier 3) assessments provide a basis for improved discrimination between options, or help develop better options?** 5. **Have you identified, during Stage 3, the risks associated with implementing each option?** 6. **Could the options being considered possibly constrain other decision-makers' ability to adapt to climate change (i.e. contribute to climate maladaptation)?** ➤ **Options that may constrain climate adaptation can be difficult to identify at Stage 1 and 2, and may only become apparent during or after Stage 5 appraisal of options.** ➤ **Other options might be identified (Stage 4) to either avoid or mitigate the maladaptive effect.** ➤ **If it is believed that the options being considered may adversely affect the ability of other decision-makers or stakeholders to manage climate change risks in the future, their interests and involvement in the decision-making process should be considered.**

Tools and techniques

The descriptions of the tools in Table 13 have been grouped as follows:

- Qualitative Methods – which employ a systematic qualitative analysis – these are suitable for use at Tier 1;
- Alternative Methods – which usually employ a semi-quantitative analysis in order to compare different attributes or parameters, and can be used at Tier 2; and
- Quantitative and Economics-Based Methods – which (usually) employ a fully quantitative analysis of risks, costs and benefits – which are suitable for use at Tier 3. This will include:

  ➤ Assessment of the costs of the options and any wider social and economic implications.
  ➤ Assessment of the environmental impacts and benefits of the options. Such assessment needs to be based on a risk assessment of the impacts and needs to allow for and reflect adequately the uncertainties in these assessments.

The choice of tool will depend on the decision-making criteria adopted at Stage 2. Economics-based tools are appropriate if financial criteria are the only ones that apply. Normally, a comprehensive assessment of the costs of adaptation would consider not only economic criteria, but also social welfare and equity.

Given the number of tools, two columns are included to assist in the selection of potentially useful tools: 'C' for complexity and 'D' for data requirements. Both parameters are rated on a scale of L (low); M (medium); and H (high).

Table 13: Tools and techniques for Stage 5						
Tool/technique	Qualitative methods	Alternative methods	Quantitative and/or economics based methods	C[6]	D[6]	Comment
Consultation Exercises	✓			M	M	Outlined in Stages 1 & 2
Focus Groups	✓			M	M	
Ranking/Dominance Analysis	✓			L	M	
Screening		✓		L	M	Outlined in Stage 4
Scenario Analysis	✓	✓	✓	M	M	Outlined in Stage 3 and described in detail in Part 2, Sections 3.6 & 3.7
Cross-Impact Analysis	✓			M	M	
Pairwise Comparison	✓			L	M	
Sieve Mapping	✓			H	H	
Maximax, Maximin, Minimax, Regret			✓	M	M	Described in Part 2, Section 2.6.1
Expected Value			✓	M	H	Described in Part 2, Section 2.6.2
Cost-Effectiveness Analysis			✓	L	M	
Cost-Benefit Analysis			✓	H	H	
Decision Analysis			✓	H	H	
Bayesian Methods			✓	H	H	
Decision Conferencing			✓	H	H	
Discounting			✓	L	H	
Environmental Impact Assessment/Strategic Environmental Assessment		✓		H	H	
Multi-Criteria Analysis (Scoring and Weighting)		✓		M	M	Described in Part 2, Section 2.6.3
Risk-Risk Analysis		✓		M	M	
Contingent Valuation • Revealed performance • Stated performance		✓	✓ ✓	H H	H H	
Fixed Rule-based Fuzzy Logic	✓	✓	✓	H	M	Tier 2 or 3 assessments
Financial Analysis			✓	M	M	
Partial Cost-benefit Analysis	✓		✓	H	M	
Preference Scales	✓			M	L	
Free-form Gaming	✓			M	M	
Policy Exercise	✓			M	M	

[6] 'C' refers to the complexity of the tool, and 'D', the data requirements. 'L' is low; 'M' is medium; and 'H' is high.

Stage 6: Make decision
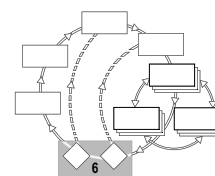
Introduction

The aim of Stage 5 options appraisal and the earlier analytical stages is to inform the decision-making process. The final step, then, is in bringing the information together, evaluating it against the objectives and defined decision criteria. This may include a review of whether the decision ojectives and criteria remain appropriate in the light of the preceding analysis. Stage 6 includes the effective communication of the analysis in a way that will assist decision-makers and stakeholders in understanding the trade-offs between different courses of action.

Key issues

REDEFINING THE PROBLEM

The framework identifies two key decision points as part of Stage 6. These questions may be considered following any tier of preceding risk assessment, option identification and appraisal stages. They may also be considered **during** these stages. They should precede any final choice between the remaining options, and implementation of the decision.

The decision points relate to two associated issues:

- whether the criteria established under Stage 2, designed to operationalise the decision problem and decision-maker's objectives, and against which options are being considered, have proved to be adequate or sufficient in light of the preceding assessment; and
- whether the problem itself was well defined, or whether it needs to be reframed following Stages 2-5.

These decision points apply to any problem where it is found that the boundaries of the problem need to be changed as a result of issues identified in the course of a decision appraisal.

In the context of climate change, these decision points provide an opportunity to recognise where problems may need to be reframed in order to either include or exclude climate change adaptation issues (see Stage 1). For example, it will be the case that many decisions will not initially consider the impact of future climate change. Where climate change is found to be a significant risk (Stage 3), such problems may require that additional criteria be defined (Stage 2) to accommodate the need for climate change risk management. In other cases the problem may need to be reframed and the decision-maker's objectives adjusted (Stage 1) in order to include explicitly the needs of climate adaptation. For problems initially framed as climate adaptation problems, the reverse may apply. It is likely that reframing will be particularly important for climate adaptation constraining decisions if maladaptation to future climate is to be avoided.

SELECTING THE PREFERRED OPTION(S)

Since the future is uncertain, any predicted outcome of selecting the 'preferred option' (which should emerge from the risk assessment and options appraisal process) will carry with it a degree of uncertainty. In other words, the 'performance' of the selected option might be better or, more seriously, worse than predicted. Testing each option against a range of climate and/or non-climate scenarios allows the decision-maker to come to a view on the performance of each option across the range of uncertainty represented by the scenarios. In some cases, it may be prudent for the decision-maker to opt for a less uncertain option. Where there are few uncertainties surrounding the choice of options, simpler decision criteria may suffice (see Table 14). However, it is likely that the more complex probabilistic decision criteria will be called upon for many decisions where climate change is a contributing uncertainty factor – and this can be determined through consideration of the questions in the box below. Where appropriate, the decision-maker may wish to implement a number of options with broadly equivalent prospects.
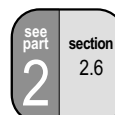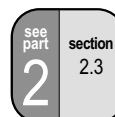
In reviewing the information coming out of the options appraisal process, decision-makers may want to know how sensitive any end ranking of options, and hence the end decision, is to the input data and key modelling and other assumptions. For this reason, reference is made to tools for sensitivity and **robustness analysis**, and to tools for expressing uncertainty (e.g. use of **ranges and intervals** and **deliberate imprecision**).

Decision-makers and other stakeholders need the results of the analysis to be presented in a clear and concise manner. It will be important to pro-vide a comprehensive overview of the analysis findings stating key assumptions, data sources and any uncertainties contained within them. The possible consequences of uncertainty for the choice and performance of the preferred option(s) should be described. It is essential, therefore, that both the analysis and any conclusions reached are transparent. Not only will this help ensure that the results are correctly interpreted, but also that other stakeholders or users of the results have confidence in them.

Questions

Key questions for Stage 6

1. **Is there a clear 'preferred' option?**
   - ➤ **If not, you may need to gather more information and return to the 'assess risk/identify options/appraise options' loop.**

2. **Could the adoption of different criteria (including any weights applied to criteria) and approach lead to the choice of a different option?**
   - ➤ **If not, you should have reached a robust decision.**
   - ➤ **If so, you have not necessarily identified the best option.**

3. **If there is not a clear preferred option:**
   - ➤ **Did you define your problem correctly at Stage 1, or could it be re-defined?**
   - ➤ **Were the criteria chosen in Stage 2 adequate? If not, do you need better criteria?**

4. **Has the specification of the problem and objectives under Stage 1 proved adequate in light of analysis under Stages 2-5?**
   - ➤ **For example, additional issues, additional or better criteria may have become apparent during Stages 2-5, particularly as a result of wider stakeholder involvement.**
   - ➤ **If climate change was not part of the initial problem, but risk assessment indicates that climate could be a significant risk factor, the problem may need to be re-framed in order to include climate adaptation objectives and identify potential adaptation options.**

5. **Does the manner in which risk and uncertainty was accounted for allow for robust decision-making?**

6. **Does the assessment provide a clear understanding of the importance of risk and uncertainty?**
   - ➤ **Are information and data presented in a form that decision-makers can readily use?**
   - ➤ **Are circumstances described (e.g. climate or non-climate scenarios) where the decision might fail to meet the established criteria?**

7. **Has the decision-maker's attitude to risk and uncertainty changed as a result of the assessment (particularly with regard to risks associated with climate change)?**
   - ➤ **If so, the decision-making criteria may need to be redefined (Stage 2).**

8. **Does the decision arrived at have implications for others' decisions? Will it help or constrain climate adaptation by other decision-makers? (see Stage 5, Question 6)**
   - ➤ **If the latter, the problem may need to be reframed under Stage 1 and/or further criteria developed under Stage 2.**
   - ➤ **The interests and involvement of other decision-makers or stakeholders in the decision-making process should be considered.**

Decision-makers should have confidence in an analysis that properly recognises sources of uncertainty, including significant gaps in the analysis, and the implications for the choice of and prospective performance of options. Such an analysis may not be able to recommend with confidence one option over another.

Obviously, the manner in which the results are reported will depend on the tools used in the analysis. All analyses should present a summary of the trade-offs associated with adopting one option over another, including:

- the associated risks, benefits and costs of each option;
- the key parameters affecting the decision, in particular the key uncertainties and the sensitivity of the end results to these; and
- the distribution of impacts of the different options on different groups in society, over time and geographically.

Tools and techniques

Table 14 list some of the useful tools for decision-making.

Table 14: Tools and techniques for Stage 6			
Tool/technique	**Simple decision criteria**	**Probabilistic decision criteria**	**Decision sensitivity**
Hedging and Flexing	✓		
Minimax, Maximin, Maximax and Regret	✓		
Expected Value		✓	
Portfolio Analysis		✓	✓
Sensitivity Analysis			✓
Robustness Analysis			✓
Ranges and Intervals			✓
Deliberate Imprecision			✓
Pedigree Analysis			✓
Policy Exercise			✓

Stage 7: Implement decision and Stage 8: Monitor, evaluate and review
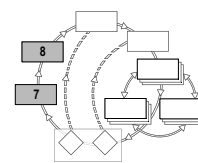
Once a decision has been reached, two further stages can be identified:

- implement decision; and
- monitor, evaluate and review.

The prime purpose of these guidelines is to help the decision-maker reach a decision and we do not therefore discuss in detail the 'best' means to implement and monitor a decision. However, a few key points are highlighted below.

At the very minimum, each decision-making process should set out what the key risks or uncertainties are and how they may affect the overall decision. Knowledge of such factors enables decision-makers to place confidence (either explicitly or implicitly) in the recommendations stemming from the options appraisal.

Clearly, it is desirable that a decision that affects the public enjoys public support. To assist this process, constructive communication can be used to address misconceptions and misunderstandings over climate change, risks and uncertainties. Indeed, steps should be taken to ensure that the importance of uncertainty to the end decision is effectively communicated in any event. This should include providing:

- an appreciation of the overall degree of uncertainty and variability and the confidence that can be placed in the analysis and its findings;
- an understanding of the key sources of variability and uncertainty and their impacts on the analysis;
- an understanding of the critical assumptions and their importance to the analysis and findings; this should include details of any such assumptions which relate to the subjective judgements of the analysts performing the analysis;

- an understanding of the unimportant assumptions and why they are unimportant;
- an understanding of the extent to which plausible alternative assumptions could affect any conclusions; and
- an understanding of key scientific controversies related to the assessment and a sense of what difference they might make regarding the conclusion.

The guiding principles when assessing and describing uncertainty are transparency and clarity of presentation.

Implementing options can be accompanied by significant policy and project management risks. This is particularly the case if the option is technically or managerially complex, is not subject to agreement with stakeholder groups, or involves significant financial expenditure (HM Treasury, 2001).

Finally, the success or otherwise of a decision should be monitored – did the predicted outcomes materialise? Quantified targets and indicators against which to monitor the performance of a decision should be developed.

Of course, further research, which may include focused data acquisition and/or monitoring of the environment can provide additional information that can help reduce decision uncertainties. This itself might be a preferred option. Monitoring can be used as an 'early warning' system for the detection of trends which require a new problem to be resolved and the decision-making process to be initiated. Monitoring can also provide short-term forecasts, supporting emergency and other rapid adaptation responses.

Monitoring also covers review of climate change risk assessments and decisions, following updated climate change scenarios or new information about climate change impacts.

However, research and data collection should also be targeted to reduce uncertainties associated with **risk characterisation**, assessment and management. This could include research to improve knowledge of and ability to forecast:

- the consequences or impacts of potential hazards;
- present-day and future changes in climate hazards;
- present-day and future changes in non-climate-related hazards; and
- the performance of risk management options.

Part 2

Part 2

1. Risk and uncertainty

1.1 Introduction

All decisions are intended to bring about some future benefit to someone or something, and involve choices (e.g. whether to act, whether to implement policy A or B, etc.). Without uncertainty, these decisions would be straightforward. Reality, however, is far more complex and hence all decisions involve judgements regarding uncertainty. Identifying the sources of uncertainty, understanding how they contribute to decision uncertainty, and the management of uncertainties within the assessment and decision-making process, are therefore essential to making well-informed decisions. While not all decisions produce the benefits that were intended, any decision should, even with the advantage of hindsight, be justifiable on the basis of the available knowledge at the time of the decision.

In this chapter the concepts of risk and uncertainty are briefly discussed. The principles of risk assessment and risk analysis are introduced, and their usefulness to the management of risk discussed. Different types of uncertainty are described, including their importance to decisions that might be influenced by, or concern the management of, future climate. The importance of identifying climate-dependent risks, and their relevance for decision-making, is discussed in Chapter 2. The key features of climate change risk assessments are described in Chapter 3.

1.2 Risk, uncertainty and confidence

Before introducing the principles of risk assessment and risk analysis, it is important that the meanings of the terms 'risk' and 'uncertainty' are made clear, especially as they can mean different things to different people. The use of the terms risk and uncertainty in this report is set out in Box 1.1.

Risk is commonly defined as the product of the **probability** or **likelihood** of occurrence of a **consequence** (see Figure 1.1). The consequence (or set of consequences or impacts) is usually associated with exposure to a defined hazard, which is often detrimental or harmful. However, risk assessment is equally applicable to the analysis of uncertain beneficial outcomes.

Uncertainty describes the **quality of our knowledge** concerning risk. Uncertainty may affect both the probability and consequence components of the risk. Hence our knowledge of future hazards posed by a changing climate involves uncertainty, which is compounded by the prospect of man-made changes in climate. The impacts associated with any particular future climate are also uncertain. The outcome of decisions taken to reduce climate impacts, or exploit climate-dependent opportunities, is a further source of uncertainty. While research aims to reduce uncertainties, the primary purpose of adopting a risk-based approach to decision-making is to

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Box 1.1: Definitions of risk and uncertainty

Risk: Risk is the combination of the probability of a consequence and its magnitude. Therefore risk considers the frequency or likelihood of occurrence of certain states or events (often termed 'hazards') and the magnitude of the likely consequences associated with those exposed to these hazardous states or events.

Uncertainty: Uncertainty exists where there is a lack of knowledge concerning outcomes. Uncertainty may result from an imprecise knowledge of the risk, i.e. where the probabilities and magnitude of either the hazards and/or their associated consequences are uncertain. Even when there is a precise knowledge of these components there is still uncertainty because outcomes are determined probabilistically.*

* The term 'aleatory uncertainty' is sometimes used where probabilities and dependent consequences are **precisely** known. 'Epistemic uncertainty' is used to describe situations in which probabilities and consequences are **imprecisely** known.

ensure that uncertainty is acknowledged and treated rigorously in the decision-making process.

It is also important to recognise the definitions used in decision theory (e.g. Tversky and Kahneman, 1992; Camerer and Weber, 1992), based on the original work of Knight (1921). Some decisions are taken under circumstances where the probabilities that particular outcomes or consequences will occur in the future can be known (as in a fair game of chance). These are **decisions taken under precise uncertainty**, and they are sometimes referred to as 'decisions taken under risk'. For many decisions, however, probabilities cannot be known or estimated. These are a special class of **decisions taken under uncertainty**. '**Risk**' is commonly used to describe situations in which both types of uncertainty apply (Knight, 1921; Morgan and Henrion, 1990).

Risk assessment is the process of establishing information concerning hazards, and the exposure and vulnerabilities of defined receptors. **Risk analysis** is the process by which knowledge concerning the probabilities, uncertainties and magnitude of future events is brought together, analysed and organised by the decision-maker. Risk analysis includes risk assessment, risk evaluation, and the identification and assessment of risk management alternatives.

Risk assessment may involve either *quantitative* or *qualitative* techniques and information to describe the nature of the probability component of the risk. Both techniques can be used to describe our knowledge of risk where probabilities can be estimated with some level of confidence. Qualitative techniques are particularly useful in circumstances where we lack knowledge of the probabilities. Risk assessment may therefore involve the combination of qualitative and quantitative information.

Both the hazard and the consequence have *magnitude*. For example, the risk of *significant* damage to trees in an area of forest due to winds *greater than Force 10* may be one event in a hundred years[7]. Many statements of risk, such as this, result
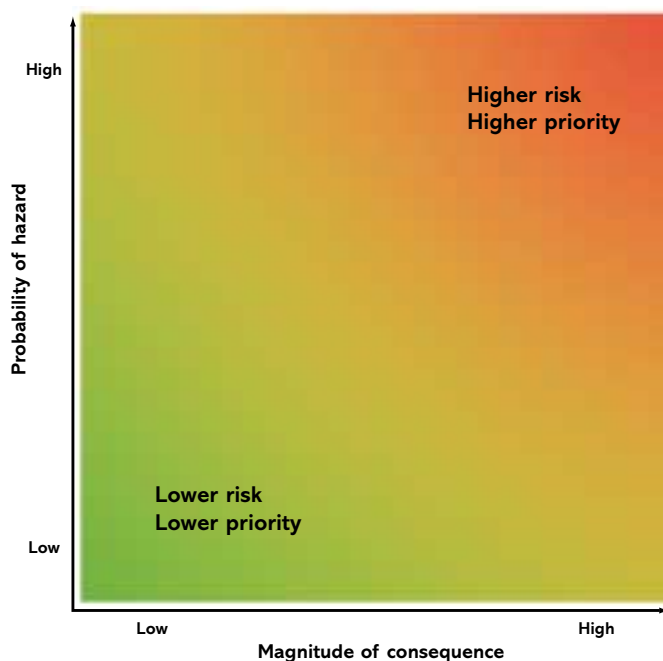
Figure 1.1: Risk depends on both probability and consequence. Climate represents a present-day hazard that we manage based largely upon past experience. Global warming may change the future probability associated with a hazard of a particular magnitude, thereby affecting the probability associated with a particular consequence. For example, intense rainfall may become more frequent, leading to an increase in flooding risk. The aim of climate change risk assessment and adaptation decision-making is to assess and manage the risk to defined receptors or exposure units.

[7] In this risk statement, the probability is expressed in terms of the expected frequency or return period of the event. This may be communicated as a percentage, e.g. a 1% annual risk of an event.

from an analysis of data in some form of risk assessment. As such they describe the observed or historical risk. However, the usefulness of a risk analysis is to provide a forecast or predictor of a future risk of concern to a decision-maker.

In other words, the risk associated with a particular circumstance is a characteristic of that situation, and can be estimated or forecast (in terms of probability and consequence). Both the probability and the magnitude components of a consequence may be uncertain. Since future climate change is uncertain, and variations in local weather and climate are governed (within uncertain limits) by chance (see Chapter 3), the assessment of climate change impacts, and the appraisal of decisions regarding adaptation, falls within the area of applied forecasting, risk assessment and risk analysis.

The degree of uncertainty associated with an 'estimate' of risk is reflected in the degree of associated confidence (i.e. the lower the uncertainty, the greater the degree of confidence in the estimate of risk). Where data exist on the occurrence of past events (e.g. measurements of daily rainfall) it may be possible to calculate the probability (or 'risk') of a future event (e.g. daily rainfall exceeding a certain threshold that may be associated with a particular level of harm or benefit). With suitable data, and using statistical techniques (e.g. **maximum likelihood methods**), it is possible therefore to obtain a quantitative estimate of the uncertainty associated with the calculated probability or risk.

In many situations, however, relevant data, information or understanding about the risk will be very limited. Nevertheless, it may be possible to identify upper and lower bounds to the risk (e.g. worst- and best-case scenarios), based on the available information. These bounds should reflect the extent of our uncertainty of the risk. In other cases it may be useful to obtain subjective judgements (e.g. from people with acknowledged expertise) regarding the level of confidence associated with the probability, consequence and nature of the risk. Clearly, these subjective judgements are uncertain, and the extent of the uncertainty should be acknowledged by the expert, or estimated by canvassing the expert judgement of a larger sample of people with similar expertise.

1.3 Risk analysis and risk management

The focus of many risk analyses is about making decisions concerning the management of rare (i.e. low probability) and/or uncertain detrimental events, for example avoiding the risk of extreme flooding. Risky decisions are usually associated with a number or range of potential outcomes: for many real-world decisions these outcomes may be either detrimental or beneficial, depending on the decision-maker's perspective. For example, flooding events may help to maintain or improve the conservation status of wetlands, but at a cost to property or farming incomes. These different outcomes may be associated with different probabilities, such as the probability of a river level exceeding the height of a flood defence. Associated with each possible outcome of a decision is a level of performance or 'payoff' (the balance between all the benefits and disbenefits). For a detrimental event, the pay-off is negative, but in the absence of the event, the pay-off may be zero (see Section 2.6 for further details). However, most decisions entail some level of investment and the associated cost will usually enter into the calculation of the pay-off. The decision-maker will be interested to identify options or strategies that, in some sense, minimise the disbenefits or maximise the benefits associated with the risk.

For most decisions it may be neither possible nor desirable to determine the risk as a single figure or statement. Often it is more useful to retain and communicate the **likelihood** and impact components of risk. This allows the decision-maker rather than the risk assessor to decide policy and ethical issues. For example, the decision-maker may wish to implement a policy of risk-aversion. This requires information on the relative likelihoods of severe as opposed to low-consequence outcomes. The impact of different decision options on all the components that contribute to the overall risk can then be assessed (even though the overall value of risk may be similar).

Similarly, it may be possible to assess all impact types in common currency, but the decision-maker may well wish to impose his own value-judgements on different types of impact (environmental, social, economic, for example). It is generally, therefore,

best for the risk assessor to present outcomes in terms appropriate to the receptor, using multiple attributes where necessary (see Section 2.6.3).

1.4 Risk-based decision-making

Decision-making on the basis of risk is relatively straightforward if several conditions are met:

- The analysis includes all significant hazards and impacts that could affect and be affected by a decision;
- Likelihoods and consequences are known or can be calculated for all significant outcomes for all decision options (now and in the future);
- Costs of implementing all decision options are known;
- Consequences can all be expressed in a common unit of 'currency' that is comprehensible to all stakeholders;
- The decision-maker is '**risk neutral**', or if not risk neutral is able to specify a preference for particular types of risk. (This may include a preference for high probability/low consequence events over low probability/high consequence events. It might include a preference to address risks where the uncertainty is low, compared to those where the uncertainty is high.)

These conditions are rarely met in full. Risk assessment is rarely a purely quantitative or objective process that leads to an unambiguous 'preferred option'. A range of options appraisal techniques is linked to assessment of risk to account for complex objectives, constraints and values which cannot be simply quantified (see Table 13 in Part 1 for further details). In addition, the decision-maker will need to be aware of important differences between the public perception of risk and the results of any 'objective' risk appraisal.

1.5 Frameworks for environmental risk assessment

Defra, the Environment Agency and the Institute for Environment and Health published revised overarching guidance (including a framework) on the use of risk assessment for environmental decision-making (DETR, 2000b). Defra and the Environment Agency recommend the use of this framework in their assessment and management of environmental risks.

The principal elements of the framework are:

- the importance of correctly defining the actual problem at hand;
- the need to screen and prioritise risks before detailed quantification;
- the need to consider all risks at the options appraisal stage; and
- the iterative nature of the process.

Central to the framework is advice on the use and structuring of environmental risk assessment for improved risk management (see Part 1, Figure 2). The framework introduces many issues pertinent to decision-making, such as: the role of uncertainty; social aspects of risks, risk perception and the role of the media; quantification of risk; and the relationship between risk estimation, risk management and decision-making. The present report conforms to the DETR (2000b) framework as appropriate, while reflecting the particular characteristics of decisions that will need to take account of climate variability and future climate change.

1.6 Risk and the assessment of climate change impacts

Climate change will result in changes to the frequency of occurrence of climate hazards, such as a heavy rainfall day or a drought (Chapter 3 and Hulme *et al*, 2002). Expressed another way, it will result in a change in magnitude of an event that occurs at a given frequency (e.g. once per decade). The rate of future climate change is uncertain, and therefore decisions regarding the future need to be informed by an analysis of the climate risk, or change in risk. Risk assessment can be used to assess the likelihood of uncertain future events or 'hazards' on specified receptors and exposure units. Combined with impact assessment and valuation techniques, risk assessment can also assess the significance of these events. More information on climate change risk assessment is provided in Chapter 3.

see part **1** | stage **5** | table **13**
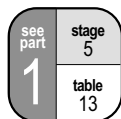
Two components of the approach to risk assessment as recommended in DETR (2000b) are particularly useful for the assessment and analysis of complex environmental problems:

(i) **Tiered approaches** are used to enable the problem to be studied in a broad, holistic way to begin with, before more in-depth studies are undertaken. This enables a wide range of hazards, processes and impacts to be identified and assessed in a qualitative fashion. The most significant risks, from the decision-maker's point of view, can then be assessed in more detail. The use of tiered approaches facilitates risk characterisation, risk screening and prioritisation. Not only can high priority risks be identified, but also areas of uncertainty that may be reduced by additional work can be highlighted.

(ii) **Conceptual models** are used to help to identify possible connections and dependencies between the hazard(s) and receptor(s) that may be impacted. These models can help identify the ways in which risks and harm may arise, identify important processes, (including environmental pathways) and possible risk control points. They may also be used as a basis for more detailed quantitative assessment and modelling where appropriate.

Climate change risk assessments attempt to define the consequences (or impact) of future climate on vulnerable or climate-sensitive exposure units and receptors (see Figure 1.2). The **exposure unit** is defined as the system considered at risk from hazardous events. Exposure units are often described in terms of the geographical extent, location and distribution of the population or populations of **receptors** at risk. Further information is provided in Sections 3.2 and 3.3.

An important aspect of climate risk assessments is to define the **pathway** or hierarchy of cause and effect that leads from climate variability and change to the consequence for the exposure unit and receptors. These pathways may be represented by **influence diagrams**, process diagrams, **event trees,** or more complex system models. The reason

risk assessment has such an important role in making decisions about the need to adapt to climate change is that the subsequent analysis should identify the key processes and critical factors by which the risk can be reduced or otherwise managed. Knowledge about the risk, and areas of uncertainty, are identified. The process helps identify the range of options available to the decision-maker, and contributes to the appraisal of their likely performance.

Hence there are many benefits of a formal, risk-based approach to climate impact assessment:

• Risk assessment, alongside **environmental impact assessment** and valuation techniques,[8] provides an assessment of the severity of consequences arising from different decisions, and this analysis often includes assessment of outcomes ('what might happen') arising from specified causes.

• This approach provides a framework for combining probabilities and consequences to provide additional information of value to the decision-maker. This might include, for example, profiles of risk allowing assessment of the importance of low probability/high consequence events compared with more frequent events with less severe consequences.

• Risk assessment deals explicitly with uncertainty concerning our knowledge of events and outcomes – in fact if there were no uncertainty then a decision would be a matter of weighing-up options on the basis of 'perfect' knowledge of future events. This would include perfect knowledge of the probabilities and consequences of random events (i.e. risk as defined in Section 1.2). As it is, the future is uncertain, and risk assessment naturally deals with uncertainty.

• The risk assessment process also requires the decision-maker to address some difficult questions. In particular, risk assessment as such does not answer the question of how to value dissimilar types of impact. For example, various decision-makers (e.g. industry and regulators) may have different decision-mak-

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[8] See, for instance, the UKCIP report "Costing the impacts of climate change in the UK" (Metroeconomica, 2003).

Hazards and drivers   Pathways/intermediate receptors   Receptors for risk assessment
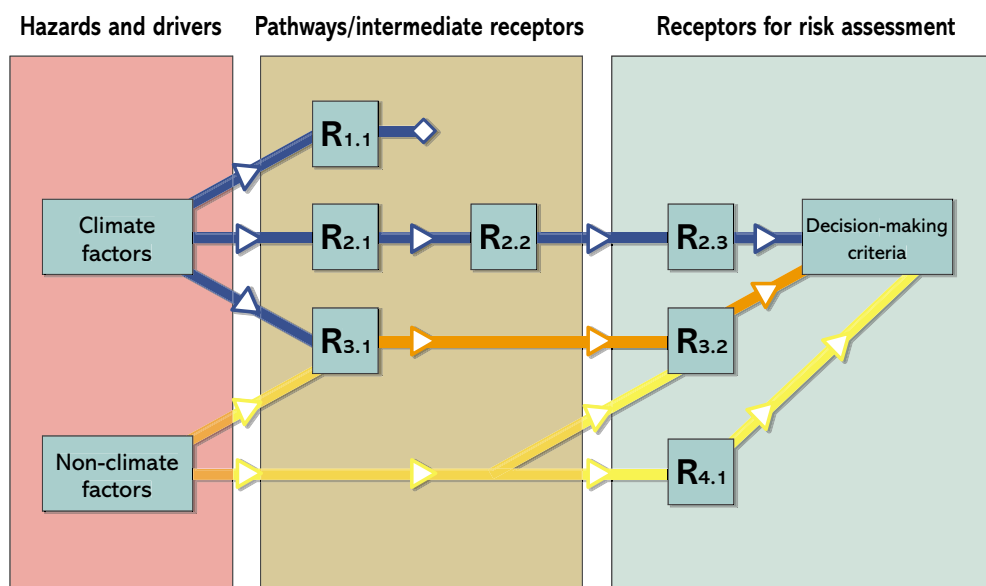
Figure 1.2: The pathway linking hazards (climate and non-climate factors), receptors and decision criteria. Probabilities may be associated with events or circumstances that link components in each pathway, connecting possible climate or non-climate hazards to particular consequences for particular receptors $R_{1.1}$, $R_{2.1}$, etc. Events may be defined in terms of the probability of a climate variable exceeding a certain magnitude, and the consequences for the receptor. The receptors represent important features within the exposure unit, or system at risk. Decision criteria will be defined in terms of risk assessment endpoints that apply to one or more important receptors ($R_{2.3}$, $R_{3.2}$ and $R_{4.1}$ in the case shown here). Risk assessment endpoints may be defined for intermediate receptors (eg $R_{2.2}$) in some circumstances, for example where existing data would support the analysis. The risk assessment endpoints should help the decision-maker define levels of risk (probabilities and consequences or impacts) that are acceptable, tolerable or unacceptable. Note that the receptors are not equally affected by climate hazards. Hence, if the decision criteria were properly defined only in terms of $R_{1.1}$ and/or $R_{2.3}$, this would be a climate adaptation decision (see Section 2.3.1). Criteria properly defined in terms of $R_{3.2}$, or in terms of $R_{2.1}$ and $R_{4.1}$, would be a climate-influenced decision (see Section 2.3.1). Criteria properly defined in terms of $R_{4.1}$ would exclude consideration of climate change. Note that not all receptors and consequences are necessarily equally relevant to the decision criteria. Some that are relevant may be excluded from the risk assessment for a variety of reasons (e.g. less relevant than others, lack of data, correlation of response with other receptors and endpoints, etc).

ing criteria. Nor does it provide an answer to ethical issues such as how a small risk to many people should be compared with a large risk to few. It does, however, provide a framework that enables these issues to be raised.

• Importantly, risk assessment deals explicitly with uncertainty in decision-making rather than giving an over-confident view of what is known. It provides a tangible means of incorporating risk into decision-making. Tools and techniques of risk assessment, in conjunction with environmental assessment and economic appraisal techniques, have been widely used for:

➤ Identifying hazards, consequences and 'pathways' of events or processes that lead to a risk occurring.
➤ Identification of important components, weak links, and redundant elements of complex systems.
➤ The optimisation of designs, particularly in the engineering field, that account for risks and costs while meeting other performance criteria.
➤ Analysis and presentation of the implications of a range of decisions on risk. For example, a decision option that reduces commonly occurring low-consequence outcomes may need to be compared with one that is more effective at reducing rarer, higher-impact outcomes.

1.7 Types of uncertainty

As described in Section 1.2, the concept of risk combines knowledge of both the probability of a consequence and its magnitude. Uncertainty describes a condition where we lack certain knowledge that we think may be important to making a decision. Where we know the probability associated with a particular rainfall event and the consequences of the event, but not when or where such an event will occur, that is risk. Where we do not know the probability and/or the consequence, that is uncertainty. Hence we are confident in our knowledge that the climate is changing (IPCC, 2001a, p.4) but our knowledge of the precise nature, extent and rate of these changes is imperfect or limited.

Nevertheless, we may be able to estimate or understand the consequences of particular events, even though we are uncertain as to their likelihood – we are confident of the outcomes, but uncertain or ignorant of the probability of their occurrence. Vulnerability studies aim to determine how sensitive or how vulnerable[9] a receptor is to a particular hazard. In such studies we effectively analyse a scenario (see Section 3.6) that assumes that a particular hazardous event may occur, and determine the likely consequences. For example, the consequences of flooding are well known. Hence the consequences of an increase in flood frequency and magnitude can be determined with considerable confidence, even if the probability of such an event is itself very uncertain. However, for many climate change risk assessments, there may also be considerable uncertainty about the impacts. This uncertainty is imposed on top of the uncertainty concerning the events that lead to the impacts. Figure 1.3 presents these concepts of risk and uncertainty concerning both hazards and impacts. In the figure, the top-right quadrant shows risk. The other three quadrants show different kinds of uncertainty.

There are many ways of classifying sources of uncertainty. Some climate-related examples are given below.[10] However, in terms of climate change risk assessment, it needs to be emphasised that these types of uncertainty apply to both the assessment of the change in climate dependent

hazard and to the assessment of the impact or consequence associated with the hazard.

Future emissions of greenhouse gases, and the global and local climate consequences of these emissions, are all subject to uncertainty, due to imperfect knowledge of future changes in energy use and other emission sources. A fuller discussion of the sources of the uncertainties incorporated in scenarios of future climate is provided in Section 3.6.3 and 3.6.4 of this report, and in Chapter 7 of the Scientific report on the UKCIP02 climate scenarios (Hulme *et al*, 2002). Climate downscaling models (see Section 3.6.7) and climate impact models (see Section 3.8) are also subject to model uncertainty.

1.7.1 'REAL WORLD' ENVIRONMENTAL UNCERTAINTY; INHERENT AND NATURAL INTERNAL VARIABILITY

The world we live in is characterised by events that, despite perfect knowledge, can only be described probabilistically (pure 'risk'). For example, life expectancy can only be described statistically as the probability (or risk) of surviving to a particular age, or dying of a particular cause. Many environmental processes possess these statistical characteristics, reflecting essentially random processes that govern particular events. For practical purposes this includes the weather and climate, which are variable over all spatial and temporal scales. Weather, for example, cannot be predicted reliably more than a few days in advance (see Section 3.5.3 for further details). There is uncertainty in the timing, duration, spatial location, extent and other characteristics of weather 'events' such as droughts, cold spells and storms. So, while it may be possible to estimate the probability and magnitude of a particular event (such as a flood) that is likely to occur within the next 20 years, it is not possible to say whether this will occur in 2003 or 2023. **Natural variability** may, within a defined period, act to reinforce human-induced climate change, or reduce it. Examples of uncertainty due to natural variability include:

- Environmental events such as the timing and magnitude of volcanic eruptions, earthquakes, or the collapse of sections of the Antarctic ice sheet.

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[9] See Section 3.1 for an explanation of these terms.

[10] Draws on Moss and Schneider (2000).

Good

Knowledge of probability

Ambiguity about the risk
e.g.
• uncertain or unknown impacts
• no impact models
• uncertain how to value
  consequences
• lack of concern

Good knowledge of the risk
e.g.
• unchanging climate
• good historical data
• good impact models
• short term prediction

Ignorance about the risk
e.g.
• rapidly changing climate
• new/unknown processes
• complex dependencies,
  such as non-linearity
• longer term forecast
• insufficient data
• climate surprises

**Impacts well defined but
probability uncertain**
e.g.
• poor knowledge of likelihood
  of damage
• good impact/process models
• well defined impacts if event
  occurs
• longer term assessment

Poor

Poor   **Good**

Knowledge of consequence

Figure 1.3: Uncertainty is a result of a lack of knowledge of either the probability of an event, or its consequences. Where we have good knowledge of both, then we are able to characterise the risk, both quantitatively and accurately (top right). Examples of some of the factors that contribute to uncertainty about the probabilities associated with future climate statistics, and the consequences of a changed climate, are indicated.

• Average climate (mean April daily rainfall), extremes of climate (maximum April daily rainfall), frequency of climate events (number of April 'showers').
• Stock markets, social and some ecological systems. These are characterised by many interrelated players or processes interacting in complex, often non-linear ways. There is no prospect of predicting the future or understanding a large part of the variability shown by these systems, which are therefore described probabilistically.
• Future choices made by societies, businesses or individuals that affect the social and economic environment in which climate adaptation decisions are taken and implemented (see Section 3.7). There is little prospect of predicting just what those choices will be. For example, changes in longer-term demographics, planning, and taxation are all inherently uncertain, but could all influence the outcome of adaptation decisions.

1.7.2 DATA UNCERTAINTY

There are limitations on the accuracy and precision with which we can measure the physical state of the world, and the amount of data that we have available or can collect. Data uncertainty arises because of:

• Measurement error (random and systematic, such as bias);
• Incomplete or insufficient data (limited temporal and spatial resolution); and
• Extrapolation (based on uncertain data).

Care needs to be taken to determine that where measurements or data exist they correspond to the process or object that we wish to know about. For example, monitoring data on off-shore wave heights may not be precise or accurate. However, even if it was not subject to measurement error, off-shore wave height may be a poor predictor of the height of waves arriving on adjacent beaches

due to other, perhaps unknown, factors contributing to uncertainty governing on-shore wave height.

Data uncertainty can be particularly acute when attempting to determine the risk associated with extreme events, including those dependent on weather and climatic conditions. Although there is often extensive information on climate conditions, for example, long-term average rainfall, establishing past (or forecasting future) probabilities of extreme events, such as the 1 in 100 year rainfall event, is often uncertain. Because such events are rare, the consequences may also be more uncertain, because they will seldom have been observed. Even if they have been observed, the observations may be difficult to extrapolate to other situations or locations.

1.7.3 KNOWLEDGE UNCERTAINTY

For most real-world decisions the available theoretical and empirical knowledge is unlikely to provide complete, sufficient, or even partial understanding of the problem facing the decision-maker. The risk analyst may lack knowledge or useful data about the nature of the processes, the interactions and dependencies between different parts of the system, or the probabilities of possible outcomes. In such cases one approach is to seek expert or public opinions as to the degree of belief concerning knowledge of possible futures or process outcomes. The subjective assessment of probability and the associated confidence may, in many circumstances, be the only way to obtain estimates for quantitative risk assessments. In circumstances where we are aware or have some insight that there is a chronic lack of knowledge we should acknowledge 'ignorance' (Hoffmann-Riem & Wynne, 2002).

Knowledge uncertainty includes **uncertainty about the future**. The future evolution and/or aspects of the dynamics of certain physical systems can be forecast or hindcast with considerable skill and confidence. Examples include tidal movements and short-term weather. However, social, economic and ecological systems provide a forecasting challenge. An obvious example is the future emissions of greenhouse gases, or the effectiveness of policies to mitigate these emissions. Scenarios

(e.g. of future emissions) are used to capture aspects of this uncertainty.

1.7.4 MODEL UNCERTAINTY

Most decisions are based on some form of underlying model of the important influences and pay-offs associated with different options. Model uncertainty is a particular example of knowledge uncertainty (see above). It reflects the situation in which we have insufficient understanding to form the basis of a rational, self-consistent model that describes a system that can be used to analyse decisions. These models may be conceptual or heuristic (learning by trial and error). Other, technical models are used to:

- describe data (statistical models);
- describe known processes (e.g. environmental systems models);
- assess risks (risk assessment and **stochastic process models**) and impacts (impact and valuation models);
- examine the influence of decisions on the future (decision models);
- study the influence of the future social/environmental systems on the outcomes of decisions.

Sources of model uncertainty include:

Model choice and structure. There may be uncertainty concerning which processes to represent, and how they are represented, within a particular model.[11] It is, of course, desirable that the model used to assess climate risk explicitly includes all those variables that can be influenced or controlled by the decision-maker to help appraise options for the effective management of the risk. However, this is rarely possible unless incorporated into the design of the model. Any difference between the model output and the options available to the decision maker contributes to uncertainty concerning the effectiveness of particular options, and hence the choice of the best option (decision uncertainty, see Section 2.2).

The model designer and user must satisfy themselves that the model structure incorporates known or suspected sensitivities to climate variables expected to change over the period of any climate

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[11] For example, different Global Climate Models differ in their forecasts of future climate, due to differences in their detailed structures, even though they are based on the same fundamental physics (see Section 3.6.4).

change risk assessment. Using different models may also help to improve confidence in predictions.

Model input values. The values of the variables needed as inputs to models may be uncertain (e.g. as represented by values for climate variables taken from each scenario or **ensemble** member,[12] such as the UKCIP02 scenarios (Hulme *et al*, 2002)). These uncertain inputs may be described by a range, as a fuzzy set, or taken from a probability distribution of potential values for use in a quantitative Monte Carlo-based risk model (see Appendix 3 and the web-based tools resource).

Model parameters. In certain models based on fundamental understanding of the underlying physical processes, **parameter** values may be known with high confidence. However, for many climate forecasting, downscaling, and impact assessment models used in climate impact risk assessments (see Chapter 3), parameter values are estimated from limited data of uncertain quality. This is achieved by a process known as model or parameter-fitting. The goodness-of-fit can be estimated by a variety of statistical techniques of varying sophistication, including the use of maximum likelihood estimators. The goodness-of-fit is dependent on a number of factors, including: (i) the quality and quantity of the data; (ii) the structure of the model (see above); (iii) the number of free parameters; (iv) the values of the parameters. As a consequence, the values of the model parameters are estimated with uncertainty. This can be of particular concern where the statistical parameter estimates are shown not to be independent. As with input values, the consequences of this uncertainty can be explored through techniques of sensitivity or uncertainty analysis (Saltelli *et al*, 2001).

As with the structure of the model, there is a possibility that certain model parameters may be dependent on climate in a way not recognised by the model designer. For example, many environmental models, including water quality assessment models (UKWIR, 2002) and, in particular, ecological models, have been designed for specific purposes and have not included climate sensitivities within the structure of the model. In effect they have assumed that the past patterns of climate variability will be maintained in the future. Such models have not been framed in a way that allows them to account for climate change. Hence there is uncertainty as to their validity under changed climate conditions.

Models that provide a good match to observed data sets, and are validated under a range of different conditions, with the fewest number of 'free' (or fitted) parameters, are deemed to have a high degree of predictive of forecasting skill. Risk assessors place higher confidence in well skilled models.

Model output variables and values. The consequences of model uncertainties for model output variables can be determined to a certain extent using methods of **uncertainty** and **sensitivity analysis** (Saltelli *et al*, 2001). Output variables frequently become the inputs to the next stage of the impact assessment, so the uncertainty propagates through the assessment process. However, some of the climate variables predicted by the climate models often need some additional translation, such as downscaling (see Section 3.6.7) to make them appropriate and relevant to the needs of the impact assessment. These processes/models will also carry with them some model uncertainty.

Incorporating available knowledge within a formal model structure facilitates the examination of the consequences of different types of uncertainty, especially in model sub-components and processes, parameters, and resulting from data uncertainty. Different models or model structures can be used to assess the consequences of more fundamental uncertainties (e.g. comparing **global climate model**-based climate change scenarios). Model developers often control sources of uncertainty by making simplifying assumptions. It is therefore essential in developing or using a particular model that important assumptions are identified and assessed for their possible consequence for any analysis, and that subsequent users are aware of their limitations when arriving at their decision.

1.8 Recognising uncertainty – implications for decision-making

Clearly, for a particular outcome or decision, uncertainties may arise from a variety of sources. Categorising these, and ranking or estimating the

[12] The term 'ensemble' refers to a set of simulations (each one an ensemble member) made by the same model, using the same emissions scenario but initialised at different 'starting conditions' of climate. Hence, the difference in climate between ensemble members is a measure of the natural internal climate variability. The UKCIP02 scenarios are ensemble means, produced by averaging individual ensemble members.

magnitude of different sources of uncertainty is frequently a process that relies on expert, subjective judgement. There is not always a 'right' categorisation, and assigning a category is not as important as recognising that uncertainty is present. Failing to provide an estimate of the full range of outcomes does exclude a full representation of sources of uncertainty.

Uncertainty also affects how we as individuals or society value different issues on which decisions are made. This can be particularly significant when weighing-up different types of impact (e.g. economic, environmental, social), or impacts over different time periods. This can be considered to be a form of data uncertainty or variability.

Decisions must be made despite uncertainty – the degree and type of uncertainty can have a fundamental influence on decisions. The emphasis of this framework on an adaptive management strategy supported by post-decision monitoring and appraisal is essentially a defence against uncertainty, recognising that for many aspects of climate change adaptation, uncertainty will be significant.

Uncertainty increases the further you look into the future. It is possible to determine the climate parameters (if not the specific weather) for the next few years with reasonable confidence. This may justify a fairly detailed (quantitative) probabilistic representation of climate risk. Further into the future, uncertainties accumulate. These uncertainties are not peculiar to climate. Uncertainties associated with other future social, economic and environmental changes may be particularly important for the appraisal of decision options. Climate change is an important source of risk to the achievement of objectives established by the decision-maker. However, other non-climate factors may also be important, especially in the increasing uncertainty of the longer term. A key objective for the climate change risk assessment is to determine the balance of importance of climate vis-à-vis other risk factors that contribute to the overall risk posed to the objectives of the decision-maker.

2. Decision-making with climate change uncertainty

2.1 Introduction

Decisions must be made despite uncertainty. The knowledge that the climate has changed in the past, and is now changing as a result of elevated atmospheric concentrations of greenhouse gases (IPCC, 2001a, p.4), requires that decisions be taken to exploit potential benefits and reduce deleterious impacts (DETR, 2000a). These decisions involve choices between adaptation options. What is important is deciding what to do, given our uncertain knowledge of the future in general, and uncertain knowledge of future climate and its consequences in particular. In this context a decision to 'do nothing' should be recognised as an appropriate and positive risk management option, one that can be justified against other 'do something' options.

2.2 Outcome uncertainty and decision uncertainty

Outcome uncertainty concerns uncertainties in the environmental, economic and social impacts or outcomes associated with each **climate change scenario**, socio-economic scenario or with each decision option. In contrast, **decision uncertainty** is the rational doubt as to which decision to adopt (Green *et al*, 2000). It is partly a product of uncertainty concerning the future outcomes, including uncertainty about how quickly and by how much the climate may change, as well as uncertain changes in the future social and economic environment. Decision uncertainty may also arise due to uncertainties in present-day social and economic values (e.g. conflicting value systems) that may govern the choice between particular options. The decision-maker needs to know which option offers the best outcomes, or prospect of meeting his goals. It is not always necessary to know the precise outcome, or level of impact associated with each option. The decision-maker simply needs to know whether one option is better than another (the rank order of options). Therefore, while there will

always be some degree of outcome uncertainty, this will not always result in decision uncertainty.

Nevertheless, in many cases decision uncertainty will be associated with outcome uncertainty. In these cases it may be possible to estimate the probability associated with particular outcomes, and therefore make a decision based on risk. However, in many cases estimates of probability will not be available or possible to obtain, and then the choice between options will have to be made under uncertainty.

2.3 Climate sensitive decisions and maladaptation

This section provides guidance on identifying how decisions may, in broad terms, depend upon climate. It emphasises the potential risks associated with misjudgements concerning the significance of climate change and adaptive decision-making.

2.3.1 TYPES OF ADAPTATION DECISION

Experts such as the scientists on the Intergovernmental Panel on Climate Change recognise that climate change represents a significant risk to many activities, and emphasise the need to make decisions that will reduce any associated negative impacts.

So the task of policy-makers, planners and other decision-makers is to recognise those activities and decisions at risk from a changing climate, and to modify their decision making accordingly. In order to do so, they must (i) form a judgement as to those activities and decisions that are sensitive to climate variability and climate change, and (ii) determine the circumstances where climate will be the dominant or one of the more significant sources of risk determining a successful outcome. This judgement will be reached with reference to objectives and criteria established by or known to the decision-maker.
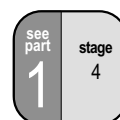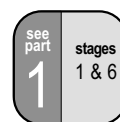
In this report we distinguish three types of climate-sensitive decision:

- Climate adaptation decisions;
- Climate-influenced adaptation decisions; and
- Climate adaptation constraining decisions.

Climate-sensitive decisions are distinguished from decisions for which climate is not a material factor (climate independent decisions, see Figure 2.1).

Many climate sensitive decisions are directly driven by the need to reduce or otherwise manage known or anticipated climate risks. Climate and climate change are often an acknowledged part of the decision-maker's initial problem. We call these **climate adaptation decisions** (see Figure 2.1). Such decisions are particularly needed in areas where climate variability and climate extremes have historically been the subject of management. In essence, we know (from past experience) that activities in these areas, and associated decisions, are sensitive to climate variability. Therefore there is greater certainty that, dependent on the extent of future climate change, additional benefits or disbenefits will be a

consequence. Examples include fluvial and coastal flood defence, extreme weather-related insurance, and the management of seasonal variability in water supply. Climate adaptation decisions will also be needed to reduce impacts consequent upon changes in average climate (e.g. average seasonal temperature, or yearly total rainfall). For example, the future choice of which crop to grow will largely be determined by the expectation that the climate will, on average, produce a satisfactory crop. However, the probability of success of any particular harvest will largely be determined by climate variability.

There are, however, many decisions which are not primarily about managing present climate variability or directly driven by a recognised need to adapt to future climate change, but whose outcomes may nevertheless be affected by climate change. In such cases decision-makers may not recognise that climate change forms a part of the decision problem. For example, climate may represent only one of many factors of varying importance in determining the outcome of the decision. Alternatively, an outcome may only be indirectly affected by variations in climate. In some cases the outcome of the deci-
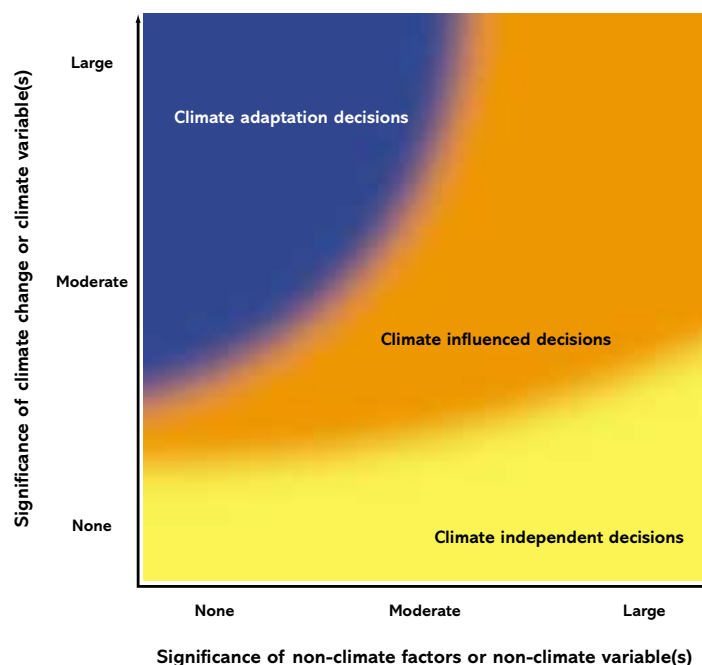

Figure 2.1: The relationship between the significant climate and non-climate risk factors, and the definition of climate adaptation and climate-influenced decision types. The boundaries are not precisely defined. Many decisions are not and will not be influenced by climate (climate independent decisions).

sion may be affected by adaptation choices made by other decision-makers. We call these **climate-influenced decisions**. Climate-influenced decisions may or may not require adaptation, depending on the significance of the climate influence.

An example of an area of climate-influenced decision-making is the management of future water demand (Environment Agency, 2001a). Changing patterns of climate are likely to influence the demand for water by agriculture, heavy industry and private citizens. However, the demand for water by these groups will also be determined by changes in technology, changes in demand for particular products and services, and changing attitudes to water use. None of these aspects of water demand can be described with certainty, but they all pose risks to the effective management of the balance between water supply and demand. It is likely that many business and investment decisions will also be climate-influenced decisions, especially those related to infrastructure development and other long-term investments.

There is not a clear distinction between climate adaptation and climate-influenced decisions. For climate adaptation decisions, climate change is likely to be one of a small number of important factors in determining the appropriate decisions. For climate-influenced decisions, climate change will represent one of a larger number of factors of varying importance, and varying degrees of uncertainty.

A third type of decision we term **climate adaptation constraining**. Climate adaptation constraining decisions lead to actions that limit or constrain the ability of other decision-makers to manage, reduce or otherwise adapt to the consequences of climate change. Such outcomes are called climate maladaptations (IPCC, 2001b). Climate adaptation constraining decisions may be implemented in order to achieve perfectly proper and well-intentioned objectives. However, they have negative consequences for others in terms of the future level of climate risk and its effective management.

In order to avoid climate adaptation constraining decisions, decision-makers need to consider the impact that their decisions may have on the ability

of their successors, or the ability of other decision-makers with other areas of responsibility, to adapt to future climate change. Hence, climate adaptation constraining decisions include the consequences of decisions taken today that restrict the freedom of future decision-makers to manage future climate risks. Climate adaptation constraining decisions can be characterised as examples of unsustainable development or a lack of 'joined-up governance'.

The risk associated with adaptation constraining decisions emphasises the need for decision-makers to review the basis by which others make decisions, and understand the consequences of those decisions for their own ability, within their area of responsibility, to adapt to climate change. The avoidance of maladaptation resulting from adaptation-constraining decisions can be made an objective of a precautionary decision-making policy or process (see Section 2.5.2).

Examples of adaptation constraining decisions include the construction of long-lived assets, such as housing developments, in areas vulnerable to increased risk of fluvial and coastal flooding (IPCC, 2001b). Such developments can reduce the options available to flood risk managers to implement flood protection measures within a flood risk area both now and in the future, perhaps when the climatic hazard has become greater and more certain. They may also require specific present and future flood protection measures as a consequence of their location, thereby reducing resources available for existing developments in need of flood mitigation measures. The UK's planning policy guidance for construction and development in areas at risk of flooding is a practical example of a **precautionary approach** aimed at avoiding maladaptation (DTLR, 2001b).

2.3.2 DECISION ERRORS: OTHER MALADAPTIVE DECISIONS

Decision-makers want to identify the best options, and choose the option that best meets their objectives and criteria. However, decision-making in the face of uncertainty inevitably leads to decisions being taken that, with hindsight, are less than ideal. Decision-makers need to consider the risks associated with the
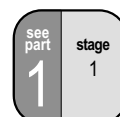
future being different to that expected, when choosing to implement a particular option.[13]

This principal can be extended to decisions concerning adaptation to climate change, and the three types of decision described above. Risk analysis does not provide a guarantee that climate change risks will be correctly identified and characterised, and the best decisions taken. Decision-makers need to be aware of the consequences of mistaken decisions. This will be conditioned by their attitude to the risk associated with climate-sensitive decisions. Therefore it is useful to consider the risks associated with incorrectly identifying climate adaptation, climate-influenced and climate adaptation constraining decisions. Climate-influenced decisions may need to consider the need for climate adaptation, even though climate is not driving the decision-making process. On the other hand, decisions being driven by a perceived need for climate adaptation may still be vulnerable to other (non-climate) sources of risk.

In addition to climate adaptation constraining decisions, we distinguish two further types of climate adaptation decision error faced by decision-makers (see Figure 2.2):

- **Over-adaptation**. Over-adaptation results when too much **weight** or significance is placed on the need to adapt to climate change. Climate adaptation decisions are most at risk of over-adaptation. It can occur for one or both of the following reasons:

  ➤ Where actions are taken as a consequence of climate change (or a particular climate variable) being wrongly identified as a significant risk or factor influencing a decision. For example, if the anticipated amount of climate change is not observed over the lifetime of the decision, or if the changes that do take place have no significant impact on the problem under consideration, but resources are committed to unnecessary adaptation.

  ➤ Where actions are taken to adapt to future climate change but where the decision-maker has failed to identify other significant, non-climate risks or factors that

should have a greater influence on the choice of option. For example, while climate change may directly affect the demand for water to irrigate domestic lawns, other social and economic factors are believed to be of greater significance for the overall management of water supplies.

- **Under-adaptation**. Under-adaptation results when too little weight or significance is placed on the need to adapt to climate change. Under these circumstances opportunities for climate adaptation may not be given a sufficiently high priority. Both climate adaptation and climate-influenced decisions are particularly at risk of under-adaptation. Under-adaptation can occur for one or both of the following reasons. They are the converse of those given above:

  ➤ Where the decision-maker has failed to consider or identify climate change (or a particular climate variable) as a factor when it may be relevant or central to making the most appropriate decision. Examples include scepticism towards the science underpinning forecasts of global warming, or basing decisions concerning coastal flood defence management upon underestimates of the rate of future sea level rise.

  ➤ Where the decision-maker has placed too great an importance on non-climate factors, compared to climate factors.

The prudent decision-maker will wish to consider the risks associated with these errors. He may wish to minimise the risk of making one or other type of error. Depending on the decision-maker's attitude to risk, he may prefer to err towards over-adaptation or under-adaptation to the climate risk.[14]

Implementing decisions that result in over-adaptation can be regarded as a wasteful use of resources. These resources may have been used in areas where adaptation to climate change is required. However, where a **precautionary approach** (see Section 2.5.2) is adopted by the decision-maker the additional cost of over-adaptation can be legitimately

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[13] No blame should necessarily be attached to such a 'mistake' if an appropriate risk-based methodology was used to evaluate the available options.

[14] Note that while the decision-maker may wish to avoid these errors he may still make a decision that, due to the inherent uncertainties, subsequent events prove to have been a mistake. Hindsight is likely to show that all decisions are flawed to some degree. However, a robust process, that considers the range of risk and associated uncertainty, should increase the chance of producing better decisions.
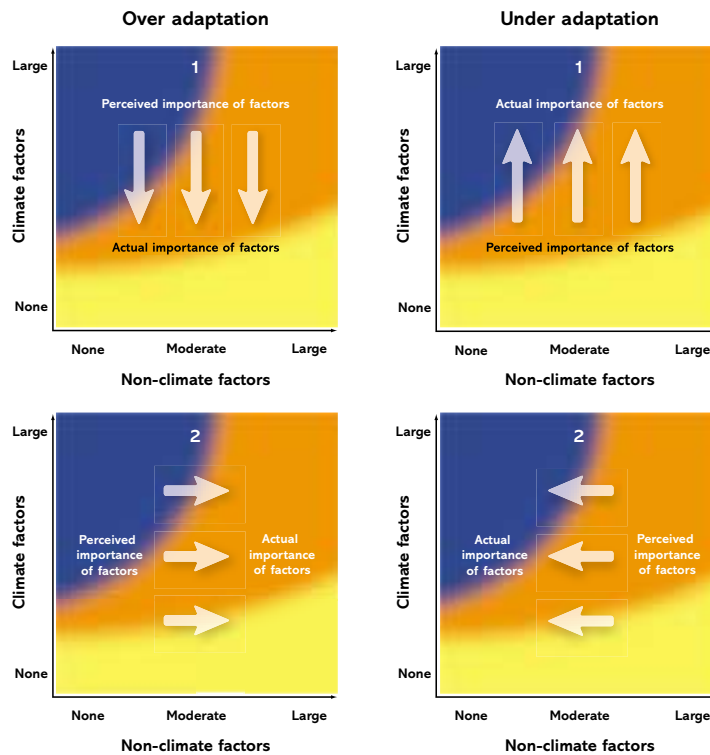
Figure 2.2: Types of decision errors associated with climate adaptation and climate-influenced decisions. A further type of maladaptive decision, climate adaptation constraining decisions (not shown) are decisions that are perceived (correctly or incorrectly) to constrain the ability of other decision-makers to cope with climate change (see Section 2.3.1).

incurred in order to provide a higher level of confidence that the adaptation will be successful in dealing with the risk. For under-adaptation errors, the risks associated with climate change will have been underestimated and negative consequences suffered (or opportunities lost) as a result of insufficient adaptation.

2.4 Hierarchical decision-making

Public sector decisions can be viewed as typically concerning (i) developments and investments, (ii) regulation or (iii) acting as a (statutory) consultee, expressing views on a proposal by another decision-maker. Each of these areas can involve decisions at policy, strategic, programme and project levels. Each decision type can require particular choices regarding the appraisal approach and criteria to be adopted. A key difference between decision types is typically the amount and reliability of available data. The decision may involve different temporal and spatial complexity, uncertainty and level of analysis detail. Some may be more contentious than others.

This section provides guidance on the types of appraisals and criteria that can be adopted when taking account of climate change uncertainty for different types of decision. In principle they can be applied to a wide range of public, private and business decision-making.

2.4.1 POLICY DECISIONS

Policy decisions set out overall objectives and a framework for deciding on strategies and programmes on a particular subject. They tend to be national in scope, may involve significant costs and can have major consequences, some of which may not be foreseen. Hence policy decisions are likely to involve judgements concerning uncertain outcomes. Such policy decisions require a broad-brush analysis of the issues associated with sources of decision uncertainty, so as to highlight the best policy options to be implemented. The appraisals (see DETR, 1998) involve approximate 'orders of magnitude' estimates (or assessments) of the benefits and costs of the options. They also need to take

account of the wider implications of the options, including their effects on incentives and any unintended side effects.

2.4.2 STRATEGIC DECISIONS AND PROGRAMMES

Strategic decisions and appraisals tend to be taken in an overall manner at the national level, but there may be some regional variations in the specific allowances to take account of regional variations. Strategic decisions concerning climate adaptation may take account of regional variations in future climate change, based on climate scenarios.

Decisions concerning programmes can include choosing between broad types of project that may be implemented within an area or budget head (e.g. expenditures on flood defence projects).

The appraisal of decisions for both strategies and programmes will generally entail an initial broad-brush analysis of costs and benefits, and will be more focused on particular issues or sectors (e.g. water resources or quality or flood defence), than higher-level policy decisions at the national level. However, the potential impacts of strategic and programme decisions on other sectors must not be overlooked. Greater, in-depth appraisal will be needed, involving a more detailed assessment of outcomes (and outcome uncertainties) than in the case of policy decisions, since the appraisal needs to be able to yield specific guidance on the actual level of, for example, the allowance for sea level rise or headroom factor.

Decisions concerning strategies and programmes will be guided, where appropriate, by decisions concerning broader policy in the area. In circumstances where policies are not taking account of risks associated with climate change, such policies may constrain adaptation measures being incorporated in strategies, programmes and lower levels of decision-making.

2.4.3 PROJECT DECISIONS

It is at this level of individual projects that the risks associated with future climate change may be realised. Project decisions usually entail fairly low individual costs, and consequences whose effects are limited to a specific area or group of people. However, project decisions may entail additional uncertainty because of the difficulty in downscaling long-term climate scenario information for site-specific locations and projects (see Section 3.6.7).

Decisions concerning smaller projects usually have to be taken fairly rapidly, by a decision-maker who may have little expertise regarding the implications of climate change. Moreover, many projects are not big enough to merit buying in such expertise. Consequently, it may be appropriate to rely on guidance and simple decision rules that have been formulated by more in-depth, generic analyses or higher-level policy guidance. However, project decision-makers will in general have considerably greater knowledge of the specific project area, and this knowledge may reduce uncertainty concerning the consequences of climate change. Hence, the project-level decision-maker may wish to form a judgement as to whether the general consideration of climate change at the strategic level was adequate to his specific circumstances.

Decisions concerning strategically important projects will usually require detailed, project-specific analysis of climate change risks. For major individual projects with long design lives, climate change could have significant consequences and costs. An example is the Thames Barrier and associated flood defences. These decisions will require in-depth and highly focused appraisal of the consequences of possible climate changes for the available options for the project.

The decision-maker must also be aware of the relationships between projects developed at a strategic/programme level when implementing an individual project. This should help him to avoid undesirable knock-on impacts of his decision on other projects. For instance, although building a sea defence in one location may provide protection for property behind it, it may also enhance the risk of erosion or flooding elsewhere along the shore.

2.5 Decision-making criteria
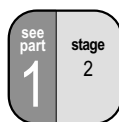
2.5.1 ALTERNATIVE APPROACHES TO RISK MANAGEMENT

The different criteria by which risk management decisions can be taken have been divided into three main groups (Morgan and Henrion, 1990). These are:

- Utility-based;
- Rights-based; and
- Technology-based.

Utility-based criteria focus on the outcomes associated with different decision options, and accomplish this using a variety of different forms and methods of evaluation. In contrast, rights-based criteria are not concerned with the evaluation of different outcomes. Rather they relate to the process that determines what actions or activities are permitted. Technology-based criteria are frequently used in the context of environmental regulation. Examples of the different forms these different decision-making approaches may take are provided in Box 2.1. The choice of criteria that can be applied in any particular circumstance may be guided or constrained by policy or other high-level guidance, for example on appraisal methods (e.g. HM Treasury 2001, 2003). The **precautionary principle** is an example of a rights-based approach, and this is discussed in Section 2.5.2.

2.5.2 THE PRECAUTIONARY PRINCIPLE AND CLIMATE CHANGE ADAPTATION DECISIONS

There is no one, single agreed definition of the precautionary principle. Sandin (1999) identified as many as 19 different usages, while Sand (2000) describes its use in a European context. Wiener (2002) and ILGRA (2002) provide recent reviews. One widely agreed definition of the precautionary principle is set out in Article 15 of the Rio Declaration (1992) '*…where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*' (see Green Alliance, 2002). While the precautionary principle is usually invoked in the context of risks to the environment and human health, it can be applied in the context of any uncertain, negative outcomes. In a climate change context the precautionary principle may often be invoked to justify a need to implement adaptation options given uncertainty concerning impacts. However, it could equally be applied to the avoidance of over-adaptation, depending on the attitude of the decision-maker to these risks.

Climate change certainly represents a potential threat, but in order to use the definition above, '*serious damage*', '*scientific certainty*' and '*cost-effective*' need to be defined for a particular decision. Recourse to the precautionary principle *requires* that any actions taken in the face of uncertainty be both robust and reversible. Moreover the principle requires the decision-maker to put in place a programme of research to reduce uncertainty, potentially therefore requiring the modification of key assumptions or changing the data used in the assessment.

As a consequence, decision-makers have tended to favour the adoption of a **precautionary approach** over the precautionary principle. Green Alliance (2002) describes the precautionary principle and precautionary approaches to decision-making, as seen from the perspective of business, NGOs and Government decision-makers. It lays out a framework for precautionary action (a **precautionary process**) that includes criteria that can be applied as part of the decision-making process. Elements of a precautionary process include:

- Precaution is part of, not instead of, good science.
- Continuing scientific monitoring and research is essential.
- Tools such as risk assessment and cost benefit analysis should be used in context.
- There is a need for genuine stakeholder and public involvement (see IEMA, 2002).
- Openness and transparency are essential.
- A precautionary decision-making process will not necessarily result in a decision to implement an extremely risk-averse option. The level of precautionary actions should be proportional to the risk.

The guidelines described in Part 1 of this report are consistent with the precautionary process recommended in Green Alliance (2002).

2.6 Decision analysis under uncertainty and risk

It is useful to consider the concept of uncertainty in relation to climate adaptation decisions. Under normative decision theory, decision-makers try to identify the options that offer the highest **expected value**. In other words, decision-makers should make choices that provide the best chance of an outcome meeting their goals. In the case of adaptation decisions, decision-makers must judge whether the adaptation they are considering using offers a better set of potential outcomes under an uncertain future climate than that offered by inaction, or some alternative action.
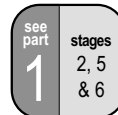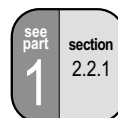
Box 2.1: Summary of the alternative decision criteria that can be applied for risk management (based on Morgan and Henrion, 1990).

1. Utility-based criteria

Deterministic benefit-cost. Estimates the benefits and costs of adaptation options in economic or monetary terms, and selects the one with the highest overall net benefit.

Probabilistic benefit-cost. As for deterministic benefit-cost, but uncertainties are incorporated probabilistically, and the greatest expected value of resulting uncertain net benefit is selected.

Cost effectiveness. A desired level of adaptation performance is selected, perhaps on non-economic grounds, and then the adaptation option selected that achieves the desired level of performance at the lowest cost.

Bounded cost or regulatory-budget approach. Aims to achieve the greatest level of climate adaptation possible within the imposed budgetary constraints.

Maximise multi-attribute utility. This is the most general form of utility-based criterion. Rather than using monetary value as the evaluation measure, multi-attribute utility involves specifying a utility function that evaluates outcomes in terms of all the attributes identified as being important to the decision. These attributes may include risks and uncertainties. The option with the greatest utility is then selected.

2. Rights-based criteria

Zero-risk. Independent of the benefits and costs, and of how big the risks are, eliminate the risks and do not allow their reintroduction. Applying the precautionary principle in its strongest sense (see Sandin, 1999) is an example of a zero-risk criteria. Zero-risk approaches cannot be applied to the management of climate risks, since these risks cannot be eliminated. However, choices over climate adaptation options may include other consequent risks that may be considered unacceptable.

Bounded or constrained risk. Independent of the costs and benefits, constrain the level of risk so that it does not exceed a specific level or, more generally, so that it meets a set of specified criteria. Applying the precautionary principle in a less strong sense (see Sandin, 1999) is an example of a criteria based on constrained risk.

Approval/compensation. Only allow people who have voluntarily given their consent to be exposed to an agreed level of risk. Such consent may be given in exchange for some form of compensation.

Approved process. The most widely used rights-based approach, although it is not strictly a decision criterion. In essence an approval process approach specifies that, if the decision-maker and other parties to a decision follow a specified or agreed process or set of procedures, then the resulting decision will be acceptable. Hence policy, regulatory and planning guidance, often stipulated by or based upon legislation, are examples of approved processes. An approved process may specify particular decision-criteria, such as cost-benefit or technology-based criteria, that should be considered as part of the process.

3. Technology-based criteria

Best available technology. Reduce the risk as far as possible with the current or best available technology. To a large extent the meanings of the words 'current' or 'best available' are determined by economics, hence technology-based criteria are often modified forms of utility-based criteria, such as BATNEEC (Best Available Technology Not Entailing Excessive Cost).

In order to identify the choice offering highest expected value, it is necessary to know all possible outcomes associated with every potential option, and the probabilities associated with each outcome (see Section 2.6.2). Once a decision problem or opportunity has been recognised and relevant objectives defined (Part 1, Stage 1), there are five further steps:
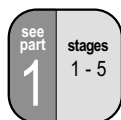
(i) determine the decision-maker's attitude to risk and decision uncertainty, and agree decision criteria (Part 1, Stage 2);

(ii) identify the variables that influence potential outcomes, determine the states of these variables and the cause and effect relationships between them (Schrader *et al*, 1993) (Part 1, Stage 3);

(iii) identify the alternative future states or circumstances that may occur (Part 1, Stage 3);

(iv) identify the alternatives or options available to the decision-maker (Part 1, Stage 4); and

(v) identify and calculate potential pay-offs associated with each combination of option and future state (Part 1, Stage 5).

In addition, the decision-maker will want to know whether his decision can be reversed. If a decision-maker can reverse a choice that led to an undesirable outcome with little effort or tangible cost, the set of potential outcomes associated with that choice will be viewed more positively than if the consequences of the decision were costly or impossible to reverse.

Only in exceptional cases will it be possible to quantify risk. In most climate adaptation cases, decision-makers will be missing one or more of the elements listed above, and therefore cannot identify the possible outcomes associated with the choice of options and the probabilities associated with each outcome. A particular challenge for climate adaptation decision-making is uncertainty concerning the extent of future changes in climate, together with changes in social, economic and other environmental states. Scenarios can be used to represent this uncertainty, where each scenario uniquely represents one possible, alternative state (see Section 3.6).

2.6.1 DECISION-MAKING UNDER UNCERTAINTY

Where the probability or risk associated with a decision is unknown or cannot be reliably estimated, the decision is being made under uncertainty. Psychologists have found empirical evidence for heuristics (learning by trial and error) and other cognitive mechanisms that humans routinely use to inform decisions under uncertainty, where decision-makers act in the absence of all the desired information (Tversky & Kahneman, 1974). A number of different approaches to decision-making under uncertainty are described below. The choice of approach is dependent on the decision-maker's attitude to the risk associated with the decision. Each approach can yield a different decision – the decision-maker must select the approach that best suits his needs.

The following approaches are described briefly in Box 2.2:

• High-risk strategy – approach based on determining and implementing the option that might provide the best outcome;

• Strategy to avoid under-adaptation – a precautionary (risk averse) approach with respect to climate impacts;

• Strategy to avoid over-adaptation – a precautionary (risk averse) approach with respect to the need to adapt to climate change and the costs of adaptation;

• Regret-based strategy – a precautionary (risk averse) approach with respect to the possible benefits associated with opportunities for adaptation that might be missed by implementing a particular option.

2.6.2 DECISION-MAKING UNDER RISK

Where the probability or risk (see Section 1.2) is known or can be estimated, the **maximum expected value** can be used to identify the best decision option. The expected value is calculated by multiplying each decision outcome (payoff value) for each future state by the probability of its occurrence. The best option would be that associated with the largest (or smallest) expected value. The largest expected value would be used when the problem is framed in terms of maximising a benefit, and the
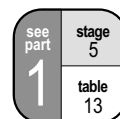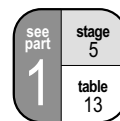
Box 2.2: Illustration of approaches to decision-making under uncertainty, using a simple, hypothetical, climate adaptation example

Table 2.1 gives a **pay-off matrix** giving the anticipated pay-offs associated with each of four levels of investment in climate adaptation measures. Pay-off matrices are derived from the application of cost-benefit or other appraisal methods that provide an overall estimate or series of estimates of the relative performance of the various options being considered. The approaches require that a common currency can be defined in order to express the overall benefits and disbenefits in terms of a value for each pay-off. The currency may be monetary, or result from an agreed, non-monetary scoring system. Illustrative pay-offs are provided for each of three scenarios of future climate change (scenario 1: rapid change, scenario 2: some change, scenario 3: no change). The choice of scenarios could be based on the UKCIP climate scenarios (Hulme *et al*, 2002). The example assumes that the impact of climate change will be negative, and will increase with the level or rate of future climate change (see bottom row of Table 2.1). Increased levels of adaptation, off-setting the potential adverse effects of climate change, are assumed to require greater levels of action and/or investment (see last column of Table). The net pay-offs are the difference between the expected adaptation benefits and the expected cost of the adaptation measures. These are the values in each cell of the matrix in Table 2.1.

High-risk strategy: the Maximax approach. This approach is based on selecting the option associated with the best of all possible outcomes, that associated with the highest possible overall pay-off. Of the pay-offs given in Table 2.1, +20 is the highest value. This is therefore the Maximax strategy – in this case, a low level of investment in climate adaptation measures (Scenario 2, low investment, pay-off = +20). Maximax is, therefore, a high-risk strategy, since the probability associated with each scenario and the pay-off are unknown. It would be the approach adopted by an optimistic decision-maker, or one who would benefit from a successful outcome, but not suffer the consequences of unsuccessful outcomes.

Strategy to avoid under-adaptation: the Minimax approach. Where we wish to be precautionary with respect to the uncertain risk posed by future climate change (i.e. we believe climate change will be important, and believe that our decisions should be weighted towards adapting to climate change), our decision could be based on applying the Minimax approach. Minimax identifies the option that results in the **lowest** value of the **maximum** pay-off associated with each option. Referring to Table 2.1, the maximum pay-offs for each option are as follows:

- High investment = -10
- Low investment = +20
- Medium investment = 0
- No investment = 0

Table 2.1: Example of a performance matrix, giving the expected pay-offs associated with four levels of investment in climate adaptation measures, for three future scenarios of climate change. The pay-off values chosen for illustration assume that the impact of climate change will be negative and increase with the level or rate of future climate change (see bottom row). Increased levels of adaptation, providing potential protection against the adverse effects of climate change, are assumed to require greater levels of investment (see last column). Pay-off values associated with each decision under each scenario may derive from cost benefit analysis.

Investment in climate adaptation options (Measured as overall cost)	Scenario 1 Large or rapid climate change forecast	Scenario 2 Medium climate change forecast	Scenario 3 No climate change
High	-10 **Minimax decision**	-50	-100
Medium	-20	0	-50 **Maximin decision**
Low	-50 **Maximin decision**	+20 **Maximax decision**	-10
No investment	-150	-75	0

Box 2.2: *continued*

The lowest value from these is (Scenario 1, high investment, -10). Therefore the Minimax strategy would comprise a high level of investment in climate adaptation measures.

Strategy to avoid over-adaptation: the Maximin approach. Where we wish to be precautionary with respect to the **investment** being made in climate adaptation measures, our decision could be based on the Maximin approach. Maximin identifies the option that results in the **highest** value of the **minimum** pay-offs under each potential option (i.e. the least bad 'worst possible' outcome). Referring to Table 2.1, the minimum or lowest pay-offs for each option are as follows:

• High investment = -100
• Medium investment = -50
• Low investment = -50
• No investment = -150

The highest value from these is -50. Hence the Maximin strategy is either a medium or low level of investment in adaptation measures, since the anticipated pay-offs are equal for the medium investment option under scenario 3 (no climate change) and the low investment strategy under scenario 1 (rapid climate change). Examining the pay-offs associated with each option under the other scenarios, the decision-maker may choose the low-investment option as providing better overall prospects than the medium investment option.

Note that, in this example, the application of each of the chosen approaches to decision-making leads to the selection of an option that delivers **some** level of adaptation to climate change, but a level that reflects the decision-maker's attitude to the uncertainty.

Regret or opportunity loss: no regret options and Minimax Regret approach. We feel **regret** if we discover that a decision made in the past produced less benefit than we expected, or if we have missed an opportunity. We may wish to identify options that could be associated with the minimum level of regret. This again is a risk averse or cautious decision strategy.

The level of regret associated with each option k can be defined for each possible future scenario j as:

Regret {k, j} = [Pay-off for the option with the highest pay-off under scenario j] minus [the pay-off for each other option k under scenario j].

This formula together with the pay-off values in Table 2.1 is used to calculate the regret values illustrated in Table 2.2.

No regret options. From Table 2.2 it can be seen that the value of regret associated with the best option under each scenario is always zero. When the highest pay-off (i.e. regret equals zero) is associated with the same option, irrespective of the future scenario, this is termed a **no regret decision** or option (see also Section 2.7.2 below). The choice of a no regret option is a formality, since it provides by definition the best outcome under any scenario. However, in Table 2.2, we do not have a no regret option.

Minimax regret approach. However, we can still select the option associated with the lowest level of regret across all possible future scenarios. This can be determined by applying the Minimax approach to the regret matrix in Table 2.2.

The Minimax regret option is identified by first determining the maximum value of regret associated with each option (see Table 2.2). These are:

• High investment = 100
• Medium investment = 50
• Low investment = 40
• No investment = 140

The minimum value of maximum regret is 40. Therefore the Minimax regret option is to have a low level of investment in adaptation measures.

Box 2.2: *continued*

Table 2.2: Regret or opportunity loss matrix. Values for the regret matrix are derived from the pay-off matrix (Table 2.1). Given the values in Table 2.1, the Minimax regret decision is to adopt a low level of investment in adaptation measures.

Investment in climate adaptation options (Measured as overall cost)	Scenario 1 Large or rapid climate change forecast	Scenario 2 Medium climate change forecast	Scenario 3 No climate change
High	-10-(-10) = 0	20-(-50) = 70	0-(-100) = 100
Medium	-10-(-20) = 10	20-0 = 20	0-(-50) = 50
Low	-10-(-50) = 40 **Minimax regret decision**	20-20 = 0	0-(-10) = 10
No investment	-10-(-150) = 140	20-(-75) = 95	0-0 = 0

smallest expected value used when framed in terms of minimising a disbenefit.

Since it may be impossible to determine with objectivity the probabilities associated with future scenarios, such as the emissions scenarios that underpin the UKCIP climate scenarios, so it can be difficult to apply the maximum expected value approach, except by using subjective estimates of scenario probability. Such approaches are not recommended, but continue to be the subject of research. However, such approaches can be useful in helping to understand the value of additional information in improving confidence in a decision.

2.6.3 DECISION-MAKING WITH MULTIPLE OBJECTIVES

Many decisions that involve consideration of the influence of climate or adaptation to climate are likely to be highly complex. They require an appraisal of the impacts of multiple factors, options and uncertainties on multiple objectives or a range of different criteria. In these circumstances techniques of **multi-criteria analysis (MCA)** can greatly aid decision-makers. The main role of MCA techniques is to deal with the difficulties that human decision-makers have in handling large amounts of diverse and complex information in a consistent way.

MCA complements techniques that rely primarily on criteria expressed in terms of monetary valua-

tion. Monetary techniques such as **financial analysis**, cost effectiveness analysis, and cost-benefit analysis are widely recommended and used for the appraisal of options, and are the subject of a number of guides and manuals (see HM Treasury, 2003; Metroeconomica, 2003; also Boardman *et al*, 1996).

Multi-criteria analysis includes a range of related techniques such as multi-criteria decision analysis, multi-attribute utility theory, the analytic hierarchy process, and applications of **fuzzy set theory**. MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities.

All MCA approaches make the options and their contribution to the different criteria explicit, and all require the exercise of judgement. They differ, however, in how they combine the data. Formal MCA techniques usually rely on the provision of an explicit relative weighting system for the different criteria. For example multi-criteria decision analysis (MCDA) involves the assignment of scores to each option on each criterion, and then combining these scores by means of a system of weights to yield an overall ranking for each option. DTLR (2001a) provides non-technical descriptions of these techniques, potential areas of application, criteria for choosing
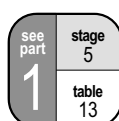
between different techniques, and sets out the stages involved in carrying out multi-criteria analyses.
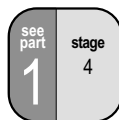
2.7 Climate change adaptation strategies and options

2.7.1 GENERIC ADAPTATION STRATEGIES

A climate adaptation strategy represents a combination of measures and options chosen to meet particular risk management criteria. Hence an integral part of an adaptation strategy is the decision-maker's attitude to climate and non-climate risks, their risk management priorities, and level of tolerable risk.

A variety of generic climate adaptation measures have been described as responses to the impacts of climate change (see Table 2.3, developed from Burton, 1996). These may be used individually, but more often a portfolio of measures may be the most appropriate option. Many of these essentially represent improved resource management (e.g. in agriculture, water resources and the coastal zone) and many have benefits in dealing with current climate variability as well as future risks. The generic benefits of adaptation include (Klein and Tol, 1997):

- increasing the robustness of infrastructure designs and long-term investments;
- increasing the flexibility of vulnerable managed systems – e.g. by allowing mid-term adjustments (including changes of activities and location) and reducing economic lifetimes (including increasing depreciation);
- enhancing the adaptability of vulnerable natural systems;
- reversing trends that increase vulnerability to climate;
- improving societal awareness and preparedness.

The success of adaptation options will depend on:

- the flexibility or effectiveness of the measures, including their ability to meet the decision-maker's criteria under a range of climate and non-climate scenarios;
- their potential to produce benefits that outweigh their costs;

- whether they are consistent with or complementary to, measures being undertaken by others in related sectors; and
- the ease with which they can be implemented.

The choice of measures will be determined by the particular objectives set by the decision-maker. The objective may be to reduce risk by attempting to manage either the hazard (e.g. increasing flood defences) or the exposure (e.g. reducing the population at risk) or both. The objective may be to minimise either the overall risk (e.g. to life or property) subject to a cost constraint, or the cost of implementing an agreed level of protection. The objective may be to maximise benefit per unit cost, in which case cost-benefit analysis might be an appropriate decision aid. In all cases, analyses need to consider uncertainties in the values of key variables for the performance of different measures, and acknowledge an acceptable level of residual risk.

One important class of risk management strategy is to reduce vulnerability by identifying other parties willing to accept the risk. Offsetting risk in this way frequently involves the payment of a risk premium, perhaps through the use of some form of insurance contract, to the party accepting the risk.

Diversification strategies aim to reduce an overall vulnerability to climate risk by developing business areas that are not sensitive to climate. In particular, diversified portfolios aim to avoid negative correlations between the performance of different business areas to climate. Diversification can also be used to reduce the risk associated with the choice of a particular adaptation measure: a variety or mixture of suitable measures may provide a more appropriate risk management strategy.

2.7.2 NO REGRET AND LOW REGRET OPTIONS

A decision option that is assessed to be worthwhile now (in that it would yield immediate economic and environmental benefits which exceed its cost), and continues to be worthwhile irrespective of the nature of future climate, is an example of a **no regret option**. The process by which no regret options are identified is outlined in Box 2.2, Table 2.2. No regret options should be clearly identified
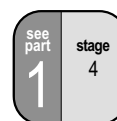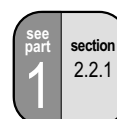
and pursued, particularly if the net benefits increase under a plausible set of climate futures. However, barriers may exist to the implementation of no regret options, and careful analysis is needed to include the possible costs of overcoming such barriers.

Limited or **low regret** are terms sometimes used to describe decisions where the cost implications of the decision are very low while, bearing in mind the uncertainties in future climate change projections, the benefits under future climate change may potentially be large (DETR, 2000a).

Implementing **no regret** and **low regret** options may only go part of the way towards resolving the decision uncertainty concerning effective climate change adaptation. Adaptation options known to be costly, or with uncertain future benefits or relative performance advantages, will remain (e.g. the construction of reservoirs). Knowledge of potential benefits will be limited by our uncertain knowledge of future climate. Consequently, some important choices will remain regarding the uncertain impacts of possible climate change. These will require careful appraisal, and the decision strategies outlined in Section 2.6.1 can help in structuring the decision-maker's approach.

There may also be '**win-win**' situations – options which reduce the impacts of climate change and have other environmental, social or economic benefits. Win-win decisions may primarily be taken for reasons not directly motivated by the need to adapt to climate change, but may simultaneously deliver some longer-term adaptation benefits. It will be useful for decision-makers to identify the circumstances where such additional benefits may arise.

see part 1 stage 4
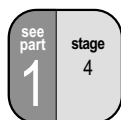
2.7.3. WHEN TO IMPLEMENT ADAPTATION MEASURES

Burton (1996) describes six reasons to adapt to climate change now:

(i)   Climate change cannot be totally avoided.
(ii) Anticipatory and precautionary adaptation is more effective and less costly than forced, last minute, emergency adaptation or retrofitting.

(iii) Climate change may be more rapid and more pronounced than current estimates suggest, that is, there is a risk of under-adaptation. Unexpected events are also possible (i.e. there is potential for high levels of regret associated with climate change).
(iv) Immediate benefits can be gained from better adaptation to climate variability and extreme climatic events – i.e. no regret options may be available.
(v)   Immediate benefits can be gained by removing policies and practices that result in mal-adaptation. An important aspect of adaptive management is to avoid the implementation of decisions that constrain or reduce the effectiveness of future options for adaptation ('climate adaptation constraining decisions' – see Section 2.3.1).
(vi) Climate change brings opportunities as well as threats. Future benefits can result from climate change, and these opportunities can be realised or increased by appropriate adaptation.

Where it is determined that climate adaptive management options may be needed, certain measures may 'buy time', delaying the point at which other options, particularly significant investment decisions, have to be made or implemented. For example, measures to manage water demand may help reduce the climatic risk to supply security, and allow decisions concerning supply-side adaptation measures to be postponed. The merits of such measures will depend on their relative costs and benefits. These include confidence that any immediate measures will achieve their objectives, and the extent to which any extra time bought will allow improved forecasts for the key climate change variables and better assessments of the direct and indirect impacts of climate change for the asset in question. In many cases, measures that buy time will also be no regret or low regret.

A decision to delay the implementation of adaptation measures can be an appropriate risk management strategy. Delay can help reduce the risk of over- and under-adaptation where uncertainties can be reduced and better information on future climate risk become available.

see part 1 **stage 4**
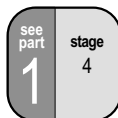
Table 2.3: Typology of possible adaptation strategies (modified from Burton, 1996)	
Adaptation type	**Description/examples of application identified from UKCIP studies**
Share loss	Insurance type strategies Use other new financial products that off-lay the risk Diversify
Bear loss	Where losses cannot be avoided: Certain species of montane fauna and flora (e.g. some arctic alpine flora may disappear from the UK) Loss of coastal areas to sea level rise and/or increased rates of coastal erosion
Prevent the effects: structural and technological (usually dependent on further investment)	Hard engineering solutions and implementation of improved design standards: Increase reservoir capacity Increase transfers of water Implement water efficiency schemes Scale up programmes of coastal protection Upgrade waste water and storm-water systems Build resilient housing Modify transport infrastructure Install or adopt crop irrigation measures Create wildlife corridors
Prevent the effects: legislative, regulatory and institutional	Find new ways of planning that cut across individual sectors and areas of responsibility (integration) Change traditional land use planning practices, to give greater weight to new factors such as flood risk and maintaining water supply-demand balance and security of supply Adopt new methods of dealing with uncertainty Provide more resources for estuarine and coastal flood defence Revise guidance notes for planners Factor climate change into criteria for site designation for biodiversity protection Amend design standards (e.g. building regulations) and enforce compliance
Avoid or exploit changes in risk: change location or other avoidance strategy	Migration of people away from high-risk areas Grow new agricultural crops Change location of new housing, water intensive industry, tourism Improved forecasting systems to give advance warning of climate hazards and impacts Contingency and disaster plans
Research	Use research to: Look at long-term issues Provide better knowledge of relationship between past and present variations in climate and the performance of environmental, social and economic systems (e.g. fluvial and coastal hydrology, drought tolerance and distribution of flora and fauna, economic impacts on key industrial sectors and regional economies), i.e. reduce uncertainty about the consequences of climate for receptors and decision-makers Improve short-term climate forecasting and hazard characterisation Produce higher resolution spatial and temporal data on future climate variability from model-based climate scenarios Provide more information on the frequency and magnitude of extreme events under climate change Find better regional indicators of climate change Develop more risk-based integrated climate change impact assessments
Education, behavioural	Lengthen planning timeframes (need to consider not just the next two to five years, but 2020s, 2050s and beyond) Reduce uneven stakeholder awareness on climate change Increase public awareness to take individual action to deal with climate change (e.g. on health, home protection, flood awareness) and accept change to public policies (e.g. on coastal protection, landscape protection, biodiversity conservation)

However, it is recommended that any delay strategy should be supported by an assessment that the existing and future level of risk is tolerable. Such a decision should depend on clear climate thresholds (benchmarks), or other criteria, being established that specify the level of climate risk at which a decision to implement adaptation measures should be reconsidered. This should be subject to regular review. Delay strategies can include the use of a factor of safety, to account for the uncertainty in the assessment of future climate risk.

Where considerable lags are involved in the implementation of adaptation measures, for example the construction of major infrastructure, attention should be given to measures to reduce the implementation phase. This may allow decisions concerning adaptation measures with potentially large but currently uncertain benefits and/or significant costs or disbenefits to be delayed, but implemented more quickly should increasing knowledge dictate.

2.7.4 CLIMATE CHANGE ADAPTATION OPTIONS AND ADAPTIVE MANAGEMENT

Adaptive management is an important strategy for handling the uncertainties associated with climate change (Green *et al*, 2000). It is the sequential process of making the best possible decision at each decision point, based upon a risk assessment and analysis of the information available at the time. Adaptive management leaves scope for decisions to be reviewed, and further decisions implemented at a series of later dates, as improved information becomes available on the nature of the present day and future climate risk.

However, this sequential process does not mean that an incremental response to climate change (i.e. adapting by a small amount in response to gradual increases in climate change) is the best response. This may well be more costly overall than implementing a long-term strategy. Nevertheless, where incremental adaptation options can be implemented, these can provide the basis of a flexible approach to the uncertainty associated with climate change.

Reducing the time required to reach and implement a decision can itself be an important adaptive

response, reducing the risk of hasty or over adaptation. It may be achieved through institutional, legislative, regulatory or planning reform, or by canvassing in advance support for actions that may be required when certain future, pre-defined and agreed conditions may be met. Delays to decision-making should be supported where the acquisition of improved knowledge, data and methods can help to reduce decision uncertainty. Where uncertainty cannot be reduced, delay should not be regarded as a substitute for making an appropriate decision concerning the management of the risks identified.

3. Key aspects of climate change risk assessment

3.1 Introduction

Climate change risk assessments form an important stage in the decision-making framework described in Part 1. This chapter describes the key issues to be considered when undertaking a risk assessment that may involve climate change as a significant factor. **In this report, the term 'climate change risk assessment' is used to refer to any impact assessment that includes consideration of the probability or uncertainty associated with the consequences of climate variability or climate change**. In most cases, probabilistic assessments of risk will not be possible. We emphasise that uncertainty is an integral component of a climate impact assessment, and therefore an approach based on risk assessment represents good practice.

Climate change risk assessments are used to determine how climate change could affect outcomes in a sector, and to evaluate the effectiveness of decisions regarding existing or new policies, programmes and projects. The risks associated with climate should be evaluated in comparison to other, non-climate-dependent risk factors. The objective of these assessments is to help decision-makers identify where adaptation to climate may be required, the adaptation options that could best accommodate the expected impacts of climate change, and the uncertainty associated with those impacts. Decisions made on this basis should lead to a better outcome in social, economic and environmental terms and can be considered as contributing to sustainable development.

3.2 Purpose and key components of a climate change risk assessment

The purpose of a climate change risk assessment is to assist the decision-maker in examining the possible consequences associated with an uncertain future climate.

It should help the decision-maker form an opinion of the:

(i) likely sensitivity (see Box 3.1) of a particular sector or area of responsibility or concern (the 'exposure unit') to potential changes in climate;

Box 3.1: Climate sensitivity, adaptive capacity and vulnerability

Sensitivity. The degree to which a system, receptor or exposure unit would be affected, either adversely or beneficially, by a particular change in climate or climate-related variable. (E.g. a change in agricultural crop yield in response to a change in the mean, range or variability of temperature.) Different systems may differ in their sensitivity to climate change, resulting in different levels of impact.

Adaptive capacity. The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, i.e. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions.

Vulnerability. Vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity.

(Based on IPCC, 2001a, p. 238).

(ii) relative sensitivity of the exposure unit to climate factors compared with other, non-climate factors;

(iii) the vulnerability of the exposure unit to climate change, including the identification of critical thresholds and coping ranges;

(iv) the capacity of the exposure unit to adapt autonomously to climate change (adaptive capacity, see Box 3.1);

(v) ease or difficulty of implementing adaptation measures; and

(vi) degree of success anticipated in mitigating any impact though an adaptive management strategy.

Consideration of adaptive capacity has largely been confined to national and regional assessments of climate change impacts, and the capacity of ecological systems to respond to climate change. Hertin *et al* (2003) consider some of the properties of businesses and management systems, that may increase the ability of organisations to adapt to climate change. These include flexible management processes that are able to integrate climate considerations into existing processes, technical capacity in climate change, risk assessment and risk management, and good relationships with key other decision-makers driving the adaptation issues.

A climate change risk assessment involves the following tasks, which are briefly discussed in this chapter:

(i) Identify and define the nature and extent of the exposure unit and receptors, agree assessment endpoints and assessment period (Part 1, Stage 2);

(ii) Identify and define a set of climate and non-climate variables to which the exposure unit may be sensitive (Part 1, Stage 3);

(iii) Use climate scenarios to help determine the climate change-dependent risk (Part 1, Stage 3), by:
  • forming a knowledge-based opinion on the extent and nature of the exposure unit's sensitivity and potential vulnerability to changes in climate variables over the assessment period;

• determining the uncertainty of the exposure unit's sensitivity and vulnerability to climate change over the assessment period; and

• modelling of climate influence.

(iv) Use non-climate scenarios to help determine the non-climate-dependent risk (Part 1, Stage 3), by:
  • identifying the vulnerability of the exposure unit to non-climatic changes over the period being considered; and
  • determining the uncertainty of the exposure unit's sensitivity and vulnerability to non-climate change factors over the assessment period.

The sensitivity of the exposure unit is assessed by reference to the component receptors.

3.3 Identification of exposure units, receptors and assessment endpoints

The exposure unit will in general be defined by the nature of the decision-maker's problem. The decision-maker will need to specify the location and geographical extent of the exposure unit and, in particular, the types of receptors at risk. These may be identified by preliminary risk assessment. Some of the receptors identified to be at risk may lie outside the decision-maker's initial boundaries for the exposure unit. The choice of receptors for more detailed risk assessment will need to be relevant to the decision-making criteria established by the decision-maker. The choice of receptor(s) and their relationship to decision criteria will need to be negotiated and agreed between the risk analyst and decision-maker.

Risk assessment endpoints represent an agreed frame of reference for the assessment of the significance of risk for the receptor(s). The choice of assessment endpoint is dependent on the exposure unit and receptor. Examples might include existing flood defence standards (e.g. a 1:200 year return period for coastal floods) or measures of water supply security.

Assessment endpoints are often referred to as 'thresholds' in the climate impact assessment literature (e.g. Jones, 2001; Smit & Pilifosova, 2001). Thresholds are often determined by reference to past records or experience of events or circumstances that define a tolerable limit to climate (see Yohe & Toth,
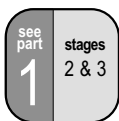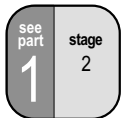
2000) (for example a particular dry summer or series of summers). A related concept is that of the **coping range** (Hewitt & Burton, 1971; Jones, 2001). This concept acknowledges that the majority of natural, social, and economic systems are adapted to and tolerate some (usually large) part of the range of climate variability normally experienced. Within this range of variability, conditions vary from beneficial to tolerable. However, limits beyond which intolerable levels of harm may be suffered often exist (see Figure 3.1) or can be defined as the basis of environmental management, climate adaptation or other policy.

Jones (2001) distinguishes two types of assessment endpoint or threshold. These can be either a fundamental property of the system or *biophysical threshold*, or a *behavioural* threshold. Biophysical thresholds '*mark a (bio)physical discontinuity on a spatial or temporal scale*'. Behavioural thresholds '*trigger a change in behaviour in the form of a social or economic outcome*'. Biophysical thresholds recognise environmental system thresholds that form a natural basis for defining risk. Examples include the water level or effective rainfall at which a river overtops its bank, or the wind speed that leads to the felling of large areas of forest.

In contrast behavioural thresholds represent points at which individuals, or society as a whole, would respond by a change in action, or points at which agreement can be reached that action would be required. Hence behavioural thresholds might be defined on the basis of a policy judgement, by decision-makers or other stakeholders, regarding the point at which climate change impacts can be regarded as intolerable. The choice of assessment endpoints in these cases will necessarily require value judgements as to the significance of the threshold (Swart & Vellinga, 1994; Parry *et al,* 1996), i.e such thresholds often require policy decisions regarding the level of risk that can be tolerated. This might also include consideration of practical and reasonable costs, through the use of criteria similar to those used to determine best practical environmental option (BPEO) and best available technology not entailing excessive cost (BATNEEC).

For these reasons, agreement upon practical assessment endpoints will usually need to be negotiated between the decision-maker, other stakeholders, and technical risk analysts. In certain circumstances, appropriate assessment endpoints might already be agreed, or can be easily adapted, based on existing practice. Where existing standards are being adapted, it will be important to determine whether the chosen standard is independent of climate change.

3.4 Identification of a set of climate variables for the climate change risk assessment
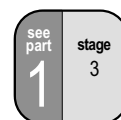
Some areas of climate risk assessment and risk management are well established, underpinned by empirical evidence and theoretical understanding of the current ('historical') influence of climate on the performance of systems. Many of these are areas that may require climate adaptation decisions as the climate changes.

However, as climate moves away from that which we have previous experienced (Hulme *et al*, 2002) there will be a need to take account of climate sensitivity in a wider range of decisions. In many of these areas there will be substantial uncertainty concerning the influence of climate. For climate-influenced decisions the choice of climate variables of potential relevance to the decision may be particularly unclear.

An important task of the risk assessment exercise, therefore, is to identify the particular climate variables that may be important in determining the nature of climatic risk. Hence the choice of climate variables should not be confined to those known in advance to be relevant to the exposure unit, or for which data are available, or for which climate forecasts or projections exist. Nor should it be confined to those variables where significant change is anticipated, given the current state of uncertain knowledge.

In all cases it will be necessary to select a suite of 'key' variables, based on:
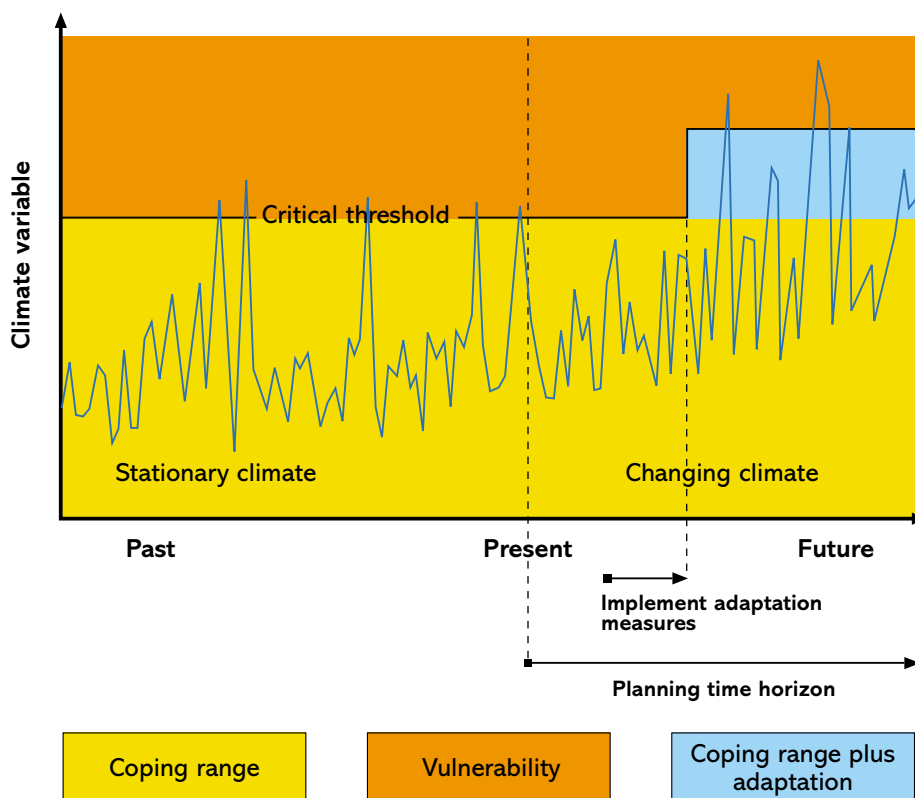
Figure 3.1: Schematic diagram showing the relationship between coping range, critical threshold, vulnerability, and a climate-dependent variable. The climate-dependent variable shows a significant degree of temporal variability. This variability is superimposed upon an upward trend, representing a change in climate that starts at the mid-point of the time series. The coping range represents the tolerable climate and the coping range boundaries may lie above and/or below the average value of the climate variable. Vulnerability to climate in this example is represented by an upper boundary, or critical threshold above which unacceptable impacts may be suffered. Adaptation aims to reduce vulnerability by increasing the critical threshold, countering the increased risk that the un-adapted threshold will be exceeded due to climate change. The figure indicates the relationship between the management of the critical threshold, and the time taken to plan and implement adaptation measures. The figure also indicates the time available to plan and implement adaptation measures from a given starting point.

(i)   knowledge, information and data concerning the exposure unit's sensitivity or vulnerability to past climate variability;

(ii) knowledge of analogous situations;

(iii) conceptual models (including the use of process influence and dependency diagrams, event trees, etc); and

(iv) empirical, statistical and/or process-based models (including simulation models).

A classification of climate variables is provided in Table 3.1 to help undertake preliminary climate change risk assessments. The table classifies climate variables as primary, **synoptic**, compound and proxy. In order to properly define the climate variables it is important to consider their statistical char-

acteristics. These are described in Table 3.2. These tables have been combined into one **checklist** for use in preliminary climate change risk assessments (see Part 1, Table 7). Further information on the type and statistical characteristics of climate variables is provided in Section 3.5.

Knowledge of the sensitivity of the exposure unit, receptors and associated assessment endpoints to past variability in particular climate variable(s) can be of enormous value in determining the likely future response under a changed climate. The influence that these variables may have either individually or in combination should be considered, taking account of any statistical or other evidence of past or future dependence between the variables.

see part **1** | stage **3** | table **7**
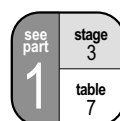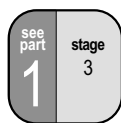
3.5 Further information on climate variables and the description of variability

3.5.1 TYPES OF CLIMATE VARIABLE

Climate variables can be divided into those derived from:

- the past measurement of weather (which may include the use of **weather generator** output or other model-derived output based on observed data); and
- the forecasts derived from global and regional climate models.

These variables, together with other climate response variables described below, may be used as inputs to impact assessment models. For climate change risk assessment, it can be useful to group them as follows (as shown in Table 3.1):

- **Primary variables**. These include atmospheric carbon dioxide (CO_2) concentrations, temperature, wind speed and precipitation. Long time series of historical data may be available for these variables for particular locations. These are also the principal variables modelled and predicted by global and regional climate models. As such they inherit uncertainties in the greenhouse gas emissions used to drive the climate models (see Section 3.6.3 and 3.6.4), but are also subject to climate model-based uncertainties. Primary variables are available at resolutions that are governed by the particular climate model used to generate them. That is they are averaged over particular spatial dimensions and time intervals.[15]

- **Variables describing synoptic scale climate features**. These variables represent features measured over a larger spatial domain. Examples of **synoptic variables** include the frequency, intensity or description of the movement of thunder-storms, cyclonic conditions, frontal systems, cloud cover, storm tracks, atmospheric or oceanic circulation indices including marine currents, swell, etc. The ability of climate models to directly represent synoptic features is dependent on the spatial reso-

lution of the model. In general the higher the spatial resolution of the climate model, the smaller is the spatial scale at which synoptic variables can be distinguished by the model.

- **Compound variables**. In many cases the key variable of interest may be a function of (or dependent upon) one or more primary or synoptic variables. Examples include humidity, evaporation, mist, fog and growing season.

- **Proxy or derived variables**. There are many potential derived or proxy climate variables. Their strong relevance or utility in helping undertake a particular assessment will govern their use. Derived or proxy variables will be recognised as having a close and possibly complex dependence on one or (more frequently) a number of other climate variables. Examples include wave climate, soil moisture, catchment run-off, and river discharge or flow velocity.

3.5.2 CHARACTERISTICS OF CLIMATE VARIABLES

Climate variables, in common with other variables that distinguish dynamic systems, may be described on the basis of particular characteristics or attributes. For decisions affected by climate change, the decision-maker will require information on a variety of characteristics of each climate variable for the risk assessment.

Climate variables are usually defined relative to their spatial and temporal domains. For example an average value may be defined:

- spatially – at a point in time (an instantaneous spatial average);
- temporally – over a defined time interval (a temporal average at a geographical point); or
- both spatially and temporally (e.g. a 30-year average value for a particular global climate model (**GCM**) or regional climate model (RCM) grid-box).

The following attributes are particularly relevant to the **characterisation** of climate (and other variables) used within climate risk assessments (see also Table 3.2):
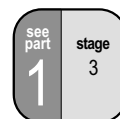
[15] For the Hadley Centre global climate models (e.g. HadCM3), the resolution is of the order of 300km x 350km, while for the regional model, HadRM3, it is 50km x 50km (see Section 3.6.3).

Table 3.1: A classification of the more common climate variables for use in preliminary climate change risk assessments. This table is to be used in conjunction with the variable properties list in Table 3.2. Note that compound and proxy variables may be influenced by non-climate factors, but these are not highlighted in this table.

Variable	Assessments should consider these aspects of the climate variable
PRIMARY	
Carbon dioxide	Particularly atmospheric concentration. Concentrations in other media (water, land) generally equilibrate rapidly with respect to atmospheric concentration, but may be significantly influenced by local biogeochemical processes.
Sea level	Long-term mean sea level is determined (with a considerable lag) by long-term climate changes. Tidal range, and distribution of tidal maxima and minima will be influenced by a number of other climate variables (see sea level entry under 'compound variables', and wave climate entry under 'proxy variables').
Temperature	Assessments of temperature will often be media-specific. Includes occurrence of frosts and freezing conditions. Assessments may need to have regard to synoptic conditions (see below).
Precipitation	All forms of precipitation are included e.g. rain, snow, sleet, hail.
Wind	Includes both wind speed and compass direction (including change in direction: backing/ veering; see Table 3.2).
Cloud cover	Conversely, ground incident light intensity. May be represented by 'cloud' or 'sunshine-days'.
SYNOPTIC	*These are variables measured over a large spatial domain*
Weather types	Classification (such as that due to Lamb) of synoptic weather types, such as cyclonic, anticyclonic, or air flow directions like westerly or southerly may be useful.
Pressure	E.g. mean sea level pressure.
Pressure gradient	Includes established indices based on pressure, such as the North Atlantic Oscillation.
Storm tracks	Determined in part by the pressure patterns and the position of the high-level jet stream.
Ocean climatology	Sea surface temperatures, ocean circulation, currents and other large scale water movements, including the El Nino/La Nina.
Lightning	As determined by the synoptic situation likely to bring about lightning incidence.
COMPOUND	*Compound variables are dependent on combinations of several of the above primary (and other) variables*
Humidity	Dependent on temperature, pressure, moisture content of the air.
Evapo-transpiration	Dependent on temperature, radiation (cloud cover), wind speed, humidity.
Mist, Fog	Dependent on synoptic conditions, temperature, moisture content of the air, wind.
Sea level	Dependent on wind speed and direction and synoptic variables including pressure and antecedent weather types. (See also sea level entry under 'primary variables' and wave climate entry under 'proxy variables'.)
Growing season	Dependent on temperature (perhaps expressed as degree-days), precipitation, cloud cover/ sunshine.
PROXY CLIMATE VARIABLES	*There are many potential proxy climate variables. Proxy variables will be recognised as having a close and possibly complex dependence on one or (more frequently) a number of other climate variables.*
Soil moisture	Dependent on temperature, precipitation, evapotranspiration.
Water run-off	Seasonal distribution of flows dependent on antecedent rainfall, evapotranspiration, as well as catchment characteristics (geology, soils, land-use).
Wave climate	Dependent on storm surge, water level, local and synoptic scale wind speed, direction and duration. (See also sea level entries under 'primary variables' and 'compound variables'.)

Table 3.2: A description of the statistical characteristics associated with the definition of climate variables for use in climate change risk assessments.
Relevant climate variables for risk screening can be identified from Table 3.1. The potential contribution to the overall risk posed to receptors associated with each characteristic of each variable should be examined. This will help determine the nature of risk posed by climate, and the relative importance of different climate variables. Possible changes in these characteristics in the future can facilitate understanding of the sensitivity of the system or particular receptors to possible changes in climate. Under each characteristic there are a number of options (combinations of characteristics) that need to be considered.

Climate variable	Characteristics of variable				Sensitivity of decision criteria/system to changes in variable	Confidence in the assessment of link between variable and decision criteria/system
	Magnitude and direction	Statistical basis of change	Averaging or sampling period	Joint probability events and variables		
Notes on the characteristics of the variables being considered. See also additional guidance in Section 3.5.2.	Changes in magnitude (M) (increases/decreases) and direction (D) (orientation) are important in determining the changes in the associated risk. Under climate change, either the magnitude or the direction of a variable may change.	The assessment will have regard to the statistical basis by which the variables are described. These will be determined in part by the sampling period (see next column). Often the mean or other measure of the average value over a particular period, or a cumulative (time-integrated and/or spatially-integrated) value, will be of interest.	The risk assessor will need to consider the temporal period and spatial scale over which the values of particular variables are determined or described. The following periods are often a relevant basis of assessment.	In certain cases it is the sequence of particular values of variables that is important. In some cases, changes in the joint probabilities of combinations of variables (wind speed, direction and rainfall, etc) will be important.	This column asks the respondent to qualitatively assess the sensitivity of their decision criteria and exposure unit to changes in the climate variable. Would a small change (increase or decrease) in (e.g.) mean summer temperature have no effect, a small, medium or large effect on the receptors of interest? The assessment of sensitivity may be relative, i.e. in comparison to other climate or non-climate variables that may affect the system or decision criteria.	This column asks the respondent to note their confidence (or lack of certainty) in their assessment of the linkage between each climate variable and their decision criteria or system of concern. IT IS NOT A JUDGEMENT ABOUT THE CONFIDENCE ASSOCIATED WITH FORECASTS OF FUTURE CHANGES IN THE CLIMATE VARIABLE BEING CONSIDERED.
Primary, synoptic, compound or proxy climate variables to be selected from Table 3.1. Other variables dependent on climate may also be identified as required by the nature of any specific assessment.	• No change (M&D) • Change (M&D) • Decrease (M only) • Increase (M only) • Rate of change (M&D)	• Average value • Cumulative (or time integrated) value • Variability in values • Frequency of values, including percentiles, extreme values, maxima and minima	• 'Instantaneous' values • Hourly or sub-hourly • 'Day' or 'Night' • Daily • Monthly • Seasonal • Annual • Decadal or longer	• Not consecutive • Consecutive occurrences • Coincident or joint occurrence with second (or more) climate variables	• Not sensitive • Low sensitivity • Medium sensitivity • High sensitivity	• Known, established • Reliable • Extremely doubtful

- **Magnitude and direction**. Most climate variables have magnitude, but some have both direction and magnitude. For example, the variable 'wind' has both magnitude and direction, but wind speed only has magnitude, whereas wind direction has no magnitude. It is changes in magnitude (increases or decreases) and direction (in the sense of orientation) that are important in determining the changes in the nature of the climate hazard and associated risk. Under climate change, either the magnitude and/or direction of a variable may change.

- **Statistical characteristics**. Risk assessors need to have particular regard to the statistical basis by which variables are described. These will be determined in part by the sampling and averaging periods (see below). Often the mean or average, mode or median of values of a variable, determined over a particular period, will be of interest. In certain circumstances the cumulative (time-integrated and/or spatially-integrated) value will be of interest.[16] In other cases the frequency or probability of particular values or events, or the probability that values of variables will fall between particular bounds, or exceed a particular (often extreme) value, will be of concern. Variables may also be defined in terms of the absolute maximum or minimum values that may be recorded, usually over a particular interval of time, or over a particular geographical area. Such variables are described as censored. Examples include daily minimum or maximum temperature. It may be that average or other **percentile** values (e.g. the monthly average value of minimum daily temperature) are required. Measures of variability are also important (e.g. changes in the year-to-year annual rainfall totals). Relevant statistics may include measures of variance, standard deviation or standard error, or more complete descriptions in terms of probability distributions or functions.

- **Averaging and sampling periods and scales**. The risk assessor will need to consider the temporal period and spatial scale over which the values of particular variables are determined or described. For example, a rainfall variable defined as annual-average six-hour-duration rainfall would represent data (actual or forecast) on total cumulative rainfall recorded over a six-hour sampling period, averaged over one year. The variable should also be defined in terms of spatial area or location(s) to which it applies.

  The averaging and sampling periods need to be chosen so that they are relevant to the dynamics of the system being assessed. In many cases the periods will be determined by the availability of data on the system and its driving climate, non-climate and response variables. In part the choice of averaging period may be constrained by past observations or available climate data. The following periods are often a relevant basis of assessment: 'instantaneous', hourly, night or daytime, daily, monthly, seasonal, annual, decadal or longer.

- **Joint probability events, association and co-variation between climate and non-climate variables**. An association between particular values of variables can be important in determining impacts. For example, two or more consecutive high or low rainfall periods (e.g. years, or summers, or days) may represent an increased level of risk. Therefore changes in the probability of occurrence of such events needs to be considered. The association between variables may include the **joint probability** of occurrence of sequences (e.g. dry winters) or combinations of particular variables (wind speed, direction and rainfall, etc). The climate variables or events may be either independent, correlated or have a degree of dependence, and these properties need to be considered if the risk is to be well characterised.

  In many cases the climate variable may depend upon other, non-climate variables. For example, annual average daily temperature may be defined in terms of altitude (e.g. sea level temperature). These dependencies are an important part of the definition of the variable, and will condition the use of such variables in impact assessment.

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[16] For example, degree-days or total winter rainfall may provide useful measures of climate for certain types of impact assessment.

Whatever the basis on which the variable is defined, the risk assessment will need to distinguish data uncertainty from natural variability (see Section 1.7.1 and 1.7.2). All variables are measured, estimated or predicted with limited accuracy and precision, and possibly with bias, i.e. there will be uncertainty as to the value of the variable. The risk assessor will need to determine or form a judgement on whether this uncertainty prejudices the use of information on the variable. The risk assessor will, in general, be interested in characterising the variability in values of climate variables. Techniques exist that allow uncertainty to be described or estimated. These apply to both data uncertainty and variability. The most familiar techniques, such as estimating the **confidence intervals** associated with variable or model parameter value estimates, make use of a wide variety of statistical techniques, based on probability theory. In situations where data are sparse, techniques derived from **fuzzy arithmetic** and **interval analysis** may be of value (see Appendix 3). Whatever techniques are used, the assessor will be required to make certain assumptions. The validity of these assumptions, and their importance for the assessment, should be considered explicitly.

3.5.3 IMPLICATIONS OF CLIMATE VARIABILITY FOR SHORT-TERM DECISION-MAKING

Climate is inherently variable and this variability is a form of uncertainty (see Section 1.7.1). Climate variability has a number of important implications for risk assessment used to support climate-sensitive decisions with relatively short payback periods.

Natural climate variability acts to 'swamp' the signal due to climate change, particularly at sub-regional geographical scales and over relatively short time periods (at least up to two decades – see Section 3.6). Many of the more important impacts of climate are associated with climate variability, and in many cases the decision-maker will be concerned with managing the consequences of low frequency, high consequence events. Examples include sub-daily extreme rainfall leading to increased flood risk, or storm-force winds, or longer-term extremes such as low seasonal or annual rainfall. Such events are use-

fully described by the return period or probability of exceedance of an event of a particular magnitude (e.g. 1 in 100 year rainfall event).

The extent of variability, and hence the probability or return period of an event of a particular magnitude, can be estimated from monitoring records, especially lengthy time series for particular variables (see Hulme *et al* 2002, Section 2.6). Variability can also be determined from statistical models, or can be derived from individual **ensemble members** from GCMs or RCMs. However, any assumption that future probabilities of climate extremes will be similar to that in the past should be regarded with caution. As climate changes, historical observations will either underestimate (if the values of climate variables are generally increasing in magnitude) or overestimate (if they are decreasing) the present-day probability of observing a particular value of a variable. This source of uncertainty (a bias) increases with the rate of change in underlying climate, and the length of time over which the observed weather or climate series is extrapolated.

For longer and higher-quality[17] time-series (e.g. temperature, sea level), statistical techniques of **trend analysis** may help distinguish underlying changes in climate variables (see Hulme *et al*, 2002, Chapter 2). Trend analysis may be particularly useful for climate variables that can be averaged over longer temporal and spatial scales. It can be used to extrapolate or adjust estimates of the present-day or near-term future climate, including the probability of events of a particular magnitude. Assumptions regarding the basis of the extrapolation should be clearly identified, together with statistical estimates of confidence in the extrapolated values.

For many climate-sensitive decisions, however, trends in climate will not be distinguishable within an available data series, even when there is an expectation that climate may change. The use of such data to estimate present-day or future climate will therefore involve a trade-off between the value gained in providing improved estimates of climate (averages, variance, ranges, correlations), and errors due to the uncertainty concerning the underlying change in climate. For advanced applications,

[17] Where quality refers to the precision, accuracy, frequency and geographical density of observations.

Bayesian methods can be used to update prior estimates of climate trends, based on new knowledge and data, and to estimate the associated uncertainty (see Morgan & Henrion, 1990).

For decisions with time horizons up to 20 years, **incremental scenarios** (see Section 3.6.5) can be used to represent 'near-future' and/or 'present-day' climate, and as a basis for examining uncertainty in climate. Incremental scenarios can be based on information and data of recent past climate variability (baseline meteorology). Incremental scenarios acknowledge that historical data may represent a biased estimate of present-day or near-future climate under conditions of a changing climate and will need to make explicit assumptions regarding likely changes in climate. Assumptions might include changes in the average, variance and covariance of important climate variables over the period of the assessment.

Longer-term scenarios, constructed from the output of global climate models, such as the UKCIP02 climate scenarios (Hulme *et al*, 2002), expert judgement exercises, or climate analogues should inform assumptions regarding incremental scenarios where possible. These are considered further in Sections 3.6.3 and 3.6.4.
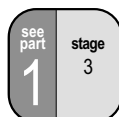
3.6 Climate and non-climate scenarios: tools for climate change risk assessment and decision-making
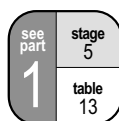
3.6.1 INTRODUCTION

Scenarios are a key tool for climate change risk assessment. They are used to identify various sources and types of uncertainty associated with our knowledge of the future, and as a tool to help analyse the consequences of this uncertainty. For decisions involving climate change, the following types of scenario are useful:

- Scenarios that represent uncertainty in **future climate**. For the UK climate, this includes the UKCIP02 scenarios (Hulme *et al*, 2002), which have superseded the UKCIP98 scenarios (Hulme & Jenkins, 1998). Other climate scenario techniques are discussed in Sections 3.6.5 and 3.6.6.

- Scenarios that describe uncertainty in the **future socio-economic environment** (see Section 3.7). Such scenarios provide a context allowing climate change risk to be judged against other sources of risk. Scenarios relevant to a particular sector or problem are available from a variety of sources, or can be developed. For the nearer-term future, scenarios may be developed based on the uncertainty revealed within quantitative and qualitative analyses of past trends. For the longer term, contextual descriptions of the future, such as those produced for use in the UKCIP (UKCIP, 2000), can be useful.

It may also be appropriate to develop other types of scenario for some studies, for example, land-use change scenarios, environmental scenarios or even impacts scenarios, so that climate risks can be analysed in the context of non-climate risks, and suitable adaptation strategies devised.

3.6.2 CHOOSING AND USING SUITABLE CLIMATE SCENARIOS IN RISK ASSESSMENTS AND DECISION-MAKING

There are a number of sources of information for climate scenarios:

- the output of climate models;
- simple incremental scenarios; and
- climate analogues.

The type and time-scale for the climate change risk assessment will determine the most appropriate scenarios to use.

For initial assessments of vulnerability or sensitivity assessments (as in Part 1, Stage 3, Tier 1), **incremental scenarios** (see Section 3.6.5) can provide information across a wide range of climate variations.

For decision time horizons of less than 20 years, scenarios will be required representing 'near-future' and possibly 'present-day' climates. These are discussed in Section 3.5.3. However, for longer-term decisions (time-scales exceeding 20 years), such as decisions with long-lasting consequences
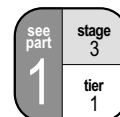
and concerning long-lived assets, a range of climate scenarios developed from global climate model output should be used (see Section 3.6.3 and 3.6.4). These should include, but should not be limited to, the UKCIP02 climate change scenarios (Hulme *et al*, 2002).

Where the UKCIP02 scenarios are used, it is recommended that all four component scenarios are used. This will:

- assist in the identification of critical thresholds in the response of the exposure unit to climate change;
- make the analysis more robust to the publication of new scenarios, which may be subject to significant revision; and
- allow decisions to be taken which are robust to the uncertainties in future climate.

If decision-makers do not have the time or resources to explore all four UKCIP02 or other scenarios, an alternative would be to use the scenarios associated with the highest and lowest emission scenarios.

However, for applications with major policy recommendations or major investment decisions, it is recommended that decision-makers should make use of the full range of UKCIP02 scenarios, as well as scenarios from other global climate models (see Hulme *et al*, 2002, Section 3.5, Table 5 and Appendix 1).

Uncertainty relating to the natural variability of the climate system can be captured through the use of several individual ensemble members. (Ensemble runs are available for the UKCIP02 scenarios.)

If data are not available for the climate variable of interest, scenario approaches based on present-day **analogues** of future climate (see Section 3.6.6) may be of value (Mearns *et al*, 2001). Care must be taken to identify the assumptions associated with the analogue chosen, and to identify ways in which it may differ from expected future scenarios for the site of interest. This approach is limited in that future changes in variability may not be captured.

More information on choosing appropriate scenarios is available in the IPCC Third Assessment Report,

Working Group II (IPCC, 2001b) and the UKCIP02 scenarios Scientific Report (Hulme *et al*, 2002).

The types of scenarios outlined above are discussed further in the following sections.

3.6.3 SCENARIOS FROM CLIMATE MODEL OUTPUT

A key framework for the assessment of risks associated with future UK climate is the set of four UKCIP02 climate change scenarios (Hulme *et al*, 2002). These scenarios provide information on possible future changes in UK climate, and climate variability, for 30-year periods centred on the 2020s, 2050s, and 2080s, and comparative data for the baseline period 1961-90. The data provided are monthly average values for climate variables, at a spatial resolution of 50 x 50km. The UKCIP02 scenarios also provide information on possible changes to extreme events, including changes in the daily statistics for some key climate variables.

The UKCIP02 scenarios have the following important properties, which are discussed further in Section 3.6.4:

(i) Some of the many uncertainties regarding our knowledge of future climate are summarised within the four scenarios. Each scenario is based on one of four different, explicit assumptions about future emissions (emissions scenario) (see Hulme *et al*, 2002, Section 3.1 and Figure 20). Hence they reflect (at least in part) the uncertainty about future emissions.

(ii) No one scenario represents a more likely future than another, and there are no 'best guess' scenarios. Each scenario is contingent on the unknown probability associated with the assumptions that underpin it. Therefore one cannot say that any one scenario is more likely or less likely because we cannot attach probabilities to the underlying emissions scenario. Further research may provide subjective estimates of the probability associated with a scenario, or delineated by two or more scenarios. Such information could be used to assess the risk associated with the scenarios.

(iii) Since only the Hadley Centre climate models are used to generate the UKCIP02 scenarios,
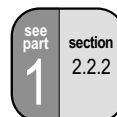
the uncertainty associated with our incomplete understanding of the climate system, and how it should be represented in models, is not reflected in the UKCIP02 scenarios. This includes differences between climate models in their sensitivity to accumulated emissions (see Section 3.6.4 below, also Hulme *et al*, 2002, Box D).

(iv) The four scenarios do not represent bounds on the future expected climate. As knowledge of the climate increases, new climate scenarios will become available, which may show different climate changes (for instance, the UKCIP98 scenarios have been updated by the UKCIP02 scenarios and these show a slightly higher rate of warming for the UK). This demonstrates the importance of understanding the sensitivity of the decisions to present-day climate variability and to changes in climate. It also stresses the need for flexible adaptation strategies for those particularly sensitive exposure units, as recommended here.

(v) The uncertainty (or lack of confidence) associated with certain climate variables (e.g. precipitation) is greater than others (e.g. temperature).

(vi) The uncertainty associated with modelling variability in climate is greater than that associated with average values for the same variables. Hence information on future extremes (e.g. local daily precipitation) is more uncertain than information on future averages (e.g. global annual mean temperature).

(vii) The confidence in modelling average values increases with the length of time over which they are averaged. Hence there is more confidence in 30-year average values than decadal averages, and more confidence in yearly average values than seasonal values. However, averages that are superimposed on trends in values need to be interpreted with care.

3.6.4 UNCERTAINTY IN CLIMATE SCENARIOS FROM GCMS

Uncertainty in climate change scenarios based on the output of GCMs derives from a number of sources. They include:

(i) **Future emissions scenarios**: The starting point for predicting future climate change are scenarios of future emissions of the greenhouse gases and other pollutants that affect climate (e.g. sulphur dioxide). Such estimation relies on combining data on past emissions (with associated data uncertainty) with predictions of how emissions may change with future changes in technology, politics, global economic development, etc (which will be characterised by real world uncertainty (see Section 1.7.1)). All these factors, and hence future emissions of greenhouse gases, are uncertain. Hence, future greenhouse gas emissions are essentially unknowable, except within extreme bounds, and therefore present an area of uncertainty that cannot be removed. The most comprehensive attempt so far to characterise emissions scenarios is the IPCC Special Report on Emissions Scenarios (Nakicenovic *et al*, 2000). It should be noted that the consequence for climate prediction of uncertainty in emissions is much less for the near future climate (2020s) than for the distant future (2080s) (see Table 7 in Hulme *et al*, 2002). Climate pathways for the four emissions scenarios do not start to diverge until just before mid-century (see Chapter 4 in Hulme *et al*, 2002 and Figure 3.2 in this report). Near-future climate is dominated by historic emissions of greenhouse gases, and natural variability in climate (see Section 7.7 in Hulme *et al*, 2002). The predicted rate of change in climate is particularly important since it affects the time available for adapting to the changes.

(ii) **Global climate models (GCMs) and regional climate models (RCMs)**: Scenarios of climate change are simply the predictions from global or regional climate models. GCMs represent the processes that govern global climate. The prediction from these climate models is uncertain, due to imperfect representation of the processes in the climate system, e.g. clouds, ocean circulation, soils, vegetation and the interactions between them. Because different climate models represent these processes in different ways, their pre-

dictions (for the same emissions scenarios) will be different. The consequences of this uncertainty is clearly illustrated in Hulme *et al* (2002), by showing changes in summer and winter temperature and precipitation from eight different GCMs. The Hadley Centre is currently developing ways of quantifying uncertainties in their climate models. These involve running many versions of the model, with slightly different model parameters and starting conditions (a form of sensitivity or uncertainty analysis). It is hoped that this method will provide information on climate changes for a given location and time as probabilities or probability density functions, rather than as discrete values. This information would represent a significant advance for quantitative climate change risk assessments, although it does not overcome the difficulty of not having probabilities for the emissions scenarios that underpin longer-term model forecasts of climate. The output of these models will always be contingent on the unknowable probability associated with future emissions.[18] The IPCC (Albritton *et al*, 2001) and Hulme *et al* (2002) describe many of the uncertainties in climate modelling. Improving GCMs will remain a significant long-term scientific challenge.

In order to provide climate change information at a scale (50km) smaller than GCMs give (typically 300km), UKCIP02 used the Hadley Centre RCM. RCMs take account of geography and topography (e.g. mountains and oceans), and small-scale weather phenomena, and are therefore better at representing local variations in climate. As with GCMs, RCMs are also subject to 'science uncertainty' and also (as with any regionalisation technique) they inherit errors from the GCMs that drive them.

(iii) **Appropriate information on climate**: Global and regional climate models provide information on future climate for a restricted range of climate variables and at a spatial resolution determined by the climate model. The coarse scale of the modelling, particularly in global

climate models, does not adequately represent local variations in climate. Even RCMs often do not generate the detail required for climate impact assessments and models, and further downscaling may be required, e.g. using statistical techniques (see Section 3.6.7).

Figure 3.2 shows the uncertainty in predictions of global temperature rise from various global climate models for the present day until 2100. The range of temperature rises demonstrates the uncertainties in future emissions (B1 (lowest emissions) to A1FI (highest emissions)) as well as the differences in the GCMs.

There is a broad consensus amongst climate modellers that, for a given emissions scenario, changes in atmospheric carbon dioxide concentrations, global mean sea level, and to a lesser degree annual average temperature can be modelled with some confidence. At the other end of the spectrum, information about climate extremes – such as changes in maximum daily wind speed – has a very low confidence attached to it. There is more confidence concerning the direction of change (i.e. whether a variable will increase or decrease in value) than in the magnitude of change, and more confidence concerning longer-term and larger spatial-average changes in climate. These different levels of confidence reflect the experts' view of the associated uncertainties – the higher the confidence, the lower the uncertainty. Examples of the confidence in some of the main climate changes are provided in Table 3.3 and are also discussed in the UKCIP02 Scientific Report (Hulme *et al*, 2002).

3.6.5 INCREMENTAL CLIMATE SCENARIOS AND UNCERTAINTY ANALYSIS

The consequences of uncertainty concerning present or future values of climate variables or climate-dependent parameters can be investigated by the use of sensitivity-type analyses (Saltelli *et al*, 2001, provide a formal description of sensitivity analysis techniques). Climate variables or parameters may be changed by small but realistic increments to inform the decision-maker about how other variables, relevant to the assessment endpoint or exposure unit, might respond to certain climate stimuli. Often these

[18] Although experts may form opinions as to the range and temporal pattern of likely future emissions, and attach subjective probabilities to particular ranges of emissions scenarios.

approaches take as a baseline a 'no change' scenario, i.e. an assumption that future climate will be similar to that experienced in the past, for which relevant and detailed data might be available. These approaches are useful for gauging likely impacts and determining the level of detail required for the risk assessment to adequately inform the decision. They can also provide a relatively simple framework for exploring the importance of joint changes in more than one climate variable, and for investigating the potential vulnerability to changes in extreme events.

These methods can also allow an examination of the sensitivity of the exposure unit to changes in climate statistics that are not readily available from other sources. Incremental scenarios can be developed for changes in extremes, inter-annual, daily and diurnal variability. These may be informed, or even bounded, by information on changes derived from the output of GCMs.

3.6.6 CLIMATE ANALOGUE-BASED SCENARIOS

If future values for climate variables for the system of interest are not available, scenario approaches based on present-day **analogues** of future climate may be of value (Mearns *et al*, 2001). Analogue scenarios can be based on historical, instrumental climate series. Reconstructed palaeoclimatic series can provide useful analogues, particularly for ecological climate impact studies. Climate analogues may be spatial (e.g. anticipating a northward shift in climatic zones) or temporal (e.g. anticipating a series of benchmark hot summers, such as 1976). However, as in all scenario approaches, care must be taken to identify the many important assumptions associated with the choice of particular analogues, and to identify any ways in which the chosen analogue may differ from expected future scenarios. In addition, the amount of information that this
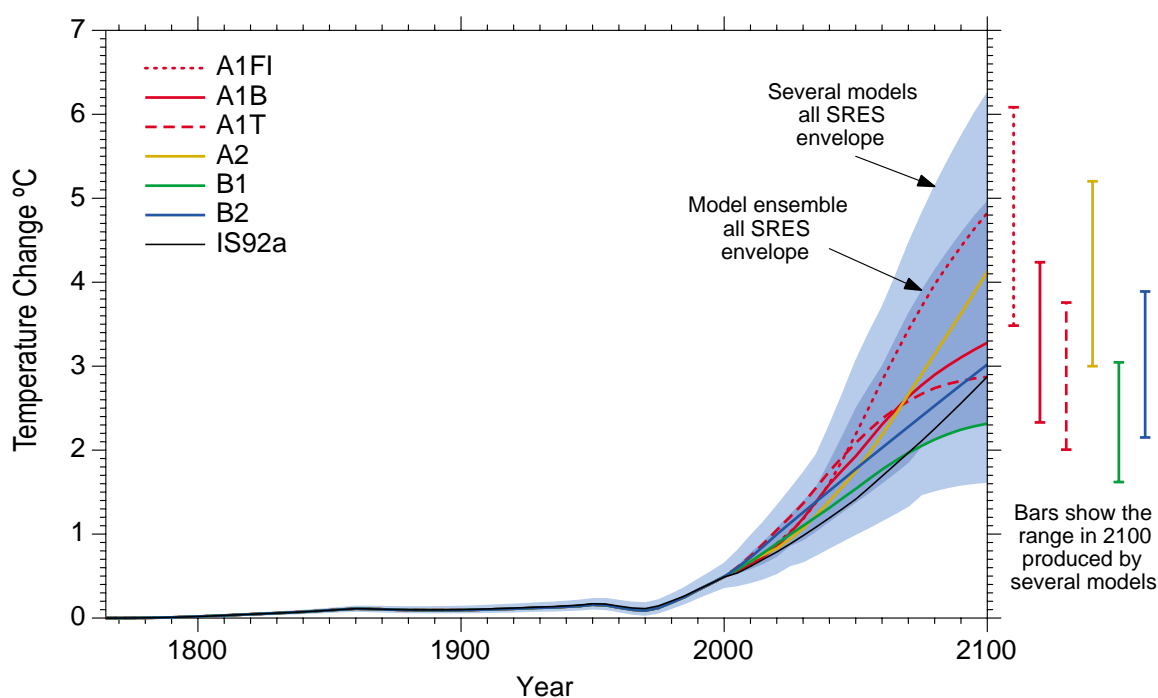
Figure 3.2: Estimated historical and range of predicted future global average temperature rises for various emission scenarios (A1FI – B1) and various global climate models (Cubasch *et al*, 2001, p.554). Note that up to the mid-21st century, 'science' uncertainty (i.e. the range of temperature change produced by the different climate models) heavily dominates over emissions uncertainty, and they are roughly equal by the end of the century. (However, at a regional level, science uncertainty dominates even by the end of the century.)

approach can yield may be limited – for example, future changes in variability may not be captured. Ideally, a suitable set of analogues (rather than a single analogue) should be considered, to represent some of the inherent uncertainty.

3.6.7 DOWNSCALING TECHNIQUES

see part 1 / stage 3 / tiers 2 & 3
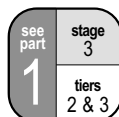
Quantitative risk assessments may make use of downscaling techniques, **weather generators** and **climate typing**. These techniques allow climate scenarios to be developed (downscaled) at more detailed time and space resolutions than those available from GCMs. Wilby *et al* (2002) discuss the various types of downscaling that can be performed:

(i) **Dynamical downscaling**: This involves nesting higher resolution, regional models within GCMs, such as was done to produce the UKCIP02 scenarios. The technique is computationally demanding, restricting the geographic domain that can reasonably be modelled and the time period over which the simulation can be run.

(ii) **Weather generators**: These tools simultaneously model the occurrence of rainfall, temperature, radiation, etc, and can be used to generate climate change scenarios by running the weather generator models with altered parameter sets, scaled according to the corresponding variable in the GCM, where this is available. These models perform well in representing observed weather, but often the information they need to generate future climate data is not produced by GCMs, so they tend to produce output that is useful within a incremental scenario or sensitivity-type study.

(iii) **Weather typing**: This technique involves developing relationships between groups of local weather variables and large-scale atmospheric circulation patterns (Bardossy and Plate, 1992). Future climate scenarios are then produced by using future atmospheric circulation indices, derived from GCMs. These schemes assume that the relationship between the local variables and the circulation patterns are stationary.

Table 3.3: Estimates of confidence in projected changes in extreme weather and climate events (IPCC, 2001a, p.15)	
Phenomenon	**Confidence in projected changes (during the 21st century)[1]**
Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Reduced diurnal[2] temperature range over most land areas	Very likely
Increase of heat index[3] over land areas	Very likely, over most areas
More intense precipitation events	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors. (Lack of consistent projections in other areas).
Increase in tropical cyclone peak wind intensities[4]	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities[4]	Likely, over some areas

[1]This assessment is based on expert judgement, and the following definitions apply:
   "Very likely" – 90-99% confidence.   "Likely" – 66-90% chance
[2]Diurnal temperature range is the range experienced within a 24-hour period
[3]Heat index: a combination of temperature and humidity that measures effects on human comfort
[4]Changes in tropical cyclone location and frequency are uncertain

(iv) **Statistical/regression-based downscaling**: This is based on empirical relationships between local-scale variables and their large-scale predictors. These relationships can be based on a range of mathematical transfer functions, predictor variables and statistical fitting routines (Wilby *et al*, 2002). Applying these modelled relationships using information on future changes in the large-scale predictors from GCMs produces the required climate scenarios. Again, this technique assumes that these statistical relationships will not change under a future climate. This important assumption should be carefully examined for each case. For example, it has been shown to be misleading in the case of precipitation (Murphy, 2000), where present-day relationships are dominated by changes in wind direction, but future precipitation will be more dependent on changes in moisture content. However, statistical approaches do have advantages: they take advantage of observed relationships; are relatively easy and quick to apply; they can produce site-specific, daily time series for future time periods; and uncertainty estimates can be obtained for the outputs.
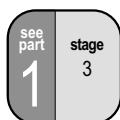
3.7 Non-climate scenarios and scenario planning

Climate and climate change is only one source of risk and uncertainty influencing the decision-maker, even where climate adaptation is the focus of the decision. Climate change may represent an important additional stress but many exposure units are already influenced by other natural (e.g. relative sea level rise) or anthropogenic environmental (e.g. over-abstraction of groundwater) change, or economic conditions, and decision-making and risk management must consider all these important risk factors.

These societal and economic pressures may have a greater or lesser influence on a decision than future climate change. Assessing the relative importance of the risks posed by climate and non-climate factors will be key to achieving sound decisions. Uncertainties about future trends (rate and magnitude) in the development of society, technological

innovation, etc, may be less, equal to or greater than the uncertainties associated with a changing climate. This non-climate context to the assessment of vulnerability becomes increasingly uncertain when the timeframe of assessment extends beyond decades. Scenario planning techniques provide a means by which these uncertainties and their consequences can be explored by decision-makers (see Schoemaker, 1991).

The four UKCIP socio-economic scenarios (UKCIP, 2000) provide contextual socio-economic descriptions and other information for use in the assessment of climate change futures. In a balanced assessment, these scenarios can help to structure analyses of non-climate sources of future uncertainty. They can also inform the choice of values for non-climate variables that are important components of risk assessments. (An example of their use is provided in Environment Agency, 2001b).

3.8 Modelling climate influence

When addressing climate risk and impact problems, knowledge of the system and its relationship to climate is clearly important. This knowledge is especially valuable when the processes linking climate variables to the response of the exposure system are understood, even where significant uncertainties have to be acknowledged. While relevant monitoring data may be available for some systems, experimental evidence will rarely be available, so the risk assessment stage may need to be informed by an impact model or modelling studies.

These models summarise the relevant information and knowledge about how climate change and other important non-climate factors could affect the system under a variety of decision options. Models may be needed for the following reasons:

- The variables of interest are not provided directly by the climate scenarios.
- The impact of concern may relate to the components and properties of a specific system – and this will be a function of system variables and parameters as well as other
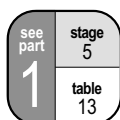
secondary or compound climate variables (e.g. water reservoir storage capacity, wind resistance of a building).

These modelling studies generally take climate scenario data as input, and model additional processes, often at finer spatial and temporal resolution, to generate information more closely related to the specific impact and decision being considered. The influence of the various statistical properties of each climate variable (see Section 3.5) should be considered where appropriate.

In this context, a 'model' may range from conceptual insights into the influence of climate and other variables on a system, to more sophisticated and technical approaches using computer-based mathematical or other forms of model (e.g. wind tunnel or wave tank physical model).

A hierarchical approach should be adopted to modelling climate influence on a system. Gaining a thorough and broad-brush understanding of the system is recommended before more resource-intensive modelling of specific parts is undertaken. Techniques that help identify possible interactions, process links and sensitivities should be used in these initial stages (see Part 1, Stage 3, Tier 1). **Process influence diagrams, conceptual models, dependency mapping** are frequently used, preceding and possibly providing a basis for development of quantitative models and methods. Such techniques will often be more appropriate than detailed process modelling, which may not be supported by the available data.
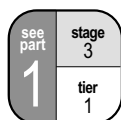
Where relationships can or have been established between the various components, statistical and risk-based techniques (Stage 3, Tier 2) and more sophisticated **process-response models** (Tier 3) can be used. In some cases, existing models of complex systems will be available. Studies using these models are normally carried out by specialists in specific disciplines and techniques. Examples include rainfall-runoff modelling for fluvial flood assessment, sea level rise and storm surge modelling for coastal flood risk assessment, or the modelling of ecological systems to assess changes to plant and animal populations.
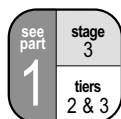
More advanced quantitative risk assessments (as described in Part 1, Stage 3, Tier 3) should consider making use of probability density functions and other statistical methods and models (e.g. to characterise the variance, covariance and causality between climate and other system variables), where suitable data are available.

3.8.1 IMPACT MODEL UNCERTAINTY

These additional modelling studies cannot reduce the uncertainty stemming from the original climate model. In fact, as all models are subject to model uncertainty (see Section 1.7.4), the need to use an impact model adds to the uncertainty inherited from the climate model. In the majority of cases an impact model will require other types of input, in addition to those dependent on climate. Some of these inputs may reasonably be assumed not to change over the period of the assessment (i.e. show no time-dependent trend). However, they may still be subject to variability and other forms of uncertainty. Other inputs may be expected to change over the period of the assessment, and forecasts for these variables will be needed. These forecasts may come from a model-based trend analysis, some other forecasting model, or using a scenario-based approach (see Section 3.6). All these approaches will carry with them particular assumptions and other sources of uncertainty. Some of these uncertainties may be amenable for quantification, using the model, as part of a probabilistic risk assessment. However, others will remain unquantified and the results of any probabilistic risk assessment will be contingent on these assumptions. It is therefore an important requirement of any risk assessment that such assumptions are clearly identified and where possible supported, and justified in terms of their importance for any conclusions.

Hence it should not be assumed that the uncertainty associated with future climate change (e.g. summarised within the climate scenarios) is necessarily more important or significant, in terms of its relevance to a particular decision, than that contained within the impact model. Both contribute towards the overall uncertainty associated with an impact assessment. Indeed, in order to reduce uncertainty in climate change risk assess-

see part **1** stage **3** tier **1**

see part **1** stage **3** tiers **2 & 3**

ments, a decision-maker may find that increasing knowledge of how a particular system responds to present-day climate variability, or to uncertain future values of non-climate variables, may be more important than reducing the uncertainty over the extent of future climate change.

Appendix 1
Case study

Appendix 1 – Case Study

Example application of the decision-making framework

It is not possible to present more than a flavour of the application of the guidelines (Part 1) to a particular case study. This example aims to provide a simplified illustration of the application of the guidelines. It does not consider implementation and monitoring. Real-world applications of the framework are usually complex and case specific, requiring the collation, analysis and synthesis of a wide variety of knowledge, information and data, and the use of appropriate techniques selected from a large portfolio. Similarly, the iterative and tiered nature of assessments applied to real-world problems cannot easily be represented within a short example.

Mixed broadleaf woodland enhances conservation and amenity value.

Outline of an analysis of a decision concerning forestry development

A substantial upland area within the catchment of a river in Wales has traditionally been devoted to sheep grazing, and in particular the production of lambs which are sold for rearing on higher quality lowland pasture. The income generated by this activity has declined in the last ten years, and a decision to reduce the subsidies provided for this activity means that the landowner is considering new uses for some of the land.

The landowner's main objective is to diversify land use on the estate over the next 40 years. The landowner is considering various options, including forestry. Other land in the area has been used for the commercial production of softwoods. The wood has been sold into a variety of markets (pulp, particle board and construction timber). Recently, the landowner has become aware of commercial interest in the value of woodland for sequestering and storing carbon. There are also well advanced proposals to build a combined heat and power (CHP) generating plant within the district, exploiting the availability of local sources of bio-fuel.

Stage 1

1. **Where does the need to make the decision come from? What are the main drivers behind the decision? What beneficial objectives are intended?**

Identify problem and objectives

The main drivers for the decision are an interest in forestry combined with the harrowing experience for livestock farmers of the recent outbreak of foot-and-mouth disease. Other factors are the poor returns on existing agricultural use of the land, combined with the removal of subsidies for the current farming activity. The landowner's primary beneficial objective is to make forestry a sus-

tainable activity on his land; this will entail optimising the income generated from forestry and associated recreational activities.

2. Is the problem explicitly one of managing present-day climate or adapting to future climate change?
i.e. Is the problem perceived to be a climate adaptation decision problem?

The problem is not one of managing present-day climate or of explicitly adapting to climate change.

3. If the main driver is not related to climate or climate change, is climate change believed to be a factor in the problem?
If so, how important is climate change believed to be, relative to other factors?
i.e. Is the problem perceived to be a climate-influenced decision problem?

Climate change may be a significant factor influencing the decision. Forestry crops and their operational management are affected by climate. Climate change could alter the potential impacts on the environment associated with forestry. Climate change could also affect the demand for forestry products, recreation and tourism services, perhaps making woodland in Wales an appreciating asset. Furthermore, Government climate change mitigation policies make firm commitments to renewable energy, of which forests are a potential source – the landowner is fortunate that a CHP plant is planned for the neighbourhood. There is also a possible one-off payment for carbon sequestration in woodland, though only unofficial markets exist at present. Such payments in respect of the carbon sequestration potential might also be sensitive to climate change if it results in an increased policy emphasis on the need for sequestration.

4. Is it a policy-, programme- or project-level decision?

This can be considered to be a project-level decision. The owner recognises that it is likely to be a costly enterprise with little expectation of major income from the market for many years.

5. Who or what will benefit or suffer as a consequence of the problem being addressed?
Who are the key stakeholders representing these interests?

In addition to the owner and his dependants, key stakeholders include the Environment Agency (EA), Countryside Council for Wales (CCW), Forestry Commission (FC), the local authority and, if there are historic sites within the area, Cadw and the local archaeological trust. Local people are also key stakeholders: they are not aware of the proposed change of use and will have concerns about it. The river and tributaries within the catchment have significant Salmonid fishing interests and these too are key stakeholders. The presence of two Special Areas of Conservation (SACs), and the possible existence of historic sites, will also widen the number of key stakeholders. The project will require some initial investment, which will be secured by a mortgage.

6. Have timescales been established for making and/or implementing a decision?
Do these timescales constrain the time available for the decision appraisal, or vice versa?

Timescales for making the decision will be governed by the need to undertake an environmental appraisal, consult with stakeholders, and obtain the required permissions and grant funding.

7. Is the decision expected to provide benefits in the long-term (> 10 years)

The decision is expected to have long-term consequences and benefits, over 50 years. These include environmental improvement,

or have other long-term consequences? Describe what they are, the likely time period, and to whom they may be important. Decisions with long-term consequences are likely to be more sensitive to climate change.

social acceptability and utility, and increased opportunities for local employment.

Stage 2

KEY QUESTIONS FOR DECISION-MAKER

Establish decision-making criteria

1. **What makes the correct decision? In other words, what are the criteria against which your options will be appraised in Stage 5? Criteria might include the risk of the option not succeeding, ease of implementation, cost, equity, public approval, public acceptability, etc.**

The owner wishes to establish a sustainable woodland estate that will provide a range of benefits to his family and the local community for many generations. Apart from environmental improvement, social acceptability and employment, there is a need to optimise income to offset the cost of unmarketable assets. Hence, one of the most important criteria will be the availability of Government grant-aid to provide an income stream. Approval will depend on meeting environmental and community benefits required under the Woodland Grant Scheme and Farm Woodland Premium Scheme (which are currently under review in Wales). The existence of 2 SACs raises the possibility of further management agreements (and possibly grants) from CCW to extend or enhance the sites as part of the Forest Plan.

2. **What are the legislative requirements or constraints? For Government agencies, does the decision require an appraisal that explicitly considers both costs and benefits (as, for example, required by the Environment Act 1995)? Do guidelines exist that set out the approach that should be taken to the appraisal (e.g. DTLR, 2001b, HM Treasury, 2001 & 2003)?**

A firm of forestry consultants has been engaged to obtain necessary information from the FC on the Woodland Grant Scheme and Farm Woodland Premium Scheme and to investigate whether Government grants are likely to be offered for biomass schemes in Wales. They will also advise the client on any regulatory constraints and requirements associated with the proposed change of use for the land, represent the client to the regulatory authorities and other stakeholders, and analyse projected income (including grants) for the enterprise. In order to receive grant aid and to meet the requirements of Environmental Impact Assessment (EIA), the proposed project will need to address the objectives of the Welsh Assembly Government's Forestry Strategy and to comply with practice laid down in the UK Forestry Standard. The consultants may also advise the client to seek certification under the UK Woodland Assurance Standard. Protection of the SACs and any historic sites found by survey or known to be present will have to form part of the Forest Plan submitted to the FC.

3. **What are the rules for making the decision, given the uncertainty in climate change? For instance, is your organisation risk averse or focused on maximising benefit, or minimising cost?**

The key decision rules relate to minimising the costs associated with any forestry development, and offsetting these against grants that may be available for qualifying developments. The landowner is highly risk averse with respect to decisions affecting land use. Total costs of establishment to five years vary from about £3,200 to

If risk averse, minimum (no or low) regret and precautionary approaches to decision rules should be considered.	£5,500 per planted hectare. Current grant aid lies between £700 and £1,350 per hectare. The owner wishes to aim at a cost net of grant of £2,500 per planted hectare at year five, but will accept a cost up to £4,000 per planted hectare depending on the extra environmental benefits that might be obtained for the higher cost.
4. What is the decision-making culture of your organisation? **Is the culture one of open and explicit decision-making?** **Do different stakeholders need to be involved in the decision-making process? If so, how?** **Is the goal consensus, or a demonstrably 'rational', if not consensual, choice?**	Decision-making will be by the landowner on the basis of professional advice. The views of other stakeholders will be considered according to statutory requirements and best practice as set out in the UK Forestry Standard and UK Woodland Assurance Standard.
5. Could the decision being considered possibly constrain other decision-makers' ability to adapt to climate change (i.e. contribute to climate maladaptation)? **Options or decisions that may constrain climate adaptation can be difficult to identify at this stage. They may be only apparent after Stage 5.** **If it is believed that the decision being considered may adversely affect the ability of other decision-makers or stakeholders to manage climate change risks in the future, their interests and involvement in the decision-making process should be considered.**	Not known at this stage. However, a key objective of the risk assessment is to identify possible consequences for other stakeholders associated with different forestry options. It will be necessary for these stakeholders to consider whether their future needs for climate adaptation might be adversely affected by any forestry development.
6. Who is the ultimate decision-maker?	The ultimate decision-maker is the landowner, but the decision to implement a particular forestry development option will be dependent on the receipt of FC grant-aid following approval of the scheme submitted. The owner is unlikely to pursue an option that arouses serious opposition in the local community.
7. Has climate change already been accounted for at a strategic level? **If so, was consideration of climate change at the strategic level adequate? Does the strategy take account of all possible climate change outcomes?**	No.

8. What resources are available to help you make the decision?
This will help determine how in-depth your decision-making process can be, and what tools are appropriate to assist in the process.

The consultant has been contracted to investigate a variety of forestry options. The contract allows for staged payments, on the basis of an initial preliminary assessment, and proposals for further more detailed assessments if required. The consultant will take further expert advice, under sub-contract if necessary, from scientists in the FC, UKCIP, and other organisations. This may include the influence of future climate on tree growth and forestry activity, as well as the environmental and social impacts of forestry options.

Stage 2 *continued*

Establish exposure units, receptors and risk assessment endpoints

KEY QUESTIONS FOR DECISION-MAKERS AND RISK ANALYSTS

1. Have receptors at risk and the exposure unit been defined?

The risk assessment will estimate the probability of timber yields under different climate change scenarios.

For the purposes of tree growth and investment appraisal, the exposure unit will be the area of land subject to the forestry project. Characterisation of the exposure unit includes altitude, aspect, slope, nature of the soils, access, and present-day climate. The principal receptors of interest will be the different forestry tree species being considered. However, in order to fully characterise the risks of benefits and disbenefits associated with the development, a variety of other receptors will need to be considered. These will help identify risks associated with the water environment, diffuse pollution, landscape change and conservation value. The risk to these receptors may extend beyond the boundary of the forestry development, increasing the exposure unit to the landscape or catchment scale. The risk posed to these features by the forestry development may also be affected by climate change.

2. Have assessment endpoints or thresholds been identified as a basis for assessing risk to the exposure unit and receptors?
Assessment endpoints should be directly relevant to the problem, useful to the decision-maker, and amenable to risk analysis.
One or more assessment endpoint may be required, dependent on the complexity of the problem.
Can assessment endpoints be analysed in terms of:
    a) Past records and future scenarios of climate variability?
    b) Other non-climate factors?
Can assessment endpoints be developed to provide a basis of quantitative (Tier 3) risk assessments (Stage 3) if required?

A variety of assessment endpoints have been discussed by the consultants appointed by the landowner. They have decided to estimate the probability that the landowner will achieve (or not achieve) the criteria established in Stage 2 'Key questions for decision-maker' (1) and (3). This is a risk-based approach. In part it will require an assessment of future changes in the markets for the variety of forestry products under consideration, as well as the capital and operating costs for each option. It also requires forecasts of the capacity of the site to produce particular annual yields of a variety of timber products. These yields under present climate can be calculated from standard tables and software. Modelling by experts could provide estimates of yields under particular scenarios of future climate. Such estimates would be more uncertain than those based on standard methods (if the uncertainty associated with the future climate is ignored). The future recreational and other wider benefits associated with the development will also form part of the assessment.

3. Have assessment endpoints and timescales over which they will be assessed been agreed between decision-makers (policy-lead, programme officer or project manager), stakeholders, and risk assessors?
If there are consequences beyond this time frame, e.g. to future stakeholders ('sustainability'), it may be beneficial to consider longer timeframes.

It has been agreed that further advice will be sought from forestry scientists on the likely impact of projected climate change on forestry yield class and on the interactions with the freshwater environment up to 2050. If, following Stage 3, Tier 1 assessment climate change is determined to be potentially significant, variations in yield and interactions with the freshwater environment will be determined for a variety of future climate scenarios.

Future demand and price of the products associated with some of the options are very uncertain. Both present day and future community and recreational benefits are difficult to determine. The consultants will utilise available market reports and analyses to provide a range of scenarios for each forestry option up to 2050.

However, one of the most important considerations will be the income from grant aid available over the initial five years of the project.

4. Have all project management issues been agreed? For example:
Are the resources and time allocated to undertake the risk assessment reasonable and proportionate to the importance and urgency (see Stage 1) of the decision problem?
Are the objectives clearly defined and achievable?
Are the necessary expertise and data accessible?

Yes.

Stage 3, Tier 1

Preliminary climate change risk assessment

Describing risk screening by the forestry and scientific consultants.

1. What is the lifetime of your decision? Over what period are the benefits of the decision expected to be realised? This will inform the choice of climate scenarios to be used in future analysis, and how they are interpreted.

Timescales have been established by the decision-maker and his consultants (see Stage 2 'Key questions for decision-maker' (1) and (3)). The benefits of the decision are expected to continue to be realised far beyond the immediate period of assessment.

2. Which climate variables are likely to be significant in relation to meeting your decision criteria?
Does information on past variability in climate or past extremes of weather indicate potential vulnerability to climate change?

Research by the FC and other organisations enables expert judgement and qualitative assessments of climate influence to be used to identify potential constraints on the enterprise under consideration.

Preliminary risk screening indicates 12 climate variables that may influence forestry yield, operational management, and other forestry benefits and impacts.

Appendix 1 – Case Study

Vulnerability to changes in mean climate may be less obvious, and therefore more difficult to foresee than vulnerability to changes in climate extremes.

Windthrow represents a potentially serious forestry risk, which might worsen with climate change.

For example, major influences of climate on tree growth and yield are likely to be associated with increased carbon dioxide (CO_2) concentration, changes in summer precipitation and annual and seasonal average temperatures. Expert advice suggests that, for the species being considered, increased tree growth is associated with increased CO_2 concentration, increased average annual and seasonal temperatures, increased summer rainfall and decreased late summer soil moisture deficits, while reduced growth is associated with reduced temperatures, decreased summer rainfall and increased late summer soil moisture deficit. The different species being considered are known to differ in their sensitivities to these climatic variables. Growth is known to be particularly sensitive to reductions in late summer rainfall below threshold values. These thresholds depend upon the species being considered.

Windthrow represents a serious forestry risk, and the risk increases with average wind speed and storm frequency. Forestry operations are also sensitive to the level of precipitation. Restrictions on operations such as harvesting that might damage wet soils and increase erosion risks may need to be imposed when cumulative rainfall exceeds certain levels.

It is possible (though unlikely) that the presence of woodland on the site could impact favourably on flood risks downstream. For this catchment, based on past data, a significant flood risk is associated with rainfall events with a return period of 50 years. However, as this is not yet a 'marketable' benefit it is unlikely to impact on the business case. The presence of woodland may aggravate low flows in streams in late summer, affecting migratory fish and breeding habitat. The frequency of low flows sufficiently serious to affect fishery interests, based on the period 1961-1990, is thought to be 1 year in every 8 to 10.

Increased fire risk can also be associated with increased recreational use of forestry and, to a certain extent, vegetation type. Established fire risk assessments identify rain-free period, relative humidity and wind speed as important climate-dependent risk factors.

Losses from pests and disease vary with respect to some of the species that are being considered. Such losses are believed to be dependent on climatic as well as other factors.

3. How might future changes in these climate variables affect your decision and ability to meet your decision criteria?

The overall impact of climate change on tree growth, forestry operations and environmental impacts of forestry will depend on the balance of change in these variables over the longer term. However, overall quantification in terms of changes in forestry yield, operating costs, and impacts will be very uncertain.

Are certain climate variables likely to be of greater significance than others?

Judgements should be based on information contained within the latest UKCIP climate change scenarios. Climate analogues may also be helpful.

Changes in the frequency and magnitude of extreme values of climate variables are more difficult to predict, and more uncertain, than changes in mean values.

The more serious impacts on yields would probably be associated with a change in the wind climate towards higher mean wind speeds and frequency of storm events. Again, the forest types being considered differ in their sensitivity to extreme winds. Future forecasts of these variables are subject to high uncertainty, and they do not currently fall outside the envelope of natural variation for the UK, making this a 'low probability – high uncertainty – high consequence' risk for those particular species at risk. However, sophisticated wind-risk modelling available from the FC for forest management means that the risk of windthrow can be kept under review, and management measures to control it instituted, if forecasts of a worsening wind climate harden.

The consequence of possible increases in winter rainfall for present day and future forestry operations, and levels of investment in soil and water management protection measures, will need to be considered.

Reduced late-summer river flows might become more frequent under scenarios of decreased summer rainfall. Such an outcome could harm conservation value and have a deleterious effect on fish stocks. This risk will merit further hydrological analysis and discussion with the EA and FC; its control could impose constraints on the total area afforested and on forest design either now or in the future. Against this, partial shading of water by properly managed riparian woodland will improve the freshwater environment under present-day conditions, and could provide increasing benefits under increased summer temperatures. This is a no regret benefit.

How the incidence of forestry pests and diseases might change under differing climatic conditions is the subject of ongoing research and is uncertain. Forecasts for many tree species and diseases are not available, but analogue climate conditions are believed to provide useful models in some instances. Current research indicates that spruces may be increasingly adversely affected by aphid attack under all current scenarios of future climate.

The consultants conclude at this stage that climate change could influence species choice and forest design, and will generally underline the desirability of trying to establish a robust ecosystem and flexible management ethos. These qualities are, in any event, fully consistent with the needs of multi-purpose and sustainable forestry in the UK, and with the owner's objectives.

4. If an initial portfolio of options exists, is it possible at this stage to judge the potential significance of the impacts of climate change to the options?

Initial consideration of the variety of options available (see Stage 4 (1) overleaf) suggests that yields, forestry operations and costs, and environmental and community benefits will differ between the options. Each will differ in its sensitivity to various climate and non-climate-dependent factors recognised above. These conclusions are summarised in a report by the consultants.

Is the risk posed to certain receptors likely to be of key importance to the choice of option?

5. **Is there uncertainty regarding forecasts of particular climatic hazards, or their associated impacts? Can the level of confidence associated with particular hazards and their impacts be determined?**

Reference to the latest climate change scenarios (Hulme *et al*, 2002) suggests that the variables identified as important are forecast with differing levels of confidence. The forestry experts decide to compile a screening report summarising:

(i) the known sensitivity of yield estimates, forestry operations and environmental impacts associated with each tree species to each climate variable. Variables will be examined individually and in defined combinations.

(ii) local data on each climate variable (monthly mean values +/- 1 standard deviation, 3 sites, 1980-2000);

(iii) the forecast changes in the most directly relevant variables available in information obtained from www.ukcip.org.uk/scenarios, taken between two 30-year periods (1961-1990 and 2006-2035) for each of four scenarios;

(iv) estimates of confidence associated with the forecast changes in each variable.

6. **Can any climatic variables, or impacts be screened out at this stage?**
For example, because they are not likely to affect the choice of option or would apply equally to all possible options.

Of 12 climate variables considered initially, it is agreed that four variables can be excluded from further consideration because their influence on successful forestry management of the species likely to be under consideration (see Stage 4 (1)) are considerably less important than other climate and non-climate variables. Two additional variables are excluded from the assessment of climate change impacts on the basis that expected changes in the three-month mean values over the period being considered are less than 10% of observed variability (based on +/-2 standard deviations of comparable three-monthly averaged data). The basis of these opinions is recorded.

7. **What other (non-climate) factors could also be relevant in relation to meeting your criteria?**

Of most importance will be the extent to which the different forestry options meet the criteria needed to pass EIA and obtain grant funding. Consistency with the Wales Forestry Strategy, compliance with the UK Forestry Standard, the probability of long-term environmental improvement, levels of employment and social acceptability will all be very important.

The particular characteristics of the site and its surroundings (e.g. geology, relationship to critical loads, aspect, slope and access) will affect tree yield, forestry management options, operational costs, and the level of risk associated with potential environmental benefits and disbenefits. These are included for further assessment in Tier 2. Forestry management practices can be used to increase yield and reduce impacts, and the consideration of these in relation to each forestry option is part of the standard assessment process.

Certain management options might be available to reduce wind blow and fire risk.

Factors not dependent on climate and the exposure unit should also be considered (see Stage 2) but they are not considered further here.

Stage 4, Tier 1

1. What type of options should be considered? What are the likely consequences of the 'do nothing' option, or of not adjusting existing options to take account of forecast changes in climate?

Harvesting of short-rotation coppice may be constrained by increasingly wet soils.

2. If the risk assessment stage has identified climate change as a significant factor for your decision, then can options be identified that are more robust to climate change? Generic climate adaptation strategies may help identify specific options appropriate to the particular problem.

Initial options identification

The consultants have identified a variety of options that might meet the landowner's specific objectives. They are:

(i) short-rotation poplar or willow coppice (SRC) (to exploit market and subsidies for the production of renewable energy sources);

(ii) mixed broadleaf woodland (to enhance conservation and amenity value, and supply of hardwood timber, especially for local niche markets such as wood-craft and furniture);

(iii) single species of fast-growing conifer, for a variety of general uses (construction, pulp, biofuel);[19]

(iv) mixed conifers for a variety of general uses (construction, pulp, biofuel);

(v) production of Christmas trees.

Associated with each option are a range of forestry management practices. Options (i) – (iv) may also attract investment from 'carbon traders' and the consultants will investigate this market.

Options (ii) and (iv) are considered to be more robust for the climate change risks identified in the initial analysis. SRC (a clonal crop) is vulnerable to pest and disease under present climate and these might become increasingly difficult to manage under climate change. The frequency of harvesting may be constrained by increasingly wet soils. It has a high water demand and could impact more adversely than other broadleaved options on stream flows under scenarios of decreasing summer rainfall. Moreover, it has a limited present-day, and uncertain future market, which could decline if research identifies more efficient forms of renewable energy or if lowland farms, with higher potential productivity, move towards energy crop production. Option (iii) would represent an increase level of risk due to the dependence on a single tree species. The main candidate conifer (Sitka spruce) may suffer from increased insect attack and possibly windthrow. All conifer options have to recognise increased risks of acidification which, although linked to other drivers of environmental change, are modified by climatic factors such as rainfall.

Nonetheless, all woodland options could represent a clear benefit to the environment, compared to existing uses, through a reduction in diffuse pollution of water from soil disturbance and from input of fertilisers, pesticides, faecal bacteria and parasites such as *Cryptosporidium*.

[19] That is, a single species of conifer over the maximum proportion of the scheme allowed in the UK Forestry Standard.

3. **Can 'no regret' and 'low regret' options be identified?**
    Potential no regret options would perform well under present-day climate, and under all future climate scenarios.

Options (ii) and (iv) could, arguably, be described as low regret. Timber prices are currently at a historic low and such that the foregoing of a highly productive conifer in favour of forestry with higher conservation and amenity value is not as obvious a financial sacrifice as it would have appeared in the recent past. Options (ii) and (iv), because of the greater variety of tree species with associated beneficial uses, are likely to be more robust to the consequences of climate change than other options.

4. **Can the options be defined in a flexible manner to allow for sources of uncertainty?**
    e.g. Can adaptation options be identified that could be increased at a later date, or implemented separately or in combination or in sequence to provide flexible levels of response to risk? For example, could staged options be appropriate?

Yes – through initial forest design and ongoing management practice. It is appreciated that a combination of options might provide a lower exposure to both climate and non-climate risks.

5. **Delay is a possible option. Would it be feasible or advisable to delay making a decision until further information is available? Consider: the rate of climate change vs. the timescale for implementing the decision, the magnitude and nature of the risk (especially in relation to low probability high consequence events that are also highly uncertain), the value (reduction in uncertainty) to be gained from improved monitoring or research to better characterise the climate hazard (including climate scenarios and ensembles), exposure pathways, impacts and costs, and the effectiveness of risk reduction and management options.**

There would be a case for delaying decision until the review of grant aid in Wales is completed. Climate change should not be a reason for delaying a decision: (i) the risk of failure of any particular forestry option is unlikely to be strongly dependent on changes in climate; and (ii) further research on future climate changes, or forestry sensitivity to climate, is unlikely to reduce decision uncertainties within a timeframe relevant to the decision-maker.

Stage 5

1. **How do these options rate in relation to the criteria and risk assessment endpoints established at Stage 2, and as informed by the Stage 3 risk assessment?**
    Where there are multiple criteria, MCA techniques may be used.
    Can different levels of confidence be

Initial options appraisal

Initial screening of the options against the criteria established in Stage 2 suggested that:

Option (iii) (single species of conifer) could fail to gain approval for grant aid and might also fail to meet the criteria of a successful passage through EIA. It is also in conflict with the owner's desire to establish a sustainable and robust ecosystem and has the drawbacks identified in Stage 4 (2) above. It is a high-risk option and was rejected.

attached to the likely performance of different options? If so, what are they?
Can particular options be confidently excluded because they are unlikely to meet the acceptability criteria?

Option (i) (short-rotation coppice) over the whole area could fail EIA and may be vulnerable to pest and disease. Nonetheless this management system was retained in the appraisal as a potential use that would be viable for part of the area and that would generate a rapid return on investment.

Option (v) (Christmas tree production) would not qualify for grant aid, though it would have to go through EIA, where it might also have a difficult passage. Moreover, it would fail to satisfy the owner's desire for a forestry estate and would compromise the environmental benefits of decreased pesticide use in switching from agriculture to forestry. It was rejected as an option for the whole area but retained in the analysis as a potentially valuable cash crop that would generate a rapid return on investment – and one with a more certain market than option (i).

Options (ii) and (iv). Option (ii) (broad-leaved mixed woodland), could attract higher grants under national forestry policies to encourage the expansion of native woodland and might, like option (iv), be able to penetrate a number of markets including that for woodfuel. It could also attract less opposition from stakeholders and be less likely to interfere with water quality and yield than any other option. However, establishment costs would be high. Option (iv) is likely to have higher productivity than (ii), but climate change might lead to increases in productivity of trees planted under either option.

2. **Do you need more precise definitions (operational definitions) of these criteria to appraise the options?**

Operational definitions of the financial and environmental objectives set by the landowner provide adequate criteria, and will be subject to Tier 2 risk assessment.

3. **Would other criteria have led to a different form of options appraisal?**

The consultants will assess each option against a wider range of criteria in order to determine the acceptability of the different options to different stakeholder and interest groups.

4. **Would further, more detailed Stage 3, 4 or 5 (Tier 2 or Tier 3) assessments provide a basis for improved discrimination between options, or help develop better options?**

Further assessment would allow particular issues identified during Tier 1 assessments to be examined in more detail, and might help resolve uncertainties concerning certain options. (See text below summarising Tier 2 assessment.)

5. **Have you identified, during Stage 3, the risks associated with implementing each option?**

Major risks associated with the options have been identified above. Risks associated with the implementation of options (ii) and (iv) include a contractual obligation to repay any grant-in-aid received should the forest fail to become established within 10 years.

6. **Could the options being considered possibly constrain other decision-makers' ability to adapt to climate change (i.e. contribute to**

As a result of the risk assessment, the possible increase in the severity of low river flows has been identified as a potential risk. However, the presence of well-designed riparian woodland can have a positive impact through shading. The consultants will undertake a

climate maladaptation)?
Options that may constrain climate adaptation can be difficult to identify at Stage 1 and 2, and may only become apparent during or after Stage 5 appraisal of options. Other options might be identified (Stage 4) to either avoid or mitigate the maladaptive effect.
If it is believed that the options being considered may adversely affect the ability of other decision-makers or stakeholders to manage climate change risks in the future, their interests and involvement in the decision-making process should be considered.

further assessment of the risk, advise on the relative risk of each option, and if appropriate, propose measures that might reduce any risk. In doing so, they will take account of advice from the FC and Environment Agency. (See also Stage 6, Question 8.)

Conclusion of Tier 1 risk assessment, options identification and options appraisal

Risk screening identified a number of climate variables that affect forestry yield, operations and environmental consequences of forestry and, of those, a subset that due to climate change may lead to changes in annual forestry product yields over a period of 20 - 30 years. The interaction of trees and precipitation has implications for water quality and quantity in the catchment. Some of these need to be followed up because of potential impacts on fish stocks, other aspects of freshwater habitat quality and water supplies. The consultants recommend that full Tier 2 procedures are followed for a forestry investment appraisal using standard (i.e. current climate) data. They also recommend that advice should be sought from the FC and others on whether quantification of the impacts of climate change on yield and species suitability, forestry operations and environmental consequences would be feasible at reasonable cost. Scientific expertise would be required to examine UKCIP climate change scenarios for the region with respect to rainfall, and to evaluate the risk of deleterious effects of low flows on fish stocks. The latter would be worth some investment as it could represent a risk, prejudicing successful passage through EIA.

Woodland may increase the risk of low stream flows in summer, but can also decrease the risk through shading.

Options had been identified at the outset, and the risk assessment structured in a way, that allowed flexibility in defining new options involving forestry use. Tier 1 appraisal had allowed one option to be excluded but clearly revealed that mixing of options could be preferred. At this stage, the remaining options will be further refined. In particular, new options will be identified that start to subdivide the area for the generation of mixed options. Risk assessment has noted that riparian areas will require special management and could

Christmas trees can generate an income quickly.

provide a focus for areas of native broadleaved woodland. The lower ground close to access routes might provide suitable sites for a 'cash crop' of short rotation coppice and Christmas trees.

Summary of Tier 2 risk assessment, options identification and options appraisal

Within the Tier 2 assessment, the guidelines are again followed. Individual responses to the guideline questions are not identified here. Instead, an overview of the Tier 2 risk assessment and options appraisal is presented.

Tier 2 risk assessment and options appraisal commenced with scientific advice from modellers who advised that the FC's Ecological Site Classification model did not identify any special constraints on species choice associated with climate change in the area under consideration. The physiological models available predicted general yield increases in broadleaves and conifers but could not yet account for possible impacts of events such as summer drought and increased pest losses. The FC confirmed that an experimental model indicated an increasing yield loss in Sitka spruce associated with aphid attack (but this might not cancel out the gain from CO_2 fertilisation and increased temperature). Nonetheless this species will be at risk. The benefits associated with the choice of Norway spruce for a Christmas tree crop might also be at risk in the longer term if they suffer an increased frequency or intensity of aphid attack under warmer conditions. Qualitative advice also warned against using more southerly provenances (with faster growth rates) as reduction in frost-days did not equate to invulnerability to serious loss from frost.

Hydrological advice from the EA and FC indicated that, for the size of scheme proposed, low flows in summer would not be a significant problem assuming good design and compliance with Forests and Water Guidelines. It was noted that under certain conditions met by parts of the site, afforestation could actually improve summer flows. Option (ii) was determined to represent the least risk to summer flows. Further appraisal was then based upon:

- quantitative analysis using existing data and information on forestry yield, operational costs, and environmental impact assessment;
- assessment of grant-aid available; and
- market research based on local interviews, review of existing literature and expert judgement;

in order to estimate the likely commercial future value of forestry products.

In terms of forestry product yield, the consultants considered a risk-based approach that would aim to estimate the probability of achieving particular annual yields, under a range of present-day and future climate scenarios, for the variety of tree species being considered under the remaining options. However, the underlying methods were not considered to be robust, and too costly for this particular project. They might be appropriate for a Tier 3 assessment, perhaps as part of a wider future forestry strategy for the region. Instead, they recommended that a qualitative modelling approach based upon Ecological Site Classification that could identify areas where, based principally on soil moisture deficits, certain species would fail to make timber size within the assessment period.

Based on their market research, the consultants presented a range of incomes from potential forest products. These forecasts took account of a wide range of information sources including recent trends in demand for wood products and assessments of the future market for other forestry products.

Forecasts were combined into an investment appraisal that noted potential qualifications due to climate change and other factors against each option. For example: yield would probably increase for all options; if a decrease in return period for major storms occurred, conifers (option iv) would probably be at more risk than native broadleaves and both high-forest systems (ii and iv) at greater risk than SRC and Christmas trees. The largest uncertainty relates to the future markets for all timber products, including biofuel. The single-market crop SRC bears the highest level of uncertainty, and therefore risk.

The Tier 2 options appraisal report also included:

- an analysis of the risk factors associated with each option, and possible risk management measures;
- environmental impact assessments for each forestry option. (This included the results of consultation with other key stakeholders.)

Stage 6

1. Is there a clear 'preferred' option? If not, you may need to gather more information and return to the 'assess risk/identify options/appraise options' loop.

Make decision

The report based on the risk assessment and options appraisal concluded that there was not a clear preference between options (ii) and (iv). However, on the basis of market analysis, less uncertainty was associated with products from option (iv). Option (iii) had already been ruled out on the basis that it was least likely to meet the agreed decision criteria. Options (i) and (v) were not acceptable on the whole area though represented higher returns within 15 years than other options (grant-aid aside).

The risks associated with future climate change were determined to be small in comparison to the uncertainty in the possible value of the products associated with the two options. The potential constraints imposed by additional risk management measures were less than those already required to meet exacting environmental standards, especially with regard to protection of water quality and quantity. The consultants recommended that as this was an extremely long-term enterprise and research was improving predictions constantly, the operation should be kept under review and options reappraised every rotation – as is normal forestry practice. It was not felt that the uncertainties in the non-climate risks could be resolved by further Tier 3 assessment of these risk factors.

2. Could the adoption of different criteria (including any weights applied to criteria) and approach lead to the choice of a different option?
If not, you should have reached a robust decision.
If so, you have not necessarily identified the best option.

The criteria were based upon grant income, forestry product income, minimising costs, and the environmental and social benefit associated with a sustainable forestry development. Of these, the probability of obtaining grant income, and passing an EIA, is critical to the decision, and tied to the environmental and social criteria. The analysis has not suggested that the criteria established are inappropriate.

3. If there is not a clear preferred option:
Did you define your problem correctly at Stage 1, or could it be re-defined?
Were the criteria chosen in Stage 2 adequate? If not, do you need better criteria?

The consultants recommended that the risks associated with forestry use could be reduced, and certain additional net benefits realised, by a mixed strategy that implements options (ii), (iv) and (v) and lays plans to substitute (i) for (v) should the CHP plant materialise. That is, they identified a new diversified and flexible option. In particular they noted that:

- Short-rotation coppice and Christmas trees can both generate an income quickly and the latter is an assured market at present. However, this choice should be rapidly re-examined if the proposed CHP plant went ahead and medium- or long-term contracts – and possibly grant-aid – became available.
- Income might be increased by entering into a 'carbon agreement' with entrepreneurs, though this was a buyer's market and the contract terms needed close attention based on assessment of risk.
- Diversified forestry will spread the risk that climate change will adversely affect particular tree species, and the risk associated with changes in the market value of particular forestry products.
- Diversified forestry allows a better match of species to the variable conditions for tree growth in the area, and will have positive environmental impacts. In terms of climate change, this is a no regret option.
- Diversified forestry allows social and environmental values to be realised and is closer to the ideals of sustainable forest management (the owner's principal objective and the focus of forestry policies throughout the UK) than any single option identified in the initial appraisal.

4. Has the specification of the problem and objectives under Stage 1 proved adequate in light of analysis under Stages 2-5?

For example, additional issues, additional or better criteria may have become apparent during Stages 2-5, particularly as a result of wider stakeholder involvement.

If climate change was not part of the initial problem, but risk assessment indicates that climate could be a significant risk factor, the problem may need to be re-framed in order to include climate adaptation objectives and identify potential adaptation options.

This was a very specific problem that was well-posed. Issues identified during the assessment process did not require the problem to be re-framed. Other options, beyond forestry, could have been considered, but were excluded by the specification of the problem. Had no forestry option provided a suitable prospect with an acceptable level of risk, the problem would need to be re-framed.

5. Does the manner in which risk and uncertainty was accounted for allow for robust decision-making?

Yes. In particular, the reports identify risk factors, uncertainties and key assumptions. They are based upon known dependencies between different risk factors and consequences for forestry yield, operations, and environmental consequences. The reports provide qualitative assessments of the probability of not meeting the decision-maker's objectives in accessible language, based on past experience, and the latest research advice.

6. Does the assessment provide a clear understanding of the importance of risk and uncertainty?

Are information and data presented in a form that decision-makers can readily use?

Are circumstances described (e.g. climate or non-climate scenarios) where the decision might fail to meet the established criteria?

Yes. If implemented, the proposed forestry development would have a range of social, economic and environmental implications. The environmental impact assessment identified possible consequences for environmental management. Only those with specific implications for climate adaptation are considered here. These include:

(i) may help mitigate future flood risk within the lower catchment (though the effect is likely to be small);

(ii) may increase the fire risk to privately owned properties located in areas subject to forestry use;

(iii) may decrease the risk of soil erosion, by stabilising the banks of watercourses and increasing infiltration of areas compacted by overgrazing (risks of increased erosion from road-building and harvesting can be controlled by good practice);

(iv) will provide a recreational resource and tourist attraction that may become increasingly valued under more rapid or extreme climate change scenarios;

(v) may provide a wildlife refuge for species threatened by habitat change as a result of climate change elsewhere.

Of these, (i) (iii) (iv) and (v) are potentially beneficial, while (ii) is potentially detrimental. However, this is regarded as a small risk that can be controlled by appropriate risk management measures.

7. **Has the decision-maker's attitude to risk and uncertainty changed as a result of the assessment (particularly with regard to risks associated with climate change)?**
   If so, the decision-making criteria may need to be redefined (Stage 2).

No. The analysis of the risks associated with the decision has been informative, and helped the development of a risk conservative forestry strategy. It has not led to the decision-maker wishing to adopt a less risk-averse attitude to the forestry development.

8. **Does the decision arrived at have implications for others' decisions? Will it help or constrain climate adaptation by other decision-makers? (see Stage 5, Question 6)**
   If the latter, the problem may need to be reframed under Stage 1 and/or further criteria developed under Stage 2.
   The interests and involvement of other decision-makers or stakeholders in the decision-making process should be considered.

The analysis of environmental risks associated with the development suggest that the proposed forestry development is unlikely to hinder or worsen the scope for climate adaptation by other decision-makers. The risk of reduced flows is not certain. The preferred option provides the least additional risk of reduced summer river flows and water levels, confined to parts of the catchment. The development may also help to maintain stream flows under some circumstances. The potential impacts on the hydrology of the wider catchment may require monitoring and management adaptations in future. A decision to use all or parts of the catchment for forestry is, potentially, one that could be revised or reversed in the future. The forestry may also provide incidental adaptation benefits, such as offsetting possible increases in extreme winter flows associated with increases in rainfall intensity.

Appendix 2
Glossary

Glossary

Adaptation. See **climate adaptation**.

Adaptive capacity. The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in climatic conditions.

Ambiguity. A characteristic of a system or decision where there is only vague belief concerning the probabilities that certain states or outcomes may occur. A form of uncertainty.

Annual or decadal average frequency. The expected mean number of occurrences of events of particular magnitude over a particular period of time (e.g. a year or decade).

Appraisal. The process of examining options and assessing their relative merits. It is normally used to describe analysis prior to implementation. See **evaluation**.

Appraisal period or **life**. The period of time over which a return on an investment or other benefits resulting from a decision are expected to be realised.

Audit trail. In a non-accounting sense: evidence in the form of references, data or documents that enables an investigator to trace the path of past actions or decisions.

Best-case. An assessment of risk based on optimistic attitude to uncertainties concerning probability and impacts or opportunities. Sometimes used to provide a lower bound to estimates of risk. See also **Worst-case**.

Catastrophic failure. A characteristic of a system such that, when a particular threshold is exceeded, the performance of the system deteriorates rapidly.

Characterisation. The process by which the properties, observed and predicted performance of a system are expressed in order to support good decision-making.

Climate adaptation. The process or outcome of a process that leads to a reduction in harm or risk of harm, or realisation of benefits, associated with climate variability and climate change. See also **mitigation**.

Climate change scenario. A coherent and internally-consistent description of the change in climate by a certain time in the future, using a specific modelling technique and under specific assumptions about the growth of greenhouse gas and other emissions and about other factors that may influence climate in the future.

Confidence. An estimate or measure of (un)certainty. May be expressed descriptively and/or semi-quantitatively, or quantitatively (see **Confidence interval**).

Confidence interval. A quantitative estimate of the degree of uncertainty associated with a statistic or other estimate. Confidence intervals are described by upper and lower limit values associated with a particular level of confidence. For example, a confidence level of 90 percent can be used to define upper and lower bounds for an estimate, and indicates that there is a 90% chance that the estimate lies within the specified interval. The true value either does or does not lie within these bounds. Confidence is not the same as **probability**.

Consequence. The end result or effect caused by some event or action. Consequences may be beneficial, neutral or detrimental. A detrimental consequence is often referred to as an impact. May be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected).

Coping range. The range of variability described by a climate variable, climate-related variable or proxy climate variable whose consequences or outputs can be measured in terms of tolerable levels of harm or risk. The excedance of the coping range is expected to result in harm (Jones, 2001).

Correlation. A measure of the extent to which a change in one random variable tends to correspond to a change in a second random variable.

Criterion. Any rule or standard by which something can be judged and a decision reached. Examples of criteria include the well-posed and specific objectives established by a decision-maker and **risk assessment endpoints**. The methodologies by which different options are appraised (for example **cost-benefit analysis**, **cost effectiveness analysis**) represent different decision criteria. Attitude to risk can also be used to establish criteria to include in a decision-making process (see **risk attitude**). **Multi-criteria analysis** can help incorporate a wide-range of different decision criteria.

Decision objective. The intention put forward by the decision-maker that is to be achieved by implementing a decision or sequence of decisions.

Dependence and independence. The manner and extent to which one variable depends on another variable. Under statistical independence, if B is not dependent on A, then B is also independent of A. Where there is uncertainty as to the dependence between two variables or parameters, the importance of assumptions concerning dependence can be examined through by assessing independent and dependent cases (see **sensitivity analysis**). Influence diagrams are a technique to help identify dependence between variables or system components. Mutual independence of preferences describes cases in which scores assigned to options under one criterion are not affected by the scores assigned under another criterion. Statistical independence is stronger than independence of preferences (see DTLR, 2001a for more details).

Deterministic process, method or model. A process, method or model where the values of each input, variable and parameter have single, defined values at any point, resulting in a single value for each output variable. See **stochastic process, method or model**. Stochastic methods may be applied to deterministic models.

Ensemble. The term 'ensemble' refers to a set of simulations (each one an ensemble member) made by the same climate model, using the same emissions scenario, but initialised at different 'starting conditions' of climate. Hence the difference in climate between ensemble members is a measure of the natural internal climate variability. The UKCIP02 scenarios are 'ensemble means' produced by averaging individual ensemble members.

Environmental pathway. The connected set of processes, media and structures through which a potentially harmful event or substance may come to act upon a receptor. This term is usually applied to the environmental processes by which substances (e.g. water, chemicals) are transported from source to receptors.

Evaluation. The process of examining options and assessing their relative merits. In UK Government it is normally used to describe analysis after implementation of the preferred option.

Expected value. For an alternative outcome, obtained by multiplying each outcome or payoff by the column probability and summing the products; the mean.

Exposure unit. The system considered to be at risk. The exposure unit will often be defined in terms of geographical extent and the location and distribution of the populations of **receptors** at risk. In some cases the exposure unit and receptor may be synonymous.

Extreme value distribution. A particular family of probability density functions used to describe the probabilities of extreme values, such as annual maximum (or minimum) daily temperature. See Coles (2001).

Forecast/prediction. An extrapolation or projection of the state of a system, or value of a variable, based on available knowledge or information and

defined assumptions. Forecasts are usually either temporal and/or spatial extrapolations. Temporal extrapolations can be forward (forecast) or backward (hindcast). Where uncertainty can be estimated and a level of confidence can be assigned to a climate or other projection (see below), it becomes a forecast or prediction.

Global Climate Model (GCM). Computer models designed to help understand and simulate global and regional climate, in particular the climatic response to changing concentrations of greenhouse gases. GCMs aim to include mathematical descriptions of important physical and chemical processes governing climate, including the role of the atmosphere, land, oceans, and biological processes. The ability to simulate sub-regional climate is determined by the resolution of the model.

Greenhouse gas. A number of anthropogically produced and naturally occurring gases whose presence in the atmosphere traps energy radiated by the Earth. Carbon dioxide is the most important greenhouse gas.

Harm. Synonymous with detrimental consequence or impact.

Hazard. A situation or event with the potential to cause harm. A hazard does not necessarily cause harm.

Impact. A beneficial or (more usually) detrimental consequence. See also **harm**.

Independence. See **Dependence**.

Integrated risk assessment. An approach to the management of risk that includes all sources of hazard, pathways and receptors, and considers a wide combination of risk management options.

Joint probability. The probability of specific values of one or more variables occurring simultaneously (or sequentially) to affect a particular consequence. For example, high water levels in estuaries can depend on the likelihood of particular river flows, tidal heights, and offshore cyclonic conditions. In order to estimate the likelihood of high

water levels, the joint probability of these events will need to be considered.

Likelihood. A general concept relating to the chance of an event occurring. Generally expressed as a probability of frequency. See also **maximum likelihood**.

Limited or **low regret options**. Options for which the implementation costs are low while, bearing in mind the uncertainties with future climate change projections, while the benefits under future climate change may potentially be large. (See also **no regret options**).

Maximax. An optimistic approach to decision-making under uncertainty; select the alternative with the best single payoff. See also **Minimax, Maximin**. See **Decision Analysis** in Appendix 3.

Maximin. A pessimistic view of the possible outcomes of the decision process under uncertainty; select the alternative with the best of the worst payoffs. See also **Minimax, Maximax**. See **Decision Analysis** in Appendix 3.

Maximum likelihood. A method used to estimate values of unknown model parameters. In essence, the best estimate of an unknown parameter is that value that was most likely to have given rise to a particular set of observations. Maximum likelihood methods generally allow estimates of confidence to be associated with parameter estimates.

Minimax. A pessimistic view of the possible outcomes of the decision process under uncertainty; select the alternative with the worst of the best payoffs. See also **Maximin, Maximax**. See **Decision Analysis** in Appendix 3.

Minimax regret criterion. A cautious approach to decision-making under uncertainty; the absolute value of the difference between the payoff associated with an alternative-scenario or event pair and the highest payoff for any decision in the scenario column of the pay-off matrix. See **Decision Analysis** in Appendix 3.

Mitigation (in context). In the context of risk management, any action to reduce the probability and magnitude of unwanted consequences; see Armstrong (2001). Hence, adaptation to climate change is a strategy undertaken to mitigate the risk associated with future changes in climate. In climate change policy, mitigation refers specifically to the reduction in greenhouse gas emissions, which is an example of risk management.

Model. In its broadest sense, a representation of how a system works, or responds to inputs, and may be used as a basis of risk assessment, analysis or management by decision-makers. A model may be anything from a conceptual framework through to a fully parameterised and validated numerical representation of a system implemented on a computer. See also **Modelling tools** in Appendix 3.

Natural variability. Uncertainties that stem form inherent randomness or unpredictability in the natural world. Variability can be characterised by monitoring or other programmes of observation, by models that include stochastic processes, or deterministic models that are sensitive to their initial conditions, such as GCMs.

No regret (adaptation) options (or measures). Adaptation options (or measures) that would be justified under all plausible future scenarios, including the absence of man-made climate change. A no regret option could be one that is determined to be worthwhile now (in that it would yield immediate economic and environmental benefits which exceed its cost), and continue to be worthwhile irrespective of the nature of future climate. (See also **Limited** or **low regret options**.)

Objectives. The purposes which an organisation or decision-maker wishes to achieve in areas of concern. Broad overall objectives, or ultimate objectives, are broken into lower-level tiers which are more concrete, These may be further detailed as sub-objectives, immediate objectives, or **criteria** which are more operational, and can provide a basis for defining **exposure units** and **assessment endpoints** for risk assessment.

Opportunity loss. The difference between a given payoff and the best payoff for a scenario or state of nature. See **Minimax regret**.

Options. Ways of achieving objectives. Options might be policies, programmes, projects, schemes, systems, technologies or anything else presenting a choice, about which a decision is needed. Options may be mutually exclusive (A or B), or could be implemented individually or in combination (A and/or B).

Over-confidence. A potentially vulnerable state of underestimating uncertainty. There is a large body of evidence from cognitive psychological experiments and surveys showing that decision-makers and technical experts overestimate their own abilities, knowledge, and the precision of the information used to justify a particular choice or decision.

Parameter. Strictly, a fundamental property of a system (or model), the value of which, together with the structure of the system (or model), determines the relationship between system components (or variables). However, the term has a variety of common usages and it is often used synonymously with variable (e.g. a climate or water quality parameter).

Pathway. Provides the connection between a particular hazard (e.g. storm-force winds) and the receptor (e.g. insurance company premiums) that may be 'harmed'. The pathway may include the track of the storm, the location of domestic dwellings, nature of roofing materials, the level of consequent insurance claims.

Pay-off matrix. See **performance matrix**.

Perceived risk. Refers to the observation that the individual or public perception of risk may differ from the perception gained by a risk assessor as a result of a technical risk assessment.

Percentile. The value below (or above) which falls a specified percentage (e.g. 95%) of a set of values.

Performance. The creation or achievement of something that can be valued against a stated initial aim, expectation or objective.

Performance matrix. A matrix or table setting out the performance of each option according to each of the criteria by which the options are to be judged. Sometimes referred to as a *consequence table*. A pay-off matrix expresses the performance in terms of monetary valuations. Usually alternatives are listed down the left side of the table, possible future conditions across the top of the table, and the payoffs in the body of the table.

Precautionary Approach. A loose term justifying precautionary action taken as a response to scientific uncertainty. It is often based on a case-by-case basis by the decision-maker. See Green Alliance (2002).

Precautionary Principle. *'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'* (Rio declaration, 1992).

Precautionary Process. A framework for precautionary decision-making based on criteria for decision-making under uncertainty. See Green Alliance (2002).

Probability is used to describe the chance or relative frequency of occurrence of particular types of event, or sequences or combinations of such events. These events may be discrete or described by a continuous variable. An example of a discrete event is the probability that a particular location experiences flooding on one or more occasions during any year. The maximum depth of flooding experienced during each such event is an example of a continuous variable, which can take a range of values with different probabilities. The nature of the probability may be determined by reference to an underlying theory, or be described based upon supporting observations. See **Probability density function**.

(a) **Extremes**. Extreme events are usually defined as events, combinations or sequences of events or circumstances, that occur with low or very low probability, and that may be associated with large or potentially large consequences. It is conceptually straightforward

to analyse data and carry out modelling to establish probabilities of specific events, including the likelihood of extreme events that have not occurred in the data record. Numerous statistical methods exist (see for example Coles (2001)). There are pitfalls in assessing extremes, and several types of uncertainty can be significant. In particular there may be systematic differences between rare and severe events and 'everyday' conditions, and it may be difficult prior to the analysis to determine the critical event type, particularly for multivariate problems. For example, extreme droughts have spatial, temporal and physical (e.g. rainfall quantity and water use) components and a risk analysis under changed climatic conditions may need to take all of these into account. The 'critical' conditions may shift under climate change scenarios so it may not be sufficient to analyse events similar to those in the historical record.

(b) **'Subjective' probabilities**. Probabilities and probability distributions are often used to express or summarise strength of belief. There is continuing debate about the validity of this, however in pragmatic terms there are good reasons to accept the use of subjective probabilities if it helps inform a decision-making process. The following should be borne in mind:

- There should be consistency in eliciting probabilities.
- Probabilities should be elicited from a number of people with similar appropriate experience, knowledge or expertise.
- Some types of uncertainty may not conform particularly well to probabilistic description. For example, in the case of competing models, in what sense is it valid to calculate a weighted result based on the relative 'probabilities' of the different models being correct?
- Most applications of probabilistic analysis assume (by default) that variables are independent. This is a specific constraint which will tend to compress and underestimate

uncertainty. Other assumptions regarding specific correlations between variables or events can be implemented but require additional data.

(c) **Combining probabilistic and non-probabilistic uncertainty**. Different sources of uncertainty may require different actions to resolve. It should not be assumed that all uncertainties should be compressed onto a single probability measure or distribution. The individual components of uncertainty may influence the choice of appropriate risk management measures. For example, if analysis shows that model uncertainty is the chief source of outcome or decision uncertainty, then this implies that effort should be directed at improving models.

There are a number of emerging techniques that are specifically designed to recognise and preserve different types of uncertainty for use in risk analysis. For example, interval analysis can be combined with probabilistic analysis to produce 'hybrid' outputs that provide bounds on probability distributions rather than single 'certain' probability distributions. Using this type of approach a given statistic (such as the magnitude of event with a given probability) is assigned a range or interval representing non-probabilistic uncertainty.

Probability assignment. A numerical encoding, between 0-100%, of the relative state of knowledge.

Probability density function or **distribution**. A function that describes the probability that a variable will take a particular value across the entire range of possible values. For example daily rainfall, annual mean temperature, household flood damage loss. (See also Appendix 3.)

Projection. Any description of the future and the pathway that leads to it. A specific interpretation of a 'climate projection' refers to a climate model-driven estimate of future climate.

Receptor. The entity that may be harmed by a particular set of hazardous events.

Regret. See **Minimax regret criterion** and **Opportunity loss**.

Reliability. The probability a system performs a specified function or mission under given conditions for a prescribed time.

Residual (climate) risk. The risk that remains after risk management and adaptation to (e.g.) climate. See **tolerable risk**.

Resilience. The ability of a system to recover from the effect of an extreme load that may have caused harm.

Response. The reaction of a system to some loading. See **dependence**.

Response function. An equation or other model that links the reaction of a variable system to the loading placed upon it. The loading may be a hazardous event, a decision, or a change in policy. Often referred to as *dose-response function*.

Return period. The expected mean time between occurrences that **equal or exceed** a particular defined, usually extreme or unusual event. Often used to express the frequency of occurrence of the event (= 1/return period). Estimates of return periods are subject to uncertainty, such that consecutive events may occur at intervals greater or smaller than the average return period.

Risk. A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur are precisely known. Risk is a combination of the chance or probability of an event occurring, and the impact or consequence associated with that event. Decisions that involve risk are a special case of uncertain decisions where the probabilities are precisely known.

Risk analysis. The process by which risk assessment is used to develop risk management options to reduce, mitigate or compensate for the risk.

Risk assessment. The process by which hazards and consequences are identified, characterised as to their probability and magnitude, and their significance assessed.

Risk assessment endpoint. An explicit expression of the attributes, associated with a **receptor**, that are to be protected or achieved. Risk assessment endpoints may represent an intrinsic (e.g environmental) **threshold**, or an agreed, policy-defined threshold, at which explicit decisions to manage the risk will be required. A measurement endpoint may be defined for the attribute in terms of the probability that a certain level of performance will be achieved over a defined period of time, and with a specified level of confidence.

Risk attitude. A decision-maker's risk attitude characterises his willingness to engage in risky prospects. He is *risk neutral* if and only if he is indifferent between the risky prospect and the certain consequence. See **risk aversion**.

Risk aversion. In its strict sense, a decision-maker displays risk aversion if and only if he prefers a certain or sure consequence to any risky prospect whose expectation of consequences equals that certain amount. The opposite to risk preferrer.

Risk control point. A point or stage in the causal sequence of events, leading to the probability of an outcome that, as a result of interventions by decision-makers, allow the probability or severity of the outcome to be managed (usually reduced). One aim of risk analysis, e.g. through **event tree** (see Appendix 3) analysis, is to determine risk control points.

Risk estimation. The rigorous determination of the characteristics of risks, usually progressing from qualitative to more quantitative approaches. These characteristics include the magnitude, spatial scale, duration and intensity of adverse consequences and their associated probabilities as well as a description of the cause and effect links.

Risk evaluation. A component of risk assessment in which judgments are made about the significance and acceptability of risk.

Risk identification. The process by which hazards are recognised and characterised. In the case of climate change risk assessment, risk identification is a deliberate procedure to review, and it is hoped, anticipate possible hazards. Risks associated with

climate variability can in general be identified from past experience of climate.

Risk management. Any action or portfolio of actions that aim to reduce the probability and magnitude of unwanted consequences (or vice versa), or manage the consequences of realised risks. See also **mitigation**.

Risk neutral. See **risk attitude**.

Risk reduction. See **mitigation**.

Risk register. An auditable record of risks (hazards, pathways, probabilities, uncertainties, consequences) and their significance, and proposed mitigation and management options.

Risk screening. Following initial identification of hazards and risks, risk screening is the process by which it is determined which risks should be investigated in more detail. Risk screening is usually based on ranking or scoring methods.

Robustness. The ability of a system to continue to perform satisfactorily under load.

Scenario. A coherent, internally consistent and plausible description of a possible future state of the world, usually based on specific assumptions.

Sensitivity. Refers to the change that results (in a system or variable) from a specific perturbation in an input value, parameter value, or other assumption. Therefore climate sensitivity is the degree to which a system would be affected, either adversely or beneficially, by climate-related stimuli.

Sensitivity analysis. A structured approach to investigate how a system, model or assessment responds to small changes in input values, parameter values or other assumption. Sensitivity analysis is used to identify those input values, parameters or model assumptions that have the most significant impact on the outputs or response.

Stakeholder. People, including organisations, who have an investment, financial or otherwise, in the consequences of any decisions taken.

State or **state variable**. The condition of a system or value of system variable at a particular point in a domain (usually time and or space).

Stochastic process, method or **model**. A process, method or model where the values of some of the inputs, variables and/or parameters may take a variety of values at any point. For stochastic methods and models these are often determined by the selection of a value at random from a probability function that represents knowledge of uncertainty or variability associated with the parameter or variable. The result is that each output variable may have multiple values. Stochastic processes are frequently characterised by variables that can take a limited, small number of possible values. See **deterministic process, method** or **model**.

Synoptic. Pertaining to a general view of the whole, hence a synoptic variable is one used to describe the state of system over a wide geographical area.

Synoptic variables. These variables represent features measured over a large spatial domain, e.g. the frequency, intensity or description of the movement of thunder-storms, cyclonic conditions, frontal systems, cloud cover, storm tracks.

System. The social, economic and physical domain within which risks arise, produce consequences, and in which risks are managed. An understanding of the way in which a system may behave is an essential aspect of understanding and managing risk. In particular it is important to identify mechanisms and thresholds by which the system may fail when loaded, and the processes that provide opportunities for risk management decisions.

Threshold. A property of a system or a response function, where the relationship between the input variable and an output or other variable changes suddenly. It can be important to identify thresholds, and other non-linear relationships, as these may indicate rapid changes in risk.

Tolerability or **Tolerable risk**. The willingness to live with a particular level of risk, in return for certain benefits, based upon a certain confidence that the risk is being properly controlled or managed.

Uncertainty. A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known. A concept that reflects a lack of confidence about something, including forecasts. Decision-makers may have more or less certain knowledge of a risk.

Variable. Strictly, a fundamental property of a system (or model) that can take a range of possible values, determined by the values of other system variables and parameters, external inputs or boundary conditions. See also **state variable**. Driving or forcing variables link internal system variables to influences that are external to the model.

Vulnerability. Refers to the magnitude of harm that would result from a particular hazardous event. The concept recognises, for example, that different sub-types of a receptor may differ in their sensitivity to a particular level of hazard. Therefore climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity. Hence arctic alpine flora or the elderly may be more vulnerable to climate change than other components of our flora or population.

Weight. An expression of the importance given to a component of an analysis. For example, different models, expert opinions, or attitudes to climate change risk may be given different weights dependent on the associated level of confidence or pedigree. Weighting is often used in circumstances where it is difficult or impossible to establish a common scale or units of measurement. The use of weighting can be controversial since it can have an important influence on the outcome of an assessment. The importance of the choice of weights for the outcome of an analysis should be examined through **sensitivity analysis**.

Worst-case. An assessment of risk based on pessimistic attitude to uncertainties concerning probability and impacts or opportunities. Sometimes used when assessing the risk associated with low probability, high consequence events (possible catastrophies and disasters). Used to provide an upper bound to estimates of risk. See also **Best-case**.

Appendix 3
Summary of tools and techniques

Summary of tools and techniques

This appendix provides a brief summary of the tools and techniques mentioned in Parts 1 and 2. The table below summarises which tools can be used at each stage of the framework. The range of tools and techniques is not comprehensive, neither will all the tools be equally useful. A UKCIP web-based resource provides more detailed descriptions of the tools and techniques.[20] The web-based resource will allow new tools to be identified, and updated information on the relevance and utility of these tools to climate change risk assessments to be provided to stakeholders and other users.

Outline of tools described and usage by framework stage						
	Could tool be appropriate for Stage …?					
Tool	1 Identify problem and objectives	2 Establish decision-making criteria	3 Assess risk	4 Identify options	5 Appraise options	6 Make decision
AIDA	yes	yes		yes		
Brainstorming	yes	yes	yes	yes		
Consultation exercises	yes	yes	yes	yes	yes	
Focus groups	yes	yes		yes	yes	
Free-form gaming	yes			yes	yes	
Policy exercise	yes			yes	yes	yes
Problem-mapping tools	yes	yes	yes	yes		
Bayesian methods			yes		yes	
Checklists			yes	yes		
Decision/probability trees			yes			
Expert judgement and elicitation			yes			
Fault/event trees			yes			
Climate change scenarios			yes			
Climate typing			yes			
Cross-impact analysis			yes		yes	
Deliberate imprecision			yes			yes
Development of sophisticated modelling tools			yes			
Downscaling techniques			yes			
Interval analysis			yes			
Markov chain modelling			yes			
Monte Carlo techniques			yes			

Outline of tools *continued...*

Tool	Could tool be appropriate for Stage ...?					
	1 Identify problem and objectives	2 Establish decision-making criteria	3 Assess risk	4 Identify options	5 Appraise options	6 Make decision
Modelling tools			yes			
Pedigree analysis			yes			yes
Process influence diagrams			yes			
Scenarios analysis			yes		yes	
Uncertainty radial charts			yes			
Screening				yes	yes	
Contingent valuation					yes	
Cost-effectiveness analysis					yes	
Cost-benefit analysis					yes	
Decision analysis					yes	
Decision conferencing					yes	
Discounting					yes	
Environmental impact assessment					yes	
Expected value					yes	yes
Financial analysis					yes	
Fixed rule-based fuzzy logic					yes	
Minimax, Maximin, Maximax and Regret					yes	yes
Multi-criteria analysis (scoring and weighting)					yes	
Pairwise comparison					yes	
Partial cost-benefit analysis					yes	
Preference scales					yes	
Ranking/dominance analysis					yes	
Risk-risk analysis					yes	
Sieve mapping					yes	
Hedging and flexing						yes
Portfolio analysis						yes
Sensitivity analysis						yes
Robustness analysis						yes
Ranges and intervals						yes

Appendix 3 – Summary of tools and techniques

AIDA (Analysis of interconnected decision areas) provides a structured format for identifying the different drivers underlying a problem and thus for identifying how these may affect the solutions open to decision-makers. Through the structuring process, it also enables the analyst to check for feasible combinations of actions, and it therefore avoids unnecessary effort being spent examining infeasible alternatives. The results can be presented to reflect the associated degrees of uncertainty.

Bayesian methods. In situations of uncertainty there may be limited information on which to construct a model or undertake some form of analysis. However, knowledge of similar situations, or based on a credible hypothesis, expert or subjective judgement, may be available. Bayesian methods allow such prior knowledge to be used and improved upon as further incomplete knowledge becomes available (Morgan & Henrion, 1990). Potential applications within the climate change adaptation field are many. In particular, since historical climate data may represent our best knowledge of past climate and climate variability, new information (from climate models or climate data) can be used to improve our knowledge of present or future climate. Bayesian methods are used in decision-tree analysis in the social sciences, and are included in various decision-support expert systems, such as SIMCOAST (McGlade, 1999). The application of Bayesian methods is generally limited to a few specialists.

Benefit cost. See **Cost-benefit analysis**.

Brainstorming is a useful first-stage tool for understanding and getting to grips with a problem and for generating potential options. A brainstorming session will bring together a mix of individuals with different backgrounds and roles within an organisation and its decision-making processes.

Checklists provide a reference list of items to be verified. They enable the collective wisdom in a particular area to be accessible to less experienced personnel. In addition, they provide a degree of consistency in approach and, in some cases, a degree of reassurance that procedures (such as safety or QA procedures) have been followed.

Climate-typing involves the use of large-scale climate classifications, either indices such as Lamb's Weather Types, or schemes based on statistical grouping methods. Statistical relationships between these climate classification schemes and regional climate are developed and then applied to the large-scale output from Global Climate Models to produce scenario information at a higher spatial resolution. The major assumption with this type of approach, as with any empirical approach, is that the relationship developed under current climate conditions will be valid in a future, warmer world.

Consultation exercises are generally based around some form of document that is sent directly to those who are to be consulted. These documents typically supply a significant amount of information about the issues in question and may provide a useful mechanism for allowing stakeholders to suggest alternative options for tackling decision problems.

Contingent valuation. A method used to imply valuations, most notably in the environmental field, by asking individuals about their willingness to pay to reduce adverse consequences, such as climate change impacts, or their willingness to accept sums of money to put up with such consequences.

Cost-benefit analysis (CBA). A term used to describe the rigorous and consistent appraisal of the merits associated with each option by quantifying in monetary terms as many costs and benefits as possible, including items for which the market does not provide a satisfactory measure of value. CBA is designed to aid the selection of the options with the greatest excess of benefits over the costs and allows the choice of options to be refined. The method requires the use of a common unit, which may be monetary, and may require the use of valuation methods. A key feature of CBA is that it accounts for costs and benefits arising in different time periods, by the use of **discounting** techniques (see later), which emphasise the values of present and near-future costs and benefits over more distant costs and benefits. See HM Treasury (2003), DTLR (2001a), and Boardman *et al* (1996). See also **Partial cost-benefit analysis**.

Cost-effectiveness analysis (CEA). An assessment that compares the costs associated with alternative ways of achieving a specified objective. The aim is to identify the option that can deliver the objective at least cost. Unlike cost-benefit analysis, the level of benefit is treated as an external given, and the objective of the analysis is to minimise the costs associated with the achievement of the specified objective. This objective or level of public good is identified perhaps as a result of negotiation or consultation with key stakeholder groups. CEA can require that a form of CBA be carried out when the costs of achieving the objective are deemed too high. CEA is generally more applicable for individual project decisions that are applying decision rules or procedures that have already been determined in policy, strategic or programme decisions. The costs may include those for which the market does not supply a satisfactory measure of value. See HM Treasury (2003).

Cross-impact analysis is a simulation tool used to assess stable probabilities for interrelated events. It goes one step beyond traditional **scenario analysis** (see later) in that it recognises that risky events are not mutually exclusive and can occur in a variety of combinations, and provides a means of modelling such dependencies. The main aim of this type of analysis is to investigate the effect that the occurrence of one adverse event might have on the probabilities of other adverse events within the same time period.

Decision analysis. Any approach or process that involves the integration of utility theory, probability and mathematical optimisation, and its extension to decisions with multiple objectives, to help identify the most appropriate or 'best' decision option. The theory assumes only that the decision-maker wishes to be consistent in his preferences and decisions. Initially the problem is identified, and a (possibly) comprehensive list of decision options identified. Structural analysis would organise the options into a **decision tree**, carefully distinguishing decision nodes (splitting points at which the outcome is chosen by a decision-maker) and event nodes. Event nodes are points at which the outcome results from stochastic external events, for example the probability that a particular climate event (storm, flood level)

may be observed, or probability that another decision maker makes a particular decision, that influences ones own course of action. Next, **uncertainty analysis** can be used to assign **subjective probabilities** (see **Probability** in Appendix 2) to chance nodes, while utility analysis would stipulate cardinal utilities for outcomes. The pay-off associated with each particular outcome is weighted by the probability that such an outcome might be observed. Finally, optimisation analysis produces the best outcome according to a selected criterion, most typically maximising expected utility, or some other approach that reflects the **risk attitude** (see Appendix 2) of the decision-maker (see Toth, 2000). Where probabilities cannot be used to describe the uncertainty associated with the performance of different options under different future scenarios, decision-making criteria summarising the decision-maker's attitude to risk can be selected to help identify the most suitable option. See **Maximax**, **Minimax**, **No regret** and **Minimax regret criterion** in Appendix 2.

Decision conferencing is a group approach that has been developed around the principles of **decision analysis**. It is an interactive process, allowing for participants to revise options, values, etc. The approach uses a facilitator and an analyst to assist the decision-making group to reach a shared understanding of the problem, thereby reaching an agreed solution. The facilitator is responsible for managing the group process, whilst the analyst makes use of interactive computer software to develop a model of the problem and produce results. See also **Facilitated workshops**.

Decision/probability trees. A diagram that shows the outcomes that may occur for a series of interdependent decisions sequenced over time. The actual outcome of each of the individual decisions at each stage is not known with certainty. Appropriate analysis of the tree allows the decision-maker to develop, from the outset of the decision process, a contingent decision strategy. This indicates what is the best choice to make at each stage in the decision sequence, contingent upon the pattern of earlier decisions and outcomes. See Targett (1996) and Golub (1997). Decision trees are very similar to **event trees**. A tree will consist of the following elements:

- primary branches representing the alternative actions of strategies;
- secondary branches stemming from those representing actions, corresponding to the associated possible impacts;
- square nodes and forks in branches which represent points of decision or actions;
- round nodes and forks representing points of uncertainty in the impacts;
- probabilities for each impact of a chance event, normally written by the relevant branch; and
- end branches for each possible outcome representing the probabilistic final values.

The outcome (or payoff) at the end point of each branch in the tree summarises the consequences of each possible combination of choice and chance.

Deliberate imprecision. Qualitative methods often use descriptions that are to some extent imprecisely defined. This can be a useful format for conveying uncertainty. Ranking systems can be devised to represent different ranges of uncertainty with terms such as 'very likely', 'severe' or 'low impact'. These should be carefully defined to ensure consistency and to reduce bias (Moss & Schneider, 2000). Similar approaches can be used to promote consistent representations of probabilities and qualities of information (see Table 10 in Part 1).

Delphi technique. A well-researched method for soliciting independent forecasts from a panel of experts, with a range of relevant knowledge, over two or more rounds. Summaries of the anonymous forecasts are provided after each round. The accuracy of the forecast should improve after each iteration. Multiple rounds are expected to be particularly beneficial when the panel is small (about five), when misinterpretations are likely, and when the expertise is heterogeneous. Delphi provides more accurate forecasts than unstructured groups. See Rowe & Wright (1999, 2001).

Deterministic modelling. A model where the outcome(s) are determined uniquely by the input(s), and where all elements of the model have single values. Even so, deterministic models may produce outputs that vary in (for example) the spatial or temporal domain. Such variability may be regular and bounded, or irregular and/or unbounded (e.g. chaotic). Such behaviour can then be expressed statistically. Nevertheless, this variability is entirely deterministic. These properties are fundamental to the system represented by the model (i.e. they should not be an artefact of the model). Systems that incorporate discontinuities (thresholds) or other strong non-linear processes, complex feedbacks between processes, and time-delays or lags, tend to exhibit these characteristics. In these cases the forecast of outcomes may be extremely sensitive to the values of the initial variables or parameters. Hence uncertainty in these values means that precise predictions are not possible. Global and regional climate models are of this type. Individual ensemble members are used to investigate the effect of initial values on model predictions. For example, information from individual ensemble members is available from the UKCIP02 scenarios. Each ensemble member differs slightly in initial conditions and hence in the predictions made. A model's ability to forecast into the future may also be limited. Weather models are of this type. No matter how good our data and models, there are fundamental limits to the predictability of the weather and climate.

Discounting. An established technique for treating on an equal basis impacts that arise in different time periods. Benefits and/or costs, which are expected to accrue or be incurred at different points in time, are compared using a discount rate that reflects the decision-maker's relative valuation of benefits at different points in time. The choice of discount rate can be a key factor in determining the best option. Analyses that include the application of discount rates over long periods should be treated cautiously.

Dominance analysis. A technique based on the pair-wise comparison of two options. Where the first scores higher than the second on at least one criterion and no lower on any of the others, the first option is said to dominate the second.

Downscaling techniques. Climate scenarios based on global climate models are not generally available at a resolution suitable for the majority of sub-regional impact assessments that may concern the majority of decision makers. Downscaling refers to techniques that enable the results of **GCMs** (see Appendix 2) to be made relevant to local decision-makers and impact assessment. Downscaling techniques generally involve statistical methods of data interpolation, multivariate regression, weather circulation typing, and **weather generators**. In addition, regional climate models that incorporate greater geographical detail can use data from GCMs to produce climatic scenarios at a finer spatial resolution. While the geographical distribution of climate variation may be improved, the accuracy of this climate is completely dependent on the (largely unknown) accuracy of a particular GCM. More detail on downscaling techniques can be found in Hulme & Jenkins (1998) and Hulme *et al*, (2002). Wilby *et al* (2002) provide an example of a statistical downscaling technique suitable for application to UK-based impact assessments (see Appendix 4).

Encoding methods are useful when there is a desire to include explicitly measures of the degree of uncertainty in the risk assessment and options appraisal. Encoding methods usually involve elicitation of probabilities of uncertain parameters from relevant experts. The aim is to create subjective data on probabilities, with the key assumption that those involved are able to provide the information required. Probability encoding methods can be used to estimate uncertainty in estimates surrounding data, predictions and forecasts in the form of probability density functions or discrete probabilities. Encoding can be carried out using various methods and tools, including probability wheels (see the UKCIP web-based resource for more details[21]).

Environmental impact assessment (EIA) is an established technique for setting out the environmental impacts of options and seeking control measures and alternative options with lower environmental impacts. The conduct of an environmental impact assessment or statement may be a statutory requirement for major changes involving potentially significant environmental impacts. The

aim of an EIA is to integrate environmental considerations at an early stage in the decision-making and planning process so as to identify effective means of reducing these impacts.

Event tree. A diagram that shows the outcomes that may occur for a series of interdependent events sequenced over time. The probability or outcomes associated with each individual event may not be known with certainty. Appropriate analysis of an event tree allows the decision-maker to identify risk control points, develop risk management strategies and contingency plans. See also **Fault tree**.

Expected utility theory starts with certain basic assumptions about what is meant by coherent (internally consistent) preferences. The theory shows that probabilities expressing degree of belief, and utilities representing subjective value and attitude to risk are implied. The theory shows how those elements should combine to provide a guide to decision-making: weighting the utilities by the probabilities for all anticipated consequences of a course of action, then summing these products to give an expected (weighted average) utility. The course of action with the highest expected utility should be chosen.

Expected value provides a means to explicitly account for probabilities and uncertainties in decision-making. The approach requires probabilistic outputs from decision analysis (e.g. decision trees). It states that, given risk neutrality, the project with the highest expected value should be preferred. In reality, most individuals are not risk neutral – they tend to be risk averse. However, it is frequently argued that, for many public sector decisions, this risk averseness can be ignored because the risks to individuals are small and because of 'risk spreading'. Use of expected values is a convenient way of developing a single figure to describe the outcomes for a proposed measure. However, it does not incorporate any indication of the degree of associated uncertainty. For this reason, the use of complementary tools such as robustness analysis and sensitivity analysis is usually important.

Expert elicitation. A range of techniques which aim to elicit information and evidence from

[21] See www.ukcip.org.uk/risk_uncert/risk_uncert.html

experts on aspects of models or impacts that are otherwise difficult or not feasible to model explicitly. Expert elicitation techniques may be used, for example, to gather information about model input parameters, model processes and climate change impacts. The techniques often include methods for eliciting opinions and uncertainties, using appropriate coding techniques, including structured questions, and graphical techniques. Techniques range from assessment by individuals (which is simple and cheap but may be less dependable) to complex structured techniques for eliciting and moderating views of groups of experts. See Morgan & Henrion (1990).

Expert judgement. Use of evidence from individuals or groups of experts. This may relate to the likelihood of future events or scenarios, ranges or probability distributions of physical or model parameters, or possibly judgements relating to impacts, including relative benefits or disbenefits of different impacts. Expert judgement may also be used in interpreting and assimilating results from a range of 'competing' or alternative models.

Facilitated workshops. A small group of people who share a goal and perform various tasks, helped by impartial individuals who facilitate the group's tasks. One form of facilitated workshop is decision conferencing, a two- or three-day event involving a work group of key players who wish to address important issues of concern to their organisation, with the help of an outside facilitator and some computer modelling of participants' judgements about the issues. The computer modelling often takes the form of **Multi-criteria analysis**.

Fault tree. A technique by which many events, usually associated with the risk of failure of a system component, interact to produce other events. Fault tree techniques use simple logical relationships permitting a methodical building of a structure that represents the system with potential faults. (See also **Event tree**.)

Financial analysis. An assessment of the impact of an option on the financial costs and revenues of an organisation (usually the decision-maker's organisation).

Fixed rule-based fuzzy logic (FRBL). A technique derived from **fuzzy set theory**, that claims to allow robust decision rules and processes to be developed from qualitative and uncertain information, and conflicting expert judgement and value systems. Hybrid approaches, combining fuzzy logic with neural networks and genetic algorithms, allow potential relationships between variables to be discovered, and updated. See Downing (1998), Loia *et al* (2000). FRBL is frequently implemented as part of a computer-based expert system that may also employ an inference engine. An inference engine allows the expert system to recognise and infer rules, using a variety of forms of rule recognition and reasoning (e.g. induction, deduction). See Bardossy & Duckstein (1995).

Flexing. See **Hedging**.

Focus groups are made up of people from a variety of backgrounds that are all affected by, or have a stake in, an issue. The group is provided with detailed, relevant information regarding the issue, and is usually asked to respond to the information in a prescribed manner or to undertake a particular exercise (for example, to apply **AIDA**). A trained moderator then analyses the responses of each participant and the internal dynamics of the group to identify exactly why each person has responded in the way they have. The aim of the process is to identify the central elements of the issue and the reasoning behind different viewpoints.

Free-form gaming. A **scenario**-based game in which opposing teams, perhaps representing different stakeholder interests, are confronted with potential or anticipated, plausible and realistic problems and make decisions on the situation and on moves (decisions) made by other teams or opponents. Free-form games integrate intangible or unquantified political and social factors into strategic planning. The method is used to underpin better management of issues which are too complex to be described by traditional scientific methods. Free-form games can be structured to represent conflicts between (for example) the environment and development. Free-form games have five stages: preparation, conflict initiation, game play, exploring branches, and ending play. Preparation

includes specifying the purpose of the game, developing and collecting data for use in the scenario, and providing a referee. See Brewer and Shubik (1979).

Fuzzy set theory/fuzzy arithmetic. A technique for assessing the effects of uncertainty on the outcome or model prediction. Fuzzy arithmetic is closely related to **interval analysis**. A fuzzy number is a 'stack' of intervals. Membership of the widest interval is more possible or plausible than membership of a narrower interval. Fuzzy numbers may be combined in models to give fuzzy outcomes, very much reflecting the process used for probabilistic analysis (working with fuzzy numbers is often called 'possibilistic' analysis). Software tools are available that facilitate the construction and analysis of models where uncertainty may be best expressed by fuzziness (e.g. RiskCalc, Ferson *et al*, 1999). Fuzzy arithmetic does not impose or assume any particular degree of **correlation** (see Appendix 2) – this can be an advantage since (i) the degree of correlation may (is likely) to be unknown, (ii) it is essentially conservative, and (iii) it does not artificially underestimate uncertainty. On the other hand it may give unreasonably large uncertainties when correlation is known. Fuzzy arithmetic is not widely used compared with probabilistic analysis, and has not yet been widely integrated into risk and decision analysis. See Klir & Yuan (1995).

Hedging and flexing. The most straightforward way of dealing with uncertainty is to assume that either the best (or the worst) of all possible outcomes (scenarios) will occur for each option. One then chooses the option that gives the best possible outcome (or the least bad outcome). In other words, the decision-maker can adopt an optimistic (or pessimistic) approach towards decision-making. Where a decision-maker has adopted a pessimistic stance, this is sometimes referred to as **hedging** because one is foregoing the best outcome in order to avoid the worst (as in 'hedging your bets'). An alternative to hedging is often that of **flexing**. Under this type of approach, the option which would give the best possible results is chosen, but methods are explored that would enable the decision to be modified if the worst outcome did happen. The performance of the implemented

measures is monitored (perhaps in relation to change in the environment) to detect any signs that the worst outcome occurring.

Interval analysis. A technique for assessing the effects of uncertainties on the outcome or model prediction. The aim of interval analysis is to identify the lowest possible and highest possible value of an outcome, based on extreme values of input parameters (model parameters, physical parameters, etc). Interval analysis involves 'searching' for the combination of input parameters that together combine to produce the highest and lowest value of the output, given a particular model. Although it is conceptually simple, great care is needed to ensure that the correct combination of input values is selected. It may not be possible to select input parameter sets without trial and error, particularly for complex functions or models. Data requirements are however among the simplest of any uncertainty analysis method – only the extreme values (maximum/minimum) of all inputs considered likely or possible are needed. Of course some values may be deterministic (i.e. single values). Since the outcome is the result of **all** input parameters at their extreme values, interval analysis can give very wide bounds to outcomes. In other words, the upper and lower bounds of the output may have a very low probability of occurring. However, if the uncertainties are properly represented, the 'true' outcome is guaranteed to be within the predicted bounds. Interval analysis makes no assumptions about the probability distributions of input parameters and requires no data on this. It also does not assume any particular degree of dependence between parameters, which is partly why the resulting bounds can be so wide.

Markov chain modelling. A statistical mathematical modelling approach used to represent uncertainty in linked sequences of events, where each transition may be represented by a probability representing the likelihood or uncertainty that the transition will occur. Markov chain modelling requires that certain assumptions be met by the process being modelled. It can be used where (i) there exist a finite number of possible states, (ii) the process can be in one and only one state at a time, (iii) the process moves or steps successively

from one state to another over time, (iv) the probability of a change in state depends only on the immediately preceding state. See also **Monte Carlo techniques**.

Maximax. See Appendix 2.

Maximin. See Appendix 2.

Maximum likelihood methods. See Appendix 2.

Minimax. See Appendix 2.

Modelling tools. A model is a representation of a concept, hypothesis, observed relationships, or even reality. Models may be conceptual, physical, analogue, graphical, quantitative or qualitative, mathematical, equilibrium or dynamic, analytical, simulation, computerised, statistical, stochastic, deterministic, black box, process-based or causal, validated (or not), wrong but rarely right! Climate forecasting, impact assessment and decision-making employs the full diversity of modelling approaches. Particularly important are dynamic models, which allow the impact on a system resulting from changes in input variables to be studied through time (i.e. they describe transient responses). Such models are more complex than equilibrium models, which only describe the change to the system when it has reached equilibrium. Environmental systems, subject to many and continual perturbations, may not be well characterised by equilibrium models. (See also **Deterministic modelling**, **Process response modelling**, **Scenario modelling**, **Statistical models**, and **Stochastic modelling**.)

Monte Carlo techniques. This is a commonly used approach for estimating the impact of uncertainty and variability in parameter values and input variables of quantitative (mathematical) models. The technique selects, using a sampling scheme, values for the uncertain parameters (or variables) of interest from the relevant PDF for each parameter or variable. Multiple runs of the model produce a frequency distribution of the outcomes. Provided sufficient samples are made, then assessments of extreme (low probability) values are possible. The technique is often used to help estimate the likeli-

hood that a particular value (or combination of values) will be exceeded. Use of Monte Carlo simulation for statistical uncertainty arising from random processes is well accepted. It is possible to use it for many other types of uncertainty but these are more controversial. Examples include assigning probabilities to (i) weight competing models; (ii) scenarios of input variables; (iii) assigning probability distributions to certain types of model parameters (e.g. to represent spatial or temporal variation in parameter values). Monte Carlo simulation does not help resolve uncertainty regarding the underlying model, nor uncertainty as to the PDFs chosen to represent the uncertainty. Implicit assumptions are frequently made concerning the **independence** (see Appendix 2) of parameters (or variables) and their associated PDFs. Such assumptions reduce the complexity of the modelling exercise, or may simply be a consequence of ignorance of any dependence. By imposing these assumptions, most Monte Carlo exercises may tend to underestimate uncertainty. The availability of cheap Monte Carlo software add-ins to standard spreadsheet software has in part led to a more widespread adoption of Monte Carlo methods. See, for example, New & Hulme (2000). See also **second-order Monte Carlo** analysis.

Multi-criteria analysis (MCA) describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several (i.e. multiple) **objectives** (see Appendix 2). Approaches are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and **criteria**. It can encompass non-monetisable impacts and additional criteria that can be difficult to incorporate within a CBA. Compensatory MCA techniques combine assessments on separate criteria into an overall assessment, allowing trade-offs to be modelled (i.e. lesser scores for an option on some criteria can be offset by greater scores on other criteria). Simple weighted averaging models are compensatory, while lexicographic methods are not. Lexicographic models provide a general approach to the ordering of preferences in which options are compared based on a judgement or agreement as to the most important criterion. The best option is chosen unless other options tie for first place, in which case evaluations based on the second most important

criterion are considered to break the tie. If that is not possible then the third most important criterion is consulted and so on until one option can be chosen. DTLR (2001a) provides practical guidance on the application of techniques of MCA, in non-technical language. It is designed to help non-specialists gain an overview of the advantages offered by MCA, and what may be required in terms of resources for undertaking appraisals. The manual has more detailed appendices on various MCA methodologies, which will be more accessible to economists and other analytical specialists. (See also Metroeconomica *et al,* 2003.)

Pairwise comparison is a tool for selecting a preferred alternative, by making the trade-offs involved apparent. The tool involves comparing alternatives (over a range of criteria) two at a time until each has been compared with all the others for each criterion. Pairwise comparison involves a three-stage procedure once a short-list of preferred options has been identified:

- the criteria or impacts are listed and the alternatives are compared, in pairs, against each other – little more is required than a straight preference of, say, option A over option B in terms of criterion X;
- once all comparisons are made, the results may be recorded in a table which will make clear which alternative is better or worse for each area of significant impact; and
- this information can then be passed on to the decision-maker with the trade-offs clearly shown.

Partial cost-benefit analysis comprises the rigorous appraisal of costs and benefits that can be readily monetised, as under a CBA above, but also includes information on the nature and significance of certain important intangible (or non-monetisable) costs and benefits so as to cover the full costs and benefits of the options and to aid selection of the best option.

Pedigree analysis. A qualitative technique used in decision analysis to help define the state-of-the-art, expertise, credibility, potential reliability, or degree of consensus associated with information or knowledge. Hence statistical models are judged (in general) to have a lower pedigree than process-based models underpinned by theory enjoying a wide scientific consensus. Consider the consequences of sea level rise exceeding a particular value. The opinion of a world expert in coupled climate-ocean modelling as to the likelihood of sea level exceeding that value at any particular time in the future might be given a pedigree score of 5 (out of 5). However, his opinion as to the consequences for a local conservation site in the UK may be of less value, and given a score of 3 (he is still an expert on coastal issues). In comparison, a local conservation officer with good knowledge of the potential consequence of a given amount of sea level rise may have his impact opinion rated 5. The acceptability of such an impact, as determined by a survey of local stakeholders, may be given a higher pedigree than that of either the climate expert or the conservation officer.

Policy exercise. A flexible, structured method designed to synthesise and assess knowledge from several relevant fields of science for policy purposes directed towards complex, practical management problems. Policy exercise techniques provide an interface between scientists and policy-makers, and involve policy-makers from the outset. At its heart is the preparation of **scenarios** or 'future histories', including non-conventional but still plausible surprises, and their use to analyse policy options within an organisational structure reflecting institutional roles. Practically, the method comprises one or more periods of joint work involving representatives of these groups, plus support staff to facilitate the exercise. Views and ideas expressed by participants may be treated as unattributable. A period consists of three phases (preparation, workshop, evaluation) which can be iterated two or more times. Policy exercises can be used to provide a better structured view of problems and/or generate and evaluate policy options. See Brewer (1986), Toth (1988a,b).

Portfolio analysis. In some cases, a decision-maker may want information that goes beyond consideration of the risks arising solely from a particular decision. He may instead be concerned with the combined risk-benefit position of a number of

decisions taken together. In particular, if he is concerned that a number of fairly high-risk options have already been adopted, then he may want to ensure that he does not take on another high-risk project. Conversely, he may have chosen a series of safe but low-benefit projects and might look favourably on taking a higher-returning but also higher-risk activity. Expressed in the language of the financial investor, in such cases the basis for making a decision should be the total portfolio of an organisation's activities.

Preference scale. A scale representing relative strength of preference. Fixed scales are defined independently of the available options: 100 may be defined as the 'maximum feasible' and 0 as the 'minimum acceptable'. These are both interval scales, so 0 does not mean no preference or no benefit, any more than 0°Celsius means no temperature. In some cases, ratio scales are used. In this case the zero point is not arbitrary; it represents zero cost or no benefit. Only the unit of measurement is arbitrary, and can be defined by establishing a referent for 100, usually the most preferred option or the maximum feasible.

Probability. See Appendix 2.

Probability density function (PDF). PDFs are used to represent the relative likelihood that a parameter or variable will have a particular value. Where there is discrete set of possible values (e.g. heads or tails), the function represents the probability itself (e.g. 0.5, 0.5). Where the variation in values is continuous, the probability distribution function defines the probability that the value lies between two values, a and b. This is represented by the area under the function. Different distributions are appropriate for different processes and types of variability. A **cumulative PDF** represents the probability that the value of a parameter is greater (or less than) a particular value. The Poisson, binomial, normal (or 'bell curve'), log-normal, exponential and gamma are examples of forms of PDFs used in quantitative risk assessment. PDFs such as the Weibull are frequently used to represent distributions of hazards, or to represent likelihoods of failure. Rectangular (or uniform), triangular and other geometric distributions are used in semi-

quantitative risk assessment, frequently in conjunction with techniques of expert elicitation, fuzzy analysis and probability bounds analysis. (See Morgan & Henrion, 1990, Evans *et al*, 2000).

Probability trees. See **Decision trees**.

Problem mapping tools. There is a range of mapping tools which can be used to assist in the understanding of the linkages amongst different parameters/features of a particular situation. As such they are 'enablers' of other tools. The drawing software VISIO provides a 'mind mapping' set of shapes and inter-connectors which can be used to generate (and, importantly, modify) an on-screen 'map' of the problem. Similarly, Decision Explorer is an example of software developed specifically for 'concept mapping'. **Process influence diagrams** are a type of problem mapping tool.

Process influence diagrams. Graphical/analysis tools for representing and analysing systems. At their simplest these are block diagrams, which show components of a system and connections between components. In this form they are useful for brainstorming – the act of constructing an influence diagram can be used to identify important inputs, causal connections, feedbacks and decision points, and outcomes. A number of software tools are now available to add analytical capability to influence diagrams. In particular it is possible to set up influence diagram models with nodes representing inputs (single-valued, scenarios, probability distributions), decisions (contingent on variables), and functions such as process-response, reliability or risk functions. These models are well suited to propagating uncertainties, and for examining, for example, the impact of different policies or decisions on a range of outcomes. Models may be 'nested' such that the top layer presents a clear picture of the process while more detailed layers contain analytical details.

Process response modelling. Knowledge of sensitivities to climate variables can be represented by **process models**. Such models summarise the understanding that the model-builder has of processes determining the state of the system. In the majority of cases that understanding will be incom-

plete. Many models will have been constructed for purposes other than climate impact assessment, and may omit key variables that may change under future climates.

The decision-maker will need to know how the model has been parameterised and validated, and the goodness-of-fit of the model to 'real' data. In particular he will need to know whether the model can be applied directly to analyse the problem in hand (i.e. that appropriate input variables, data, parameter values and response variables are available), or whether the model can help inform any decision (perhaps through the simulation of a range of scenarios).

Ranges and intervals. Ranges can be used to convey 'worst case' or 'best case' assumptions, or simply to express the uncertainty on the true or the average value of a variable. The uncertainty represented by a range can be very wide – it can be difficult to bound the 'true' value within a range of uncertainty that a decision-maker would consider to be reasonable. The range of uncertainty can be particularly wide if several interval-variables are combined. Combination of several intervals within a calculation needs to be done with care to detect the combination of inputs to give the worst case/best case output. Intervals are most appropriate where there is a severe shortage of information and no justification to favour any particular values or conditions within the range. Intervals are highly 'conservative'.

Ranking. Any technique by which items are ordered with respect to one another. In the context of this report, ranking may be applied to (variables describing) climate hazards, consequences, risk, criteria, options, preference, etc.

Regret. See Appendix 2.

Risk assessment. The structured analysis of hazards and impacts to provide information for decisions. Risk assessment usually relates to a particular 'exposure unit' which may be an individual, population, infrastructure, building or environmental asset, etc. The process usually proceeds by identifying hazards that could have an impact, assessing the likelihoods and severities of impacts, and

assessing the significance of the risk, which is sometimes but not always related to the probability multiplied by the severity of the impact. Risk assessment may be carried out under a range of decision options and scenarios in order to inform and support decisions. See Downing *et al* (1999) for a discussion of risk assessment applied to climate change impact assessment.

Risk assessment also highlights the 'residual risk', which remains after implementation of a chosen course of action. Although risk assessment is often concerned with damage and disbenefits, the same procedures may be used to identify and assess benefits and opportunities. See also **Tiered risk assessment**.

Risk-risk analysis. In risk-risk analysis, individuals are asked to make trade-offs between two different types of risks. So for example, a person might be asked to trade-off a financial risk versus a health or environmental risk. The aim of such analyses is to establish an individual's preferences for different outcomes, where these are characterised by risk.

Such analyses can be used:
- to derive monetary values (as part of a **cost-benefit analysis**) for the reduction of one type of risk by comparing it with another risk for which a money value already exists;
- in standard setting, for example, when trying to determine the most appropriate threshold for an environmental standard; and
- in options appraisals, for example, concerning the benefits of health and safety legislation against the 'risks' to industry and the economy more generally of decreased economic growth.

Robustness analysis may be used to help determine the robustness of the answers within an options appraisal to possible uncertainties as to the values of key sensitive variables and parameters (as identified from the **sensitivity analysis**). It identifies the extent to which the decision-maker might be exposed to potential costs and errors if some uncertain eventualities regarding these parameters should arise in future. Robustness analysis is sometimes used to investigate the impact on the decision

of a 'reasonable' range of input values for the key parameters identified by the sensitivity analysis, or a range of values that are considered plausible.

Scenario analysis or **planning**. The use of contextual scenarios (e.g. UKCIP, 2000) can help decision-makers participating in facilitated workshops acknowledge uncertainty about the future, and thereby make assumptions about outcomes more explicit, thus directing attention at implications which may otherwise be missed. See Schoemaker (1991).

Scenario modelling. The use of scenarios and scenario modelling covers a diversity of related techniques with many applications within the climate change and impact fields. Scenarios are used to represent both qualitative and quantitative types of uncertainty. The approach parallels **sensitivity analysis**, but emphasises uncertainty concerning types of model, input variables, and the future. Different scenarios of greenhouse gas emissions (e.g. IS92a) used as inputs to various global climate models (e.g. HadCM2) with different climate sensitivities (an example of parameter uncertainty) is an example of **quantitative scenario modelling**. This is the basis of the UKCIP98 climate change scenarios (Hulme & Jenkins, 1998). (See also Appendix 4).

The contextual description of different social and economic futures for the UK (UKCIP, 2000) is an example of **qualitative scenario development** (see also **Policy exercise approach**). Scenarios are effectively a form of **'what-if' analysis**.

Types of scenario which may be appropriate to many forms of model use include: fiasco, worst case, best case, baseline, business-as-usual, best guess, trend analysis, low, medium and high, average, upper or lower percentile, etc. Scenarios may also be temporal, e.g. past, present and future (e.g. 2020s, 2050s). Since the purpose of scenario modelling is to illustrate the range of uncertainty influencing a decision or outcome, it is usually recommended that a number of different scenarios be considered. Frequently, the emphasis will be on scenario groups consisting of (i) best guess, business as usual, past trend, historical, average, baseline; (ii) worst and best case (or fiasco), lower and upper percentile; (iii) temporal scenarios (e.g. Hulme *et al*, 2002). Where assem-

blages of different scenarios are combined, it is important to understand the independent effect of each scenario dimension on the decision criteria, since these may combine or counteract each other. These interactions are likely to be very important, and may be additive (both add or subtract) or synergistic (e.g. multiplicative).

Scoring. A technique often used for comparing risks and preferences. Having identified factors which affect risk (including probability and severity of impacts), a mathematical system is set up by which individual factors can be scored and combined to establish an overall 'risk score'. These systems are generally used for risk prioritisation and screening. The aim is to produce a system that calculates relative risks, not absolute risk levels. Relative scales are defined using identified risks or available options as anchors: 10 can be associated with the greatest risk (or most preferred option on a given criterion), and 0 associated with the lowest risk (or least preferred option on that criterion). These systems should be developed and tested with care – in-built biases and scale distortions can lead to inconsistencies. The user should be aware of the limitations of the system and should not interpret risk scores as a quantitative measure of risk (unless the system has been designed to allow this).

Screening. Techniques used to identify hazards, processes and impacts that are, and are not, significant in the overall decision-making process. These are 'broad brush' techniques that generally require a reasonable understanding of the system. Screening tests are by their nature approximate and so should be designed to be conservative so that important issues are not rejected at an early stage.

Second-order Monte Carlo techniques. An approach for nesting uncertainties. This technique overcomes one of the problems with standard Monte Carlo techniques, that the input probability distributions are usually assumed to be known precisely. Consider for example monthly rainfall. We accept the natural variability that leads us to model the rainfall in any month as a probability distribution. But in future the mean and standard deviation of the distribution are not known precisely – but this uncertainty can be represented by probability distributions.

Second order Monte Carlo is a technique for separating the variability of the rainfall from the uncertainty. The results of second-order simulations are a set of probability distributions. A given statistic such as the 10th percentile has a probability distribution associated with it. The technique appeals since it enables separation of different types of uncertainty. It is, however, not routine to apply and results may be difficult to interpret. Similar reservations to Monte Carlo methods apply, that is it may underestimate uncertainty since the form of the PDF and degree of correlation are imposed.

Sensitivity analysis. A generic term used in both formal (e.g. mathematical modelling) and in decision analysis for techniques that identify key assumptions, variables or parameters for which uncertainty as to their values could significantly affect outcomes and decisions. The technique involves examining the consequences (as determined on outputs or outcomes) of changes in the values determined for each component. For example, a decision may be sensitive to the value of discount rate used within a **cost-benefit analysis**. **Monte Carlo** techniques are frequently used in formal analyses of model sensitivities. At each stage in an appraisal the assessor should focus attention on those parts of the analysis or variables highlighted by analysis of sensitivity, and seek alternative and better options, which could better accommodate uncertainties regarding these variables (see **Robustness analysis**).

Sieve mapping or **overlay mapping** provides an indication of the impacts associated with a given option by superimposing impact data graphically onto a base map. These maps provide the decision-maker with a simple, clear indication of the extent, and potentially the magnitude, of the likely consequences of a particular action. In the context of climate change, such maps have been used to illustrate those areas which are most at risk from increased flooding, which are likely to be inundated following different degrees of sea level rise, etc.

Simulation-gaming. An exercise to depict decision situations, roles, rules and procedures in order to study particular social situations in which individual decisions and their interactions are crucial to the outcomes.

Stated preference surveys. A method to value benefits or costs for which market prices do not exist. The methods involve implying underlying valuations based upon individuals' answers to questions about the choices they would make between different hypothetical alternatives. Surveys may entail direct questions of the individuals' willingness to pay for the benefit in question. However, such surveys raise difficulties as to whether consumers can comprehend the benefits in question and many respondents are unwilling or unable to give a monetary valuation figure for less tangible environmental benefits (see also **contingent valuation**).

Statistical models based on observed relationships between climate variables and the exposure unit are of considerable value in climate vulnerability and impact assessment. Statistical models are particularly valuable in situations where long time series or large spatial data sets are available that include the key climate and system response variables. Very often statistical models do not distinguish cause and effect within the structure of the model, and hence can be unreliable when extrapolating to new sites or conditions (e.g. future climates) that may differ markedly from those historical climates on which the model was based. However, statistical models can be constructed that explicitly incorporate knowledge of the causal relationships between variables, and such models provide a higher degree of confidence. Statistical models can, in general, be regarded as having a lower **pedigree** than process-based models.

Model assumptions, for example the statistical independence of climate variables used within a model, should always be explicitly acknowledged and evaluated by the originator or user of the model. Such assumptions contribute a significant source of uncertainty to the output of such models. Predictions from such models should always be accompanied by estimates of the confidence intervals attached to the output variables. These provide a description of the uncertainty and variability represented by the model (which itself should be regarded as uncertain). In practice, deterministic predictions are often presented, but should be avoided.

Stochastic modelling. An approach to modelling that attempts, through the application of quantitative probabilistic or statistical techniques, to represent variability and uncertainty in model parameters, variables and processes and (hence) outcomes. Stochastic modelling often employs deterministic (process-based) **models** (see Appendix 2) within a **Monte Carlo simulation**, to produce probabilistic results. See also **Markov chain models**.

Strategic environmental assessment (SEA) is the systematic and comprehensive assessment of the environmental consequences of a policy, strategy or plan, or programme so that they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on a par with economic and social considerations.

Tiered risk assessment. Many issues are too complex to be calculated completely and a tiered or staged approach is more appropriate. Initial stages of the assessment aim to identify a wide range of hazards and issues that may affect a decision. These are filtered or screened to identify those that have the most important impacts. It may then be appropriate to carry out a stage of prioritisation, often using a scoring scheme to identify the most important risks. Detailed quantitative analysis can then be focused on the key hazards and risks that are likely to be most influential on the decision. There is inevitably a degree of iteration in this approach.

Uncertainty analysis. An analytical process to provide information regarding the consequence of uncertainties within an assessment or model. This could include detailed examination of data uncertainties (systematic and random errors of a measurement or estimate), assumptions, real world variability, etc. Methods of **sensitivity analysis** are often used, including those based on **Monte Carlo** techniques.

Uncertainty radial charts provide an extremely simple approach for identifying and organising the uncertainties surrounding a decision problem. The tool is 'soft' in that the assessment it provides is based only on the judgements of those involved, but it has the advantage of being neither a costly nor a time-consuming tool to apply. The tool is based on

characterising three different types of uncertainty:

- uncertainty regarding the environment (physical, social, political, economic and cultural);
- uncertainty regarding the values surrounding a problem, as well as goals and objectives; and
- uncertainty regarding choices in related areas.

Valuation methods. Where the decisions concern options involving different levels of diverse environmental, social and economic benefits that the normal (scientific) analysis would present in various units (e.g. hectares of agricultural land lost, tonnes of agricultural outputs or timber foregone, numbers of Sites of Special Scientific Interest (SSSIs) and species affected, number of properties affected, etc), then economic valuation techniques aim to assess these diverse impacts consistently in a commensurate unit – money – so that the impacts of the options can be aggregated and compared. The monetary valuations in a CBA can be based on the market prices for goods that are bought and sold in the market (e.g. timber outputs). However, there is no market for many important environmental impacts. Consequently, the valuations for these environmental benefits are based on the preferences of individual affected parties. These may be determined by their responses to survey questionnaires. See **Stated preference surveys**.

Weather generators are statistical models calibrated using observed, site-specific data that allow a continuous, stochastically varying time-series of weather to be simulated. These time-series should possess the same statistical properties as the data used for calibration. The parameters of the weather generator can then be changed, based on information from a global or regional climate model, to produce an artificial time-series (i.e. a weather scenario), reflecting a changed climate for the site of interest. (See Appendix 4).

What-if analysis. A technique used to investigate the importance of assumptions regarding the future, or underpinning a model or other assessment. A form of uncertainty analysis.

Appendix 4
Useful websites

Appendix 4 – Useful websites

Useful websites

Relevant organisations

UKCIP http://www.ukcip.org.uk

Environment Agency
http://www.environment-agency.gov.uk

Defra
http://www.defra.gov.uk

Hadley Centre
http://www.metoffice.com/research/hadleycentre/
index.html

Tyndall Centre for Climate Change Research
http://www.tyndall.ac.uk

Climatic Research Unit
http://www.cru.uea.ac.uk

Intergovernmental Panel on Climate Change
http://www.ipcc.ch

**Assessments of Impacts of and Adaptation to
Climate Change (AIACC)**
http://www.start.org/Projects/AIACC_Project/
aiacc.html

Cabinet Office Strategy Unit
http://www.strategy.gov.uk
See also http://www.strategy.gov.uk/2002/risk/
risk/home.html which has links to a number of
websites (mainly government-related) with guid-
ance, advice, and other information on risk.

Terms used in forecasting, risk assessment, risk management and decision analysis

Forecasting principles and dictionary
http://www-marketing.wharton.upenn.edu/
forecast/

Society of risk analysis – risk glossary
http://www.sra.org/glossary.htm

USEPA 'Terms of the Environment' glossary
http://www.epa.gov/OCEPAterms/

USEPA environmental terminology reference
system http://www.epa.gov/trs/

Dictionary of risk terms with an emphasis on the
assessment of environmental impacts
http://www.damagevaluation.com/glossary.htm

Dictionary of risk assessment terms provided by
American Stock Exchange, with an emphasis on
financial risk management
http://www.amex.com/dictionary©

Dictionary of risk terms provided by e-risk.com,
with an emphasis on financial risk
http://www.erisk.com/reference/Encyclopedia/
ref_dic.asp

Glossary of useful terms used in risk assessment,
environmental management, benefit assessments,
health physics and waste management reports
http://risk.lsd.ornl.gov/homepage/glossary.shtml

Dictionary of some terms used in decision
analysis
http://faculty.fuqua.duke.edu/daweb/lexicon.htm

Risk assessment and decision analysis software

A variety of specialised software is available that facilitates analyses by implementing some of the techniques discussed in this report. In most cases these software products interface with standard spreadsheet (such as Microsoft Excel or Lotus 1-2-3) and/or database products. The websites indicated below provide further information on each software package, and these generally include example applications and demonstration versions of the software. The inclusion of software here does not constitute a recommendation.

Analytica (Lumina Decision systems).
http://www.lumina.com/
An influence diagram-based, visual environment for creating, analysing and communicating probabilistic models for business, risk, and decision analysis. A user-friendly interface provides hierarchical sub-models and a variety of graphs. **Analytica** is especially good when the problem at hand requires modelling of both continuous and discrete variables. The software provides dynamic links to spreadsheets and databases.

BestFit. See **RiskView** below.

CB Predictor™ (Decisioneering Inc).
http://www.decisioneering.com/cbpredictor/
CB Predictor™ is an Excel-based tool that uses established time-series and multiple linear regression forecasting methods to help identify and extrapolate trends in historical data. **CB Predictor** helps analyse data and produces insightful and accurate forecast models. Available methods include moving average, single and double exponential smoothing, additive and multiplicative decomposition, Holt-Winters' seasonal and multiplicative smoothing. The software is designed to interface with **Crystal Ball** risk analysis and optimisation software.

Clementine© (SPSS Inc).
http://www.spss.com/SPSSBI/SPSS/
Clementine is an example of data-mining software. Data-mining software enables the development of predictive models that can improve decision-making, based on the analysis of large, complex datasets. **Clementine** is one of a suite of statistical data analysis products produced by SPSS.

Criterium Decision Plus (Infoharvest).
http://www.infoharvest.ab.ca/
Criterium Decision Plus implements two different approaches to multi-attribute decision-making: analytical hierarchy processes and simple multi-attribute rating technique, based on experience and needs of agriculture. It concentrates on trying to let the user fully understand multicriteria analysis, and the effect of uncertainty in the outcomes on the preference over decision options.

Crystal Ball® (Decisioneering Inc).
http://www.decisioneering.com/crystal_ball/
A risk-analysis package add-in for Microsoft Excel. **Crystal Ball** allows a wide range of quantitative risk analysis methods to be implemented, and facilitates Monte Carlo simulation. It can be used for decision modelling using any spreadsheet-based model.

Data (TreeAge Software Inc).
http://www.treeage.com/products.htm
A program boasting a simple user interface for implementing both decision trees and influence diagrams. Offers features such as sensitivity analysis, threshold analysis, cost-effectiveness calculations, recursive Markov processes, and Monte Carlo simulation. Graphical outputs include multi-way sensitivity analyses, tornado diagrams, and probability distributions. Models built in DATA 3.5 can then be integrated into custom decision analysis applications, spreadsheets, and websites using further modules.

DecisionPro. (Vanguard Software Corporation).
http://www.vanguardsw.com/
Software implementing hierarchical decision models and decision trees. Offers features like sensitivity analysis, Monte Carlo simulation, data analysis, forecasting techniques, and optimisation.

DPL (**Decision Programming Language**)
(Applied Decision Analysis, Inc).
http://www.adainc.com/software/index.html
A powerful decision-support package that offers a synthesis of influence diagrams and decision trees, which assist in structuring complete and focused analyses. The software includes routines to undertake sensitivity analysis, showing how decisions change as values and probabilities vary. 'What-if' scenarios can be used to determine how sensitive a particular model is to changes in the input variables. This helps focus attention on those variables with potentially the greatest impact on the decision. The software automatically produces graphical and numerical outputs of the sensitivity analysis results. **DPL** contains an extensive function set, which supports most standard arithmetic, financial, statistical, and logical functions (sum, net present value, internal rate of return, mean and variance, etc.). In addition, for advanced users, DPL also supports named distributions (normal, exponential, lognormal, etc.), multiple attributes, and utility functions.

Ergo (Noetic Systems Inc).
http://www.noeticsystems.com/ergo/
A simple, but intuitive and fast program implementing Bayesian networks, allowing the expert to define variables of interest and important associations among variables by drawing the model on a computer screen. Statistical and other data can be combined with subjective assessments to specify the probability associated with each variable. Algorithms from graphical and probability theory ensure the internal consistency of the model during construction and inference.

Expert Choice (Expert Choice Inc).
http://www.expertchoice.com/software/
Expert Choice implements the analytical hierarchy processes approach (Saaty, 1980). The software facilitates (i) structuring decisions into objectives and alternatives, (ii) measuring objectives and alternatives using pairwise comparisons, (iii) synthesising objective and subjective inputs to arrive at a prioritised list of alternatives, (iv) optimising for constraints using a resource allocation module, and (v) managing decision documentation, reporting and sensitivity analysis. Expert choice is spe-

cially designed for those who are making group decisions, ensuring that decisions reflect multiple stakeholder and expert inputs.

ForecastPro and related software
(MBAWare.com).
http://www.mbaware.com/forprostaned.html
Helps select the best technique from five classes of forecasting methods: simple methods like moving averages; four types of curve fitting (straight line, quadratic, exponential and growth); low-volume/sparse data models such as Croston's intermittent demand model and other discrete data models; 12 different exponential smoothing models; and a multiplicative, seasonal Box Jenkins model. Forecasts can be linked to existing data imported from spreadsheets, text files or any ODBC source (e.g. Access, Oracle, SQL Server). Diagnostic tools help you compare and evaluate models using graphs of the residuals, error autocorrelation and numeric statistics. What-if scenarios can be handled.

GeNIe© (Decisions System Laboratory, University of Pittsburg).
http://www2.sis.pitt.edu/~genie/
GeNie is a decision modelling environment, implementing influence diagrams and Bayesian networks. It has an intuitive graphical interface that includes hierarchical sub-models, Windows-style tree view, and a comprehensive html-based online help that includes beginners-oriented tutorials for Bayesian networks, influence diagrams, and basic decision analytic techniques. **GeNie** implements multi-attribute utility functions, Noisy-OR and Noisy-AND gates, value of information, and sensitivity analysis. **GeNie** comes with SMILE (Structural Modeling, Inference, and Learning Engine), an application programmer's interface.

Logical Decisions® (Logicaldecisions.com).
http://www.logicaldecisions.com/
Logical Decisions® for Windows (LDW) is multi-criteria decision support software for evaluating choices. LDW lets you evaluate choices by considering many variables at once, distinguishing facts from value judgements, and explaining choices to others, using techniques from the field of decision analysis. The software provides five methods for assessing attribute weights. Enhanced versions of the software allow the judgements of entire groups to be captured, with results computed and displayed for either the group consensus or for any individual. Other versions can identify the most promising alternatives, subject to budgetary or other constraints.

NAIADE (**N**ovel **A**pproach to **I**mprecise **A**ssessment and **D**ecision **E**nvironments)
(Institute for Systems, Informatics and Safety, Joint Research Centre of the European Commission, Ispra, Italy).
http://suport-gestio.com/cidma/imatges/naiade/pdf
The **NAIADE** method can facilitate evaluation of adaptation options. It is a discrete, multi-criteria evaluation method, which performs the comparison of alternatives on the basis of a set of criteria. It allows the use of information affected by different types and degrees of uncertainty. The values assigned to the criteria for each alternative may be expressed in the form of either crisp, stochastic, fuzzy numbers or linguistic expressions. **NAIADE** is a discrete method (the set of alternatives is finite) that does not require differential weighting of the different criteria. It generates a ranking of alternatives using a pairwise comparison technique. It allows for two types of evaluations. The first is based on the score values assigned to the criteria of each alternative, and is performed using an impact matrix. The second type of evaluation is an equity analysis, which analyses conflict among the different interest groups and the possible formation of coalitions according to the proposed alternatives. It is flexible for real-world applications, and is particularly suitable for economic – ecological modelling.

Netica™ (Norsys Software Corp).
http://www.norsys.com/netica.html
A powerful program, implementing Bayesian networks and influence diagrams. **Netica** can use the networks to perform various kinds of inference using a variety of modern algorithms. Allows for specifying the interaction among variables in terms of conditional probabilities, equations, or data files of observations. Given a new problem of which we have limited knowledge, **Netica** will find the appropriate values or probabilities for all the unknown variables (the conditional probability distributions will be learned from these observations). **Netica** can use influence diagrams to find optimal decisions, which maximise the expected values of specified variables. **Netica** can construct conditional plans, since decisions in the future can depend on observations yet to be made, and the timings and interrelationships between decisions are considered. It is very fast and comes with an application programmer's interface (API) that allows software development around **Netica**.

OnBalance (Krysalis).
www.krysalis.co.uk/info_ob.html
OnBalance is an easy-to-use software package that facilitates multi-criteria decision analysis. The user can create criteria for all the issues that can be used to differentiate between different options. For each criterion, the user can decide on the most appropriate measurable attribute, and turn this 'score' into a 'value' on a 0-100 scale. Each criterion is weighted, and the software will then feed back the total weighted value for each option. The model can be created as a simple data grid, or one or more trees can be added. Sensitivity analyses can be used to examine the consequences of criterion scores and weighting on the performance of options.

PrecisionTree® (Palisade Cornor).
http://www.palisade.com/html/ptree.html
A decision analysis add-in for Microsoft Excel that allows influence diagrams and decision trees to be built, using a graphical interface, directly in the spreadsheet. Integrates with **@RISK**, **RiskView** and other **Palisade Corner** software products.

@RISK (Palisade Cornor).

http://www.palisade.com/html/risk.html

A risk analysis package that performs Monte Carlo simulation in any spreadsheet-based model, and can be used for decision modelling. The software allows uncertain values in a spreadsheet model to be replaced with probabilistic functions representing a range of possible values. Results can be displayed as high-resolution graphs and in a full statistical report. **@Risk** includes sensitivity and scenario analyses, overlay graphs, and multiple summary graphs. The software can be purchased as a DecisionTools Suite, which includes distribution fitting to data. A tutorial is available from the developers or can be downloaded from their web address. Palisade offer the Analytical PowerTools Interactive CD for PCs, a multimedia guided tour through all their products, as well as information about all their products. The CD can be requested through their website. See also **PrecisionTree** and **RISKview**.

RiskCalc (Ramas.com).

http://www.ramas.com/riskcalc.htm

RiskCalc supports probability bounds analysis, standard fuzzy arithmetic, and classical interval analysis. Its applications are similar to sensitivity and uncertainty analysis, implemented using Monte Carlo-based techniques within packages such as **@Risk** or **Crystal Ball**, but **RiskCalc** does not require that precise details of statistical distributions and their dependency relationships are specified when empirical data or other knowledge are lacking. RiskCalc makes available methods for conducting distribution-free or non-parametric risk analyses. The risk assessor and/or decision-maker decide what information or assumptions should be used, and the software calculates bounding estimates of risks. Often these bounds can be shown to be the best possible. **RiskCalc** can be used to quality assure probabilistic risk and safety assessments.

RISKview and **BestFit** (Palisade Cornor).

http://www.palisade.com/html/riskview.html and

http://www.palisade.com/html/bestfit.html

RiskView is a tool for viewing, assessing, and creating probability distributions. The software can determine which of 37 distributions best fits a user-supplied, hand-drawn curve. Such curves can

also be exported to **@RISK** models as a general distribution. BestFit is a probability distribution fitting tool, taking data and finding the distribution function that best fits that data. **BestFit** accepts three types of data (sample, density, and cumulative) and tests up to 26 distribution types using statistical optimisation algorithms, and allowing control over parameter fitting. Results are displayed graphically and through a statistical report, which includes goodness-of-fit statistics.

WinBUGS and **BUGS** (MRC Biostatistics Unit, Cambridge, UK).

http://www.mrc-bsu.cam.ac.uk/bugs/

welcome.shtml

WinBUGS is a piece of computer software for the Bayesian analysis of complex statistical models using Markov chain Monte Carlo (MCMC) methods (BUGS standing for **B**ayesian inference **U**sing **G**ibbs **S**ampling). The software aims to make practical MCMC methods available to applied statisticians. **WinBUGS** can use either a standard 'point-and-click' windows interface for controlling the analysis, or can construct the model using a graphical interface called DoodleBUGS. There are also graphical tools for monitoring convergence of the simulation. The software would be of most interest to sophisticated users. Typical applications include generalised linear mixed models with hierarchical, crossed, spatial or temporal random effects; latent variable models; frailty models; measurement errors and other uncertainties in response variables and covariates; censored data; constrained estimation; missing data problems; and any analysis in which informative prior information needs to be incorporated.

Tools specifically developed for climate change risk assessment

These are some of the web-based tools that are available specifically to support climate change risk assessments. They include scenario-generating models, downscaling models and tools that link scenario generators and impacts models.

CLIMPACTS (International Global Change Institute, University of Waikato, Hamilton, New Zealand).
http://www.waikato.ac.nz/igci/climpacts_webpage/
The **CLIMPACTS** system is an integrated computer-based model, developed to examine the sensitivity of New Zealand's climate, agricultural and horticultural sectors to climate change and variability. It has the flexibility to allow the user to generate a large number of climate change scenarios, to ask a range of 'what if' questions about the climate sensitivity of selected sectors. At the top end of the system is the **MAGICC** global climate model, which provides time-dependent projections of global temperature change. These changes are used to scale patterns of climate change for New Zealand, derived from more complex global circulation models, to give scenarios of future climate up to 2100. This 'scenario generator' is linked to a range of crop models, as well as an extreme event analysis tool.

MAGICC/SCENGEN (National Centre for Atmospheric Research, Boulder, Colorado, USA and Climatic Research Unit, University of East Anglia, UK).
http://www.cru.uea.ac.uk/~mikeh/software/MAGICC_SCENGEN.htm
MAGICC (**M**odel for the **A**ssessment of **G**reenhouse-gas **I**nduced **C**limate **C**hange) is a set of linked, reduced-form models that emulate the behaviour of dynamic GCMs. MAGICC calculates annual mean global surface air temperatures and sea level for various user-defined emissions scenarios, and allows users to specify alternative scenarios to the standard IPCC scenarios. It has been designed to be used with **SCENGEN** (SCENario GENerator). **SCENGEN** is a simple database that contains the results of a large number of GCM

experiments, as well as observed global and four regional climate datasets.

SDSM (**S**tatistical **D**own**S**caling **M**odel) (UK Environment Agency/Canadian Climate Impacts Scenarios (CCIS) Group, Environment Canada).
http://www.sdsm.org.uk
SDSM is a robust statistical downscaling tool that allows the user to generate multiple, low-cost, single-site climate change scenarios. These provide daily surface weather variables for both current and future regional climate. The software also performs ancillary tasks, including data quality control, statistical analyses and graphing of climate data. There is an accompanying **UKSDSM** archive, containing a set of daily predictor variables prepared for model calibration and downscaling at sites across the UK. (See Wilby *et al*, 2002.)

Appendix 5
References and bibliography

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