UK Climate
Impacts Programme

Metroeconomica
Economic and Environmental Consultants

Costing the impacts of climate change in the UK

Overview of guidelines

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Foreword

It is only a couple of years ago that the phrase 'adaptation strategy' would have been completely alien to all businesses in the UK. Now it is on the boardroom agendas of some of our more forward-looking companies and beginning to be taken up by others through their professional bodies and trade associations.

What businesses need to know is the cost of climate change. It needs this in terms of the cost of different types of climate change impacts and the costs or benefits of different responses, including adaptation strategies. This is vital information if a business is going to be able to adapt and survive.

This report provides a methodology that allows business to do this: to cost climate change impacts in a consistent, credible and comparable basis. It is the first such methodology to be published in the UK and has been written with the business audience in mind.

The businesses that will succeed in this changing world are ones that are innovative, flexible and fast moving. They are the ones that will be the first to read this report and yet it is their competitors who should be paying attention if they are to survive.

Gerry Acher CBE LVO
Member of Advisory Committee on Business and the Environment (ACBE) and Chairman of Company Reporting Working Party

Climate change is one of the most important environmental challenges the world faces – this is now recognised by an increasing number of governments and agencies world-wide. Yet the debate on how best to respond to climate change is one which, so far, has been characterised by rather too much hot air and rather too little rational thought. This set of guidelines is to be welcomed precisely because it sets out a methodology for thinking rationally about the many possible responses to climate change that governments, firms and individuals can contemplate. This methodology is based on the reasoning of the paradigm of Cost-Benefit Analysis, which states that in a world of scarce resources, rational action demands a consideration of relative benefits and costs; and that governments need to take some account of public preferences in their decision-making. Cost-Benefit Analysis, in principle, allows for high quality, consistent decision-making to answer questions such as: which climate change-induced risks should we prioritise? Which adaptation or mitigation options should be chosen to respond to these risks? And how far should we go in, for instance, adapting to sea level changes or low flow problems in rivers? Is action preferable to the 'do-nothing' scenario?

However, Cost-Benefit Analysis faces big challenges in evaluating possible responses to climate change. These include the very long timescale of impacts, serious uncertainty over environmental change and human reactions to this change, uncertainty over the effectiveness of adaptation and mitigation measures, and the very wide range of impacts that a changing climate may have. Taken together, these challenges mean we will often only be able to produce order-of-magnitude estimates of benefit-cost ratios; however, even this 'rough advice' is likely to be better than no advice. It is also desirable that a methodology be adopted which allows for the fine-tuning of the scale of analysis to suit the particular problem being addressed: that is, to apply cost-benefit thinking to the analysis itself. This means that we will often need to turn to benefits transfer-type exercises to produce efficient and timely advice for policy-makers.

This costing framework shows how cost-benefit thinking can be used to produce better decision-making on responses to climate change risks, as well as pointing out the contribution that other methods such as multi-criteria analysis and cost-effectiveness analysis can make. A strong point of the guidelines is the worked examples of applying the methodology to issues as diverse as irrigation restrictions, transport disruptions and flooding risks. Aimed at the non-specialist, these guidelines will hopefully be seen as a valuable contribution to policy development.

Nick Hanley
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Executive summary: The importance of costing climate impacts and adaptation

1. Climate change is one of the most significant challenges we face over the coming century. Some climate change is now inevitable, no matter how successful we are at reducing emissions of the greenhouse gases that cause it. These changes will affect many aspects of our lives, environment, economy and society. Decision-makers need to manage the impacts of climate change – and may need to adapt – to minimise negative impacts and maximise any beneficial opportunities. In recognition of the importance of the problem, the Secretary of State for Environment, Food and Rural Affairs recently stated: "Our use of fossil fuels is changing our climate, with potentially dramatic and potentially disastrous results. Climate change is not by any means just an issue about the environment. It is a business issue." (*Rt Hon Margaret Beckett MP, Secretary of State for Environment, Food and Rural Affairs, 26 November 2003*).

2. **Adaptation** to climate risks is most likely to be important for:

- managers of business areas that are currently affected, directly or indirectly, by weather or climate;
- those making decisions with long-term consequences (decades or longer) for land-use, built assets or population groups;
- infrastructure and business areas that are sensitive to *changes* in climate;
- contingency planning; and
- those who want to gain an 'early-mover' advantage on a climate change business opportunity.

At present, there is a lack of reliable information on the costs of climate impacts, which makes it difficult for decision-makers to judge the amount of resources that they should allocate to adaptation in any given case. These guidelines aim to help to fill this gap, by providing a standard methodology for costing climate impacts, and comparing these with the costs of adaptation measures. The methodology should enable decision-makers to calculate valid, order-of-magnitude estimates of the costs, to help identify priority climate risks and to select appropriate adaptation measures. The methodology can be applied across a range of sectors, and at a local, regional and national scale in the UK.

What is different about costing climate impacts?

Costing climate impacts and adaptation measures poses some specific problems:

- Climate change is already happening and is a l**ong-term** risk issue, though clearly extreme climatic events can occur at any time. Most climate impacts will intensify over the coming decades, as the climate continues to change. Since individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now, **discounting** needs to be applied when costing future impacts. The Treasury Green Book (HMT, 2003) recommends discount rates for different future time periods, which must be used in public sector costing studies. Costing studies in the private sector can use the '**opportunity cost** of capital' approach.
- Climate impacts on one sector or region may well have **knock-on effects** elsewhere, and these may be significant for the choice of adaptation option. The use of the impact matrices provided in these guidelines should assist in the identification of the full range of impacts.

- In some cases, climate impacts might be significant enough that they cause changes in the prices of affected goods or services. These are called **non-marginal impacts** and they should be incorporated into valuations. For instance, wheat prices across Europe rose significantly in the summer of 2003, when the hot, dry weather caused harvests to fail in several European countries.

- There is **uncertainty** about the nature and magnitude of climate change and its impacts. There is also uncertainty about how these impacts should be valued, and about the performance of adaptation measures. It is important for decision-makers to understand and manage this uncertainty. This can include using a range of climate change scenarios to value climate impacts, and employing options selection criteria that have been developed for decision-making under uncertainty.

5. To address climate risks and uncertainties fully in the decision-making process, the costing methodology should be used within the context of the climate adaptation decision-making framework provided in another UKCIP Technical Report (Willows and Connell, 2003). In particular, the methodology is an important element of the **risk assessment** and **options appraisal** stages of the framework.

Audience for the costing methodology

6. The costing methodology is a flexible approach that can be used alongside other appraisal measures. It can be applied to costing studies in the public and private sectors. However, public sector decision-makers should primarily refer to guidelines on costings given by the Treasury Green Book, and to specialist costings guidelines from government departments, where these exist. The methodology presented here is consistent with the Green Book.

7. Two reports have been produced:

- The ‘overview of guidelines’ (this report) is designed to give non-economists a sound appreciation of the methodology, without including too much technical detail. It should enable decision-makers to identify research needs and successfully commission and interpret costing studies.

- The more detailed ‘implementation guidelines’ are aimed at economists, who need specific guidance on how to value climate change impacts at a local, regional or national scale, disaggregated by sector.

Steps in the methodology

8. The costing methodology involves:

- identifying and measuring (quantifying) climate impacts in physical units;

- converting these physical impacts into monetary values;

- calculating the resource costs of adaptation options; and

- weighing up the costs and benefits of the adaptation options, and choosing the preferred option, taking account of risks and uncertainties.

9. To help users identify climate impacts, the implementation guidelines provide impact matrices for the following sectors:

- coastal zones
- water resources
- agriculture
- buildings and infrastructure.

These matrices cover a broad range of impacts, but impacts on other sectors can also be identified.

10. Having identified an impact, the user then needs to measure (quantify) it in physical terms, before it can be costed in terms of money. This may involve undertaking a climate impact study. Further guidance on climate impact assessment is provided in Willows and Connell (2003).

11. The impact matrices help to identify the direct (‘lower-order’) impacts of climate change, such as increased coastal erosion caused by sea level rise – as well as the knock-on (‘higher-order’) effects, such as reduced visitor numbers to the affected coastline. Alongside each impact, the matrices highlight the appropriate economic **valuation** methods that can be used to convert the physical impact into monetary values.

12. The methodology is flexible enough to be applied across a range of scales from broad aggregated impacts on a region down to very refined disaggregated impacts on a particular receptor.

Techniques for valuing different types of impact

13. The valuation guidelines are grouped into two categories: conventional market-based techniques and individual guidelines tailored to specific types of receptor.

14. If the climate impact affects an asset or a marketed good or service then **conventional market-based costing techniques** can be applied as follows:

- Impacts on marketed goods or services can be valued according to changes in inputs or outputs, for instance using the 'change in productivity' approach.

- For impacts on man-made assets, cost-based methods, such as the '**replacement cost**' and 'avertive expenditure' techniques, will be appropriate.

15. These techniques use market price data to value climate impacts. The guidelines for these techniques are therefore written to facilitate the use of primary data, as these should be readily available to the user.

16. Impacts on non-marketed goods or services are more difficult to value, and so the methodology includes **individual guidelines** for valuing impacts on:

- habitats and biodiversity
- human health
- recreation and amenity
- cultural objects
- leisure and working time
- non-use benefits.

17. To value impacts in these areas primary valuation studies can be conducted. These use economic techniques such as 'hedonic analysis' (which values non-marketed goods using prices for related marketed goods); 'travel cost' (which uses the total price people pay to reach a site); or 'contingent valuation' (which asks people directly what value they place on a good or service). Using these techniques will often be expensive, but in many cases it will not be feasible or necessary to conduct **primary studies**. For instance, to pass a cost-benefit test, it is often only necessary to determine whether an option's benefits exceed its costs, and the exact magnitude of the exceedance is not needed.

18. Therefore, these guidelines recommend the use of '**benefit transfer**', which transfers values from existing studies to the climate change context. Clearly, this approach introduces errors from the existing studies and from transferring to the new situation. The user will need to weigh up the accuracy of cost information required for decision-making against the time and money involved in doing a primary valuation study, as opposed to applying benefit transfer. The reports provide guidance to help users work out which approach to take.

19. Where the user identifies an impact that does not appear to be covered in the conventional market or non-market guidelines, the guideline on unvalued impacts shows how information on the impact may be presented and used alongside monetised data e.g. in multi-criteria analysis.

Avoiding mistakes

20. For some climate impacts, quantitative impacts data will not yet be available, so it will not be possible to put a monetary value on the impact. For other impacts, suitable economic valuation techniques will not exist. But, for a complete assessment, all the significant impacts must be incorporated into the decision-making process. Techniques such as multi-criteria analysis can be employed to help with these cases.

21. There is a danger of double-counting when costing direct, 'lower-order' impacts (such as loss of coastal land to sea level rise) by aggregating the associated knock-on 'higher-order' impacts (such as loss of recreational sites and private property). Double-counting errors can also occur when adding 'use values' to 'non-use benefits', and care must be taken to avoid them.

Options appraisal

22. Once climate impacts have been valued, and the resource costs of the various adaptation options have been calculated, the **decision-maker** needs to bring this information together, to compare the outcomes of each

adaptation option, and identify the 'best' course of action. Various decision-support tools can be used to help the decision-maker select the preferred option. These guidelines show how these decision-support techniques can be used in this context.

23. Where outcomes are expressed in monetary terms, options appraisal may be performed in the framework of **cost-benefit analysis** (CBA). CBA is designed to demonstrate whether the total benefits of an adaptation option are greater than its costs.

24. However, economic value will seldom be the sole criterion for decision-making – other objectives are likely to be important too. In these cases, CBA can be used within the context of other decision-support tools, such as multi-criteria analysis, to account for these wider considerations.

25. Various selection criteria can be used to differentiate between options, depending on the quality of the decision-maker's knowledge. When knowledge of the probability of an event is poor, (as will often be the case with climate change) criteria such as 'maximin' or 'minimax regret' can be used. Other techniques, such as '**net present value**', or 'expected net present value' are useful when the decision-maker has greater **certainty** about outcomes.

26. The decision-maker will want to know how sensitive his/her estimates are to the input data and models used in the analysis. She/he will also need to understand any key assumptions. Techniques for testing the factors that underpin the estimated outcomes include **sensitivity analysis**, simulation and interval analysis.

Case studies

27. This 'overview of guidelines' report includes illustrative case studies demonstrating the application of the methodology to four different issues where adaptation might be considered:

- water resources – the cost of increasingly stringent effluent standards;
- agriculture – the cost of not meeting irrigation need;
- flooding – the changing costs and impacts of flood alleviation;
- time losses – the cost of short-term disruption to transport systems.

Working towards a climate-adapted UK

28. Climate change presents a wide range of risks to decision-makers. The use of these guidelines by decision-makers in a range of sectors and regions should help in the UK's efforts to adapt appropriately to climate risks. If the guidelines are widely used, this will facilitate a national assessment of the costs of climate change to the UK.

1. Introduction

"Our use of fossil fuels is changing our climate, with potentially dramatic and potentially disastrous results. Climate change is not by any means just an issue about the environment. It is a business issue."

Rt. Hon. Margaret Beckett MP, Secretary of State for Environment, Food and Rural Affairs, 26 November 2003.

1.1 Background to the costing guidelines

It is now generally accepted that the global climate is changing as a result of human activity. In 2001 the Intergovernmental Panel on Climate Change (IPCC) concluded that there is 'evidence that most of the warming observed over the last 50 years is attributable to human activities'. This warming has been termed **climate change**, a general phrase that is used to refer to the changes in the Earth's climate anticipated to occur as a consequence of the release and accumulation in the atmosphere of greenhouse gases resulting from human activities. As a result of climate change, changes are occurring in the whole pattern of the weather, with the extent and nature of change differing from country to country, and region to region.

Although general agreement has been reached about the fact that the global climate is changing, and despite great improvements in understanding the Earth's climate, there is still uncertainty as to the impacts that are expected to accompany climate change. Decisions as to the most appropriate action to take are therefore complex. Much of the action taken to date to lessen the effects of climate change has focused on controlling and reducing the emission of greenhouse gases (and particularly CO_2). While these actions are likely to affect the situation in the future, some climate change is now inevitable.

The changes currently taking place will have wide-ranging implications for populations, economies, and the natural and built environments, presenting society with new threats and opportunities. Climate change will alter the long-term average climate and also change the incidence of short-term extremes. Since some changes are inevitable, there is a clear need to adapt to them, and to anticipate future impacts for this generation and for future generations. There are a myriad of different adaptation strategies that could be adopted for different sectors, and at different levels; e.g. local, regional, national and international, and policy, programme and project. For instance, two ways to adapt to lower summer rainfall are to install irrigation systems or to switch to alternative crops. Higher winter rainfall can be adapted to by improving flood management. Improved cooling systems can be used to adapt to warmer summers – the list is immense.

Society, however, cannot finance all of the desirable adaptation projects. Decision-makers must therefore decide whether or not a particular **risk** presented by climate change should be adapted to, and if so, what adaptation option(s) should be chosen. One approach would be to choose the option that provided the highest benefit (in terms of risks avoided) over and above their costs. Identifying such strategies is difficult, not least because the benefits are sometimes not expressed in money terms.

The value of this report is that it seeks to address this problem. It does so by providing a standard methodology that can be used to estimate the cost of climate change risks, both with and without adaptation. This allows decision-makers within the public and private sectors to compare the effectiveness of different adaptation measures in limiting the effects of climate change on the welfare of society. This means that the threats and opportunities presented by climate change can be valued, and appropriate decisions made about the allocation of resources to reduce (or enhance) these threats (or opportunities).

1.2 Aims and objectives of this report

From the above discussion it is evident that decisions relating to climate adaptation inevitably involve prioritising among climate risks, and between the alternative options available to adapt to those risks judged to be significant. More formally, a decision-maker may face two forms of adaptation analysis – namely:

- **Assessment, prioritisation and ranking of risks** – to generate valid 'order-of-magnitude' estimates for climate risks of interest, so that their relative importance can be established.
- **Adaptation option appraisal** – to generate valid 'order-of-magnitude' estimates of the net benefits of options to adapt to significant climate risks, so that the 'best' (or preferred) option(s) can be implemented.

Amongst the many considerations that organisations would take into account in any decision-making context, a key one is the **net benefit** of action, relative to the cost of doing nothing. Assuming that these 'economic' considerations are important to the decision-maker, it would therefore be useful to quantify them in the context of the two climate adaptation analyses listed above.[1]

Clearly, making decisions in either of these two contexts involves trade-offs between various impacts on different vulnerable receptors (e.g. flora and fauna, the man-made environment, and sub-groups of the general population) and the **financial cost** of investing in adaptation. In order to make such trade-offs easier for the decision-maker, it is helpful for the consequences of adaptation to be described in a single dimension, specifically, money terms, where possible. However, there is currently a clear lack of reliable cost estimates relating to the different risks that climate change presents at a regional or sector level. This makes it difficult to prioritise between different climate change risks, and draw effective comparisons between adaptation responses and the net benefit of those responses. It is this gap that this report seeks to begin to fill, by providing a methodology with which to cost climate risks to the UK. The methodology described herein provides guidance in generating broad ('order-of-magnitude') estimates of the cost of climate impacts and, in the light of these estimates, the benefits of adaptation responses to those impacts judged to require urgent action. The widespread use of the costing guidelines outlined in this report should ensure consistency in cost-benefit estimates, thereby making integration of results from different studies easier – in line with the broader aims of UKCIP.

There are specific methodological issues that distinguish the costing of climate risks and adaptation options that also warrant the development of these guidelines. One is the wide range of risks that climate change is expected to present to many environmental, economic and social sectors across the UK. Decision-makers, when devising unrelated policy, programmes or projects, should take climate risks into account. This makes consistency between standard appraisal practices an important objective if the policy response is to be cost-efficient. The guidelines allow the analyst to address this issue systematically.

A second issue is that there is a pattern of uncertainty regarding the nature, scale and spread of climate risks over long time periods that make cost-benefit estimation more complex than the usual contexts in which options appraisal is conducted. This makes it imperative that a climate adaptation costing methodology is developed that is framed within the context of climate change uncertainty, and complements the UKCIP Technical Report on handling climate risk and uncertainty (Willows and Connell (eds.), 2003).

Thirdly, given the long time-scales that are relevant to the climate change impact context, attention is also drawn in the report to the importance of the treatment of discounting costs and benefits.

These guidelines additionally serve to present the likely physical impacts of climate change alongside the monetary valuation techniques available for these impacts and serve to steer the public sector analyst when dealing with the climate change context. The same is true for the private sector analyst, though (s)he has flexibility as to

[1] As stated, economic considerations are not the sole criteria on which decisions tend to be made, particularly in the public sector. For example, flexibility, political sensitivity, avoiding irreversible impacts, equity, etc. are all important 'decision factors'. Consideration of these factors when appraising options is also dealt with in these guidelines.

the choice of valuation technique. As a consequence, these techniques are outlined in this report and in further depth in the Implementation Guidelines.

The costing guidelines are aimed at two user groups, each with different needs:

- Non-economists/decision-makers in either the private or the public sector – who need a document, with reduced technical content, that will: (a) introduce them to the main issues in costing climate risks and adaptation options; (b) allow them to identify research needs and provide guidance in commissioning work in this area; and (c) allow them to interpret the results of climate change costing studies.

- Economists/specialists in either the private or the public sector – who need a document that will provide technical support when conducting climate risk and adaptation costing studies at a local/regional scale, disaggregated by sector.

As a result, two reports have been prepared, one targeted at each user group. **This report ('Overview of guidelines') is aimed at the former user group**. As stated above, the Overview is not designed to provide technical support to users when conducting a costing study. This is the domain of the accompanying report ('Implementation Guidelines'), which is aimed at the second user group. The Overview, as the name implies, provides a synopsis of key elements of the implementation guidelines. In the text to follow, we make many links between the two reports. By reading this report, the user will gain a good appreciation of the contents of the implementation guidelines, and its potential as a tool to:

- Provide guidance on how to generate valid 'order-of magnitude' estimates of the cost of climate risks, and the benefits of adaptation to these risks.

- Minimise the potential for poor, inaccurate or inconsistent cost estimation.

- Provide the user with an iterative costing process with built-in flexibility to permit the depth of the analysis desired by the decision-maker to coincide with data, budget and time constraints.

1.2.1 RELATED AND COMPLEMENTARY GUIDANCE MANUALS

It is worth noting that a number of relevant manuals have been produced by various government departments and other institutions. These manuals provide detailed guidance on *one or more* specific aspects of climate change impact and/or adaptation assessment. For example, the former MAFF (now Defra) produced a series of guidelines on the appraisal of flood and coastal defence projects (the Flood and Coastal Defence Project Appraisal Guidance (FCDPAG) series, of which FCDPAG3 is of particularly interest since it relates to economic appraisal, (MAFF, 1999a)). The current series of guidelines can be found at http://www.defra.gov.uk/environ/fcd/pubs/pagn/default .htm. The UK Treasury has also published guidelines relevant to the methodologies contained in this manual, including the revised *The Green Book – Appraisal and Evaluation in Central Government* (HMT, 2003), available at (http://greenbook.treasury.gov.uk/), and this is recognised within these guidelines as being the primary source of guidance for public sector economic analysts.

The Flood Hazard Research Centre at Middlesex University has also produced guidance manuals, (see e.g. Penning-Rowsell *et al.*, 1992). These documents provide guidance with respect to one key impact area each; for example, coastal developments. Similarly, the Foundation for Water Research (FWR, 1996) has produced detailed guidance with respect to another key impact area: the benefits (costs) of water quality improvements (deterioration). In terms of the individual valuation methods covered in these guidelines, the DETR (now Defra) also has provided detailed guidance on, for instance, the use of multi-criteria analysis (MCA) (DETR, 2001a), and the **contingent valuation method** (CVM). (DETR, 2001b). Other related documentation published by the UK government includes *Ancillary effects of greenhouse gas mitigation policies* by Defra,[2] and *Estimating the Social Costs of Carbon,*[3] that presents aggregate costs of global emissions per

[2] http://www.defra.gov.uk/environment/climatechange/ewpscience/

[3] http://www.hmtreasury.gov.uk/Documents/Taxation_Work_and_Welfare/Taxation_and_the_Environment/tax_env_GESWP140.cfm

ton of carbon. Clearly, the costings methodology presented here does not supersede or overrule any detailed guidance provided by UK government departments in relation to specific investment programmes. Indeed, wherever possible in these guidelines we refer to the relevant guidance already existing for analysts in government departments and executive agencies.

The reason that these guidelines have been thought important to develop is that none of the aforementioned documents provides a comprehensive guide which is specific to climate risk and/or adaptation assessment. However, for public sector analysts, the advice provided in these guidelines should not supersede official government guidance, where it exists on appraising specific impacts of interest.

1.3 Structure of the report

The report is divided into five main sections. Following this introduction, Section 2 outlines the contextual framework of the report. This places the costing guidelines in the context of a climate adaptation decision, thereby defining the scope of the report. Section 3 provides an explanation of how risk (impact) assessment can be carried out using the climate impact matrices developed for this study, and is designed to help the user link specific climate impacts of interest to economic valuation guidelines. Information about the specific valuation guidelines and their use is provided in Section 4. Section 5 considers the appraisal of alternative adaptation options, including standard aspects of economic analysis that should be followed when: (1) costing specific climate risks and adaptation responses; and (2) using the estimated costs/benefits in the appraisal of alternative courses of action (or options to implement). Option appraisal under conditions of uncertainty is also considered in Section 5, since most climate change decision-making contexts inevitably involve a large element of uncertainty. A number of case studies, which illustrate the application of the costing guidelines to hypothetical climate impacts, are presented in Appendix 1.

2. Contextual framework of the costing guidelines

2.1 Introduction

This section outlines the context, or decision-making framework, within which these costing guidelines are to be used. This framework, which is shown in Figure 2.1 below, identifies the main stages comprising 'good' decision-making in the face of climate risks. The good practice framework in Figure 2.1 covers all stages in the decision-making process, from problem specification through to ex-post evaluation. The focus of this report is the economic valuation of identified climate risks and the appraisal of options to address these risks.[4] Another UKCIP Technical Report (Willows and Connell, 2003) provides this framework.

The costing methodology is an important element of Stages 3 and 5 within the framework – risk assessment and option appraisal. Application of the costing methodology in a climate adaptation decision-making context (e.g. what adaptation option should be adopted to mitigate exposure to the risks of sea level rise in a region) provides the decision-maker with a monetary measure of the outcome resulting from any course of action taken. Often, the decision-maker will have several alternative options that can be pursued; therefore, a range of possible outcomes may be realised. Moreover, there may be a range of outcomes arising from each option, reflecting uncertainty in the analysis. Once the range of possible outcomes has been described to the decision-maker, they are generally appraised in order to identify the option that provides the 'best' outcome subject to the broad objective(s) and decision criteria established by the decision-maker.

Before we explore the context of the costing guidelines in further detail, it is important to acknowledge that uncertainty is inherent in climate change risk assessment. Economic valuation is also an uncertain science. Hence, combining the two within the costing methodology essentially piles uncertainty on top of uncertainty. It is therefore important when using these guidelines that uncertainty is effectively managed, and the user fully appreciates the uncertainties inherent in the range of possible outcomes. To this end, some guidance is provided on appraising outcomes in the presence of uncertainty.[5]

2.2 Generic decision problem

2.2.1 ELEMENTS OF A DECISION PROBLEM

Any decision-making context (or decision problem), whether in the private sector or the public sector, or concerning policy, programmes or projects, involves several standard elements. First, an individual (the decision-maker) must be confronted with a 'problem'. A problem may arise as a result of, for example, changes in legislation, reviews of ongoing activities, public concerns, or the emergence of new evidence on climate risks. The **decision-maker** is the person or institution that is dissatisfied with the prospect of a future event, and who possesses the desire and authority to initiate actions designed to alter this event.[6] For example, a water company, concerned about the prospect of a demand-supply imbalance in the future, is potentially a decision-maker in this sense.[7] The water company may be dissatisfied with the imbalance because it compromises a broad company objective or desired 'state of affairs', e.g. the provision of a reliable water service at

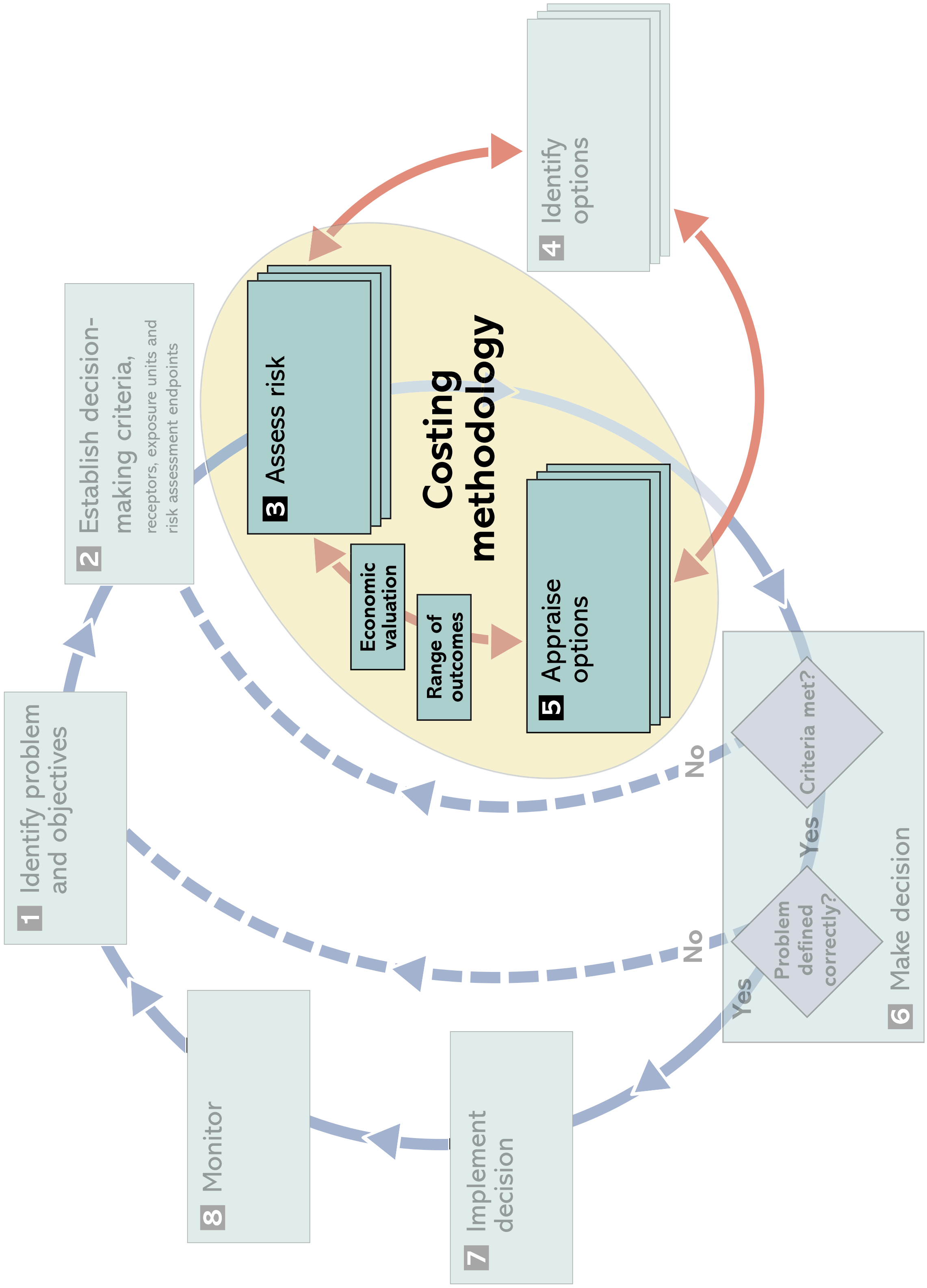
4 These options range from 'doing nothing' to 'doing a little' to 'doing a lot'.

5 A more detailed treatment of dealing with the uncertainty associated with decisions in a climate change context is provided by Willows and Connell (2003).

6 In the context of these costing guidelines, the decision-maker may represent: a national, regional or local government; a department within one of these levels of government; an environmental/economic/industry regulator; a multinational or small and medium-sized enterprise, whether privately or state-owned; or individual members of society.

7 If the supply-demand imbalance is a judged to be a direct consequence of climate change, Willows and Connell (2003) refer to such decisions as problems of climate adaptation. Climate change may not necessarily be driving the need for the decision; however, the decision to address the imbalance may be sensitive to climate change risks. If these risks are not negligible, then there may be a case for building some adaptation into the decision. Willows and Connell (2003) refer to these decisions as climate-influenced decisions.

Figure 2.1: The costing guidelines in the context of a framework to support good decision-making in the face of climate change risk.
(Based on Willows and Connell, 2003)



a reasonable cost. (The decision-maker's desire to achieve this state of affairs is the reason for the existence of the problem in the first place.)

To pursue the broad objective the decision-maker must first translate the objective into operational decision-making criteria (e.g. one criterion might involve the provision of 150 ML of raw water per day at a **unit cost** not exceeding 3 pence per litre). These criteria will facilitate the identification of alternative **options** to alleviate, in this example, the demand-supply imbalance, and allow the desired state of affairs to be achieved.[8] These options, together with a state of doubt as to which one is 'best', constitute the heart of the decision problem. In the case of the water company, is the demand-supply imbalance best addressed through, say, demand management or supply enhancement? (Or is it best not to address the imbalance, since one should always evaluate options versus the 'do nothing' option?)

Baseline definitions relevant to these guidelines

The precise specification of a decision problem involves, among other things, establishing the analytical baseline from which the magnitude of climate risks, and subsequently the effectiveness of adaptation responses, are measured. As noted in Section 1, these guidelines are designed to support the decision-maker with two stages in making climate adaptation decisions – namely:

- **Assessment, prioritisation and ranking of risks** (stage 3 in Figure 2.1) – to generate, where possible, valid 'order-of-magnitude' estimates of the cost of climate risks, so that their relative importance can be established (this extends economic valuation to Tier 3 risk assessment, as explained in Willows and Connell, 2003).

- **Adaptation option appraisal** (stage 5 in Figure 2.1) – to generate valid 'order-of-magnitude' estimates of the net benefits of adaptation to specific climate risks (this extends economic valuation to Tier 3 options appraisal, as explained in Willows and Connell, 2003).

Each of these stages has a unique reference scenario, which we need to define.

Assessment, prioritisation and ranking of risks

In this context we seek to estimate the economic value (*positive or negative*) of climate change in the absence of adaptation responses. The 'reference' scenario (or 'baseline') appropriate to this context is defined by the situation assumed to exist in a geographical and temporal context in the absence of climate change. This particular reference scenario may also be referred to as the '**without**' climate change case. Given projected scenarios for climate change, the climate change risks are calculated as the difference between the '**with**' and '**without**' climate change case.

Following the presentation given in Parry and Carter (1998), there are essentially two different reference scenarios which can be used to assess climate change risks. One is a **fixed reference scenario** in which current (natural) climatological, environmental and socio-economic conditions are assumed to prevail in the study region into the future. Taking the impact of climate change on agricultural productivity, for example, a fixed reference scenario would assume that current rates of productivity prevail over the whole period of study. In this case, the impact of climate change in any one time period is measured as the difference between the reference (current) rate of productivity without climate change, and the projected rate of productivity with climate change.

The fixed reference case, although frequently used in climate impact assessment studies, is an unrealistic representation of the future. Taking our example, agricultural productivity is likely to change over the study period irrespective of climate change (e.g. due to changing pressures on agricultural land, population growth, changes in biotechnology, etc.). Realism can be introduced by constructing projections of future (natural) climatological, environmental and socio-economic conditions in the study region in the absence of climate change – i.e. we could use a **projected reference scenario** to describe the future without climate change.

[8] The decision criteria also serve as a basis for the risk assessment and as a basis for assessing the performance of the various options under consideration. Guidance on the identification and creation of 'options' is provided both in Willows and Connell (2003) and HMT (2003), although only the former deals specifically with adaptation to climate change.

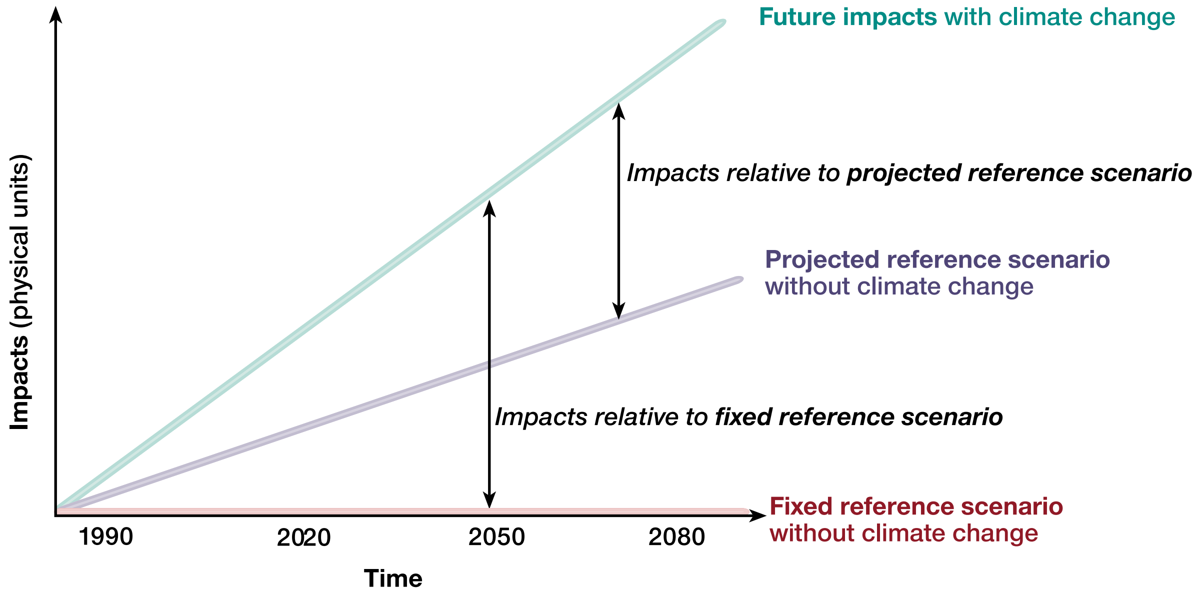


Figure 2.2: Illustrating reference scenarios for climate change risk assessments.[9] *(Adapted from Parry and Carter, 1998)*

Box 2.1: Estimating the economic value of climate change impacts
The economic value (+ve or -ve) of the climate change impact (£)[10]
equals
The estmated impact of climate change (physical units)[11]
multiplied by
The economic unit value of the impact (£ per unit)

The use of both a fixed and a projected reference scenario to assess the impacts of climate change is illustrated in Figure 2.2 above. The impact of climate change in a specific year is given diagrammatically by the vertical distance between either of the two reference scenarios and the line labelled 'Future impacts' (which in this example depicts cumulative losses in agricultural productivity as a result of climate change). In this case, the costing methodology can be used to estimate the economic value (positive or negative) of climate change on an affected (exposure) unit (see Box 2.1).

As mentioned earlier, the value of this information is that it reveals to decision-makers those climate change impacts that are likely to cause the most severe damage, and therefore those risks to which most attention should be given.

Adaptation option appraisal

We assume that decision-makers can undertake some form of **adaptation strategy** in response to important climate risks (opportunities). The effect of the adaptation response is to reduce (enhance) the future exposure of a receptor[12] to climate risks. We can think of the reduction (enhancement) in the risk as the 'effective-

[9] In the example illustrated in Figure 2.2, productivity is assumed to be lower with climate change – hence, cumulative future impacts (foregone productivity) rise over time. Also, the impacts of climate change relative to the projected reference scenario are less than those relative to the fixed reference scenario, but they could just as easily be greater – in which case the projected reference scenario would be below the horizontal axis.

[10] The reader should be aware that climate change impacts may be sufficient in scale to alter 'prices'. We discuss this possibility and its implications for economic analysis in Section 5.

[11] The impact of climate change on the exposure unit is calculated as the difference between the 'with' and 'without' climate change case.

[12] At this point it is worth making a subtle distinction between exposure units and receptors. In Willows and Connell (2003) an exposure unit is defined as the system considered at risk from climate change. An exposure unit is often described in terms of the geographical extent, location and distribution of the population or populations of receptors at risk.

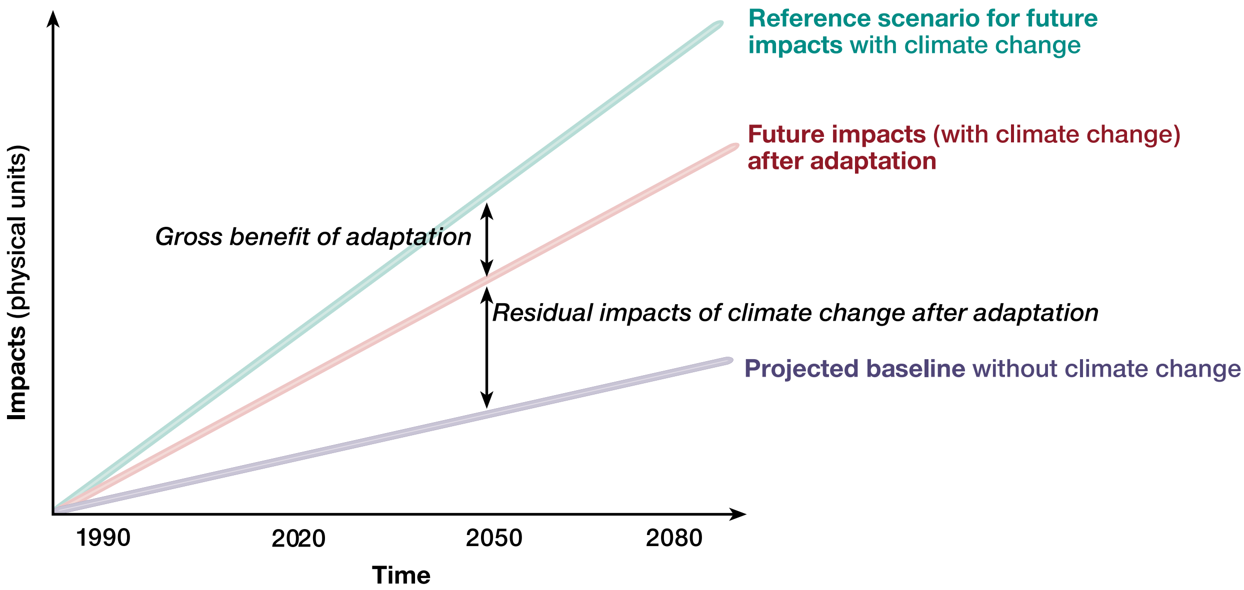


Figure 2.3: Illustration of the benefits of adaptation. *(Adapted from Parry and Carter, 1998)*

ness' of the adaptation response, or the gross benefits of adaptation. This is given by the estimated impact of climate change *in the absence* of adaptation minus the estimated impact *with* adaptation, and is illustrated in Figure 2.3. Note that in this context the reference scenario is now defined by the '**with**' climate change case, since the gross benefits of adaptation are measured *relative* to the 'Future impacts' curve.

In this adaptation decision context, the costing methodology can be used to estimate the gross monetary benefit of an adaptation strategy (see Box 2.2).

Furthermore, the magnitude of residual impacts on selected receptors across different study regions can also be evaluated.

The value of this information to decision-makers is that, together with information on the resource costs of the adaptation strategy, it can be used to ask the following general policy question:

> **Is the gross benefit of the adaptation strategy *greater than* the cost of the adaptation strategy?**

These costing guidelines are designed to allow the user, whether a private sector or a public sector decision-maker, to answer this question, which in turn allows him/her to, for example, accept or reject a single adaptation option, or to choose one option from a number of possibilities.

Box 2.2: Estimating the gross monetary benefit of an adaptation strategy

The gross benefit of the adaptation strategy

equals

The 'effectiveness' of the adaptation strategy in mitigating exposure of the receptor(s) to the climate change risks (physical units)

multiplied by

The economic unit value of the impact avoided (£ per unit)

System boundaries

The specification of a decision problem also requires the geographical boundaries of the analysis to be defined. Boundary definition will, of course, depend on the nature of the analysis being undertaken and the goals of the study 'sponsor'. Suppose, for example, that climate change is anticipated to present an adverse risk to agricultural output in one region of England, but that this will be offset by an equivalent gain in another

Box 2.3: Relationship between reference scenarios and stages in decision	
Stage	**Appropriate reference scenario**
Assessment, prioritisation and ranking of risks	'Without' climate change case
Adaptation options appraisal	'With' climate change case

region. From a national perspective the net cost is zero, and adaptation funded from general taxation would not be justified – at least in terms of national losses in the output of the affected produce. However, at a regional level, the relevant authority may well view the anticipated impacts as a 'real' gain or loss, and subsequently feel that a response is justified. The point is that **geographical boundaries must be defined according to user needs**; and given this boundary, it is only the **net** costs/benefits that are relevant. Users in the public sector should note that HMT (2003) defines the system boundary for all economic analyses to capture all impacts to the UK.

2.2.2 IDENTIFYING POSSIBLE OUTCOMES OR CONSEQUENCES

Having defined a decision problem in contexts applicable to these guidelines, we can now return to the decision-making framework described earlier to see how it is used to analyse these problems, logically and consistently.

For any given climate adaptation decision there is likely to be a number of options that could be pursued to meet the overall decision criteria. The question that beckons is, which of these options represents the preferred option(s), or the best way forward? To answer this question the decision-maker must evaluate the options against the decision criteria. This is the primary function of **options appraisal**.

However, before options appraisal can be carried out, the decision-maker needs to know, for each of the available options, what are the different outcomes or consequences that might result, and what are the uncertainties associated with these outcomes? Looking at this process in more detail, each option (A_1, A_2, …) will interact with a variety of future factors ('**states of nature**' (S_1, S_2, …)), including climate change scenarios and actions taken by other individuals or groups. These interactions will determine the outcomes of the decision problem; that is, whether the decision criteria will be met as a result of the options considered and the prevailing states of nature. Typically, a (wide) range of outcomes could occur in the context of any specific climate adaptation decision. The decision-maker is, as noted above, under pressure to choose the 'best' option. To assist the decision-maker in making their selection, the totality of possible outcomes can be presented in the form of an outcome (or consequence) array,[13] an example of which is shown in Table 2.1. This **outcome array** summarises the range of possible outcomes (O_{11}, O_{12}, etc.).

It is important to recognise when faced with an array of possible outcomes, however, that *only one* specific state of nature will actually occur. In other words, only one 'future world' will actually be realised. Since it is generally not known which state of nature will occur (i.e. the future is uncertain), all must be considered.[14] The analyst must therefore plan for a range of possible scenarios (states of nature). Also, as a further consequence of uncertainty, the outcome recorded in any cell is likely to be described as range of plausible values.

At this point it is worth emphasising that **this report is not designed to provide guidance on the development of possible future states of nature, or the identification of adaptation options available to the decision-maker to achieve the desired state of affairs**. Other UKCIP Technical Reports provide guidance to these ends – e.g. Hulme *et al.* (2002) and Willows and Connell (2003).

[13] These arrays are also known as payoff or performance matrices.

[14] In this example we only talk about three possible states of nature, but in a real climate change decision problem there may be many more possible contingencies.

Table 2.1: Example of an outcome array (or payoff matrix)

		State of nature		
		S_1	S_2	S_3
Options	A_1	O_{11}	O_{12}	O_{13}
	A_2	O_{21}	O_{22}	O_{23}
	A_3	O_{31}	O_{32}	O_{33}

How the outcomes are described – the so-called 'outcome descriptors' (O_{11}, …, O_{33}) – will normally measure the degree to which the decision criteria (and therefore the broad objectives) are met. You will recall that objectives reflect the decision-maker's desire to achieve a future state of affairs that is 'better' than the anticipated future state resulting from 'inaction'.

Economic analysis is generally concerned with the increment in money associated with taking one course of action over another. Put another way, in economic analysis the decision criterion by which we judge the success of an option in achieving the decision-maker's broad objective is based on monetary value. In this case outcome descriptors are of two types: (1) the **resource costs** associated with the option (e.g. the **economic cost** of all resources consumed by the adaptation strategy); and (2) the **economic benefits** derived from the outcome (e.g. the climate risks and associated damages avoided as a result of the adaptation response). This costing methodology aims to measure, as far as possible, the economic benefits in money terms. Since the resource costs and benefits are then expressed in the same terms – money – the difference between them (i.e. the **net benefit**) provides a valid measure of the aggregate money value of each outcome.

Reducing the outcome descriptors to a single dimension is useful in that it simplifies the identification of the 'best' option. To compare alternative options in terms of economic value, the decision-maker need only consider the net benefit of each option.

It is important to reiterate at this point that there is considerable uncertainty regarding not only the impacts of climate change, but also the monetary values of those impacts (we return to this below). A second point to note is that it is not always possible to estimate the monetary values of impacts, therefore a straightforward comparison of the net benefits of options may be misleading, or not possible (important unvalued impacts would be ignored). Furthermore, decision problems may involve objectives other than economic value, such as political acceptability; these alternative objectives cannot always be described and analysed in monetary terms. It may, therefore, be the case that each outcome is described by a combination of a monetary descriptor and non-monetary descriptors. The comparison of outcomes in the presence of multiple descriptors (decision criteria) involves the use of multi-criteria techniques. We say more about these techniques below.

Box 2.4: The aim of the costing methodology

The primary objective of the costing methodology is to provide guidance on how outcomes, corresponding to a particular combination of a specific option (adaptation response) and a specific state of nature (climate change impact scenario), can be described in monetary terms. Hence, in terms of Table 2.1, the costing methodology is concerned with how outcomes (O_{11} through O_{33}) can be expressed in money, as far as possible, given information on options (A_1, A_2 and A_3) and states of nature (S_1, S_2 and S_3).

2.2.3 OPTIONS APPRAISAL

Once the climate change risks have been quantified, and where possible valued, and the resource costs of alternative adaptation options assessed, this information can be displayed in a table of the type shown in Table 2.1. The various outcomes are then compared as the decision-maker seeks a solution to the decision problem

Box 2.5: Key decision-support tools used in these guidelines

Cost-benefit analysis (CBA) is designed to show whether the total advantages (benefits) of a project or policy intervention – e.g. an adaptation option – exceed the disadvantages (costs). This essentially involves calculating in monetary terms all of the costs and benefits, including items for which the market does not provide an observable measure of value, accruing to all affected parties. The affected parties should include not only the policy/programme/project participants and consumers, but also third parties who are affected. Basically, an adaptation project represents a good investment if the aggregate benefits exceed the aggregate costs.

Cost-effectiveness analysis (CEA) is also used to evaluate trade-offs between benefits and resource costs. However, in contrast to CBA, the benefits are measured in units other than money. Moreover, the output (or benefit) of the policy/programme/project is the same or similar for all options considered. It can be used to identify the highest level of a physical benefit given available resources (e.g. delivering the maximum reduction in risk exposure subject to a budget constraint), as well as the least-cost method of reaching a prescribed target (e.g. the supply of a given quantity of potable water).

Multi-criteria analysis (MCA) has been developed to account for the fact that some effects cannot be measured, or cannot be costed. Moreover, economic efficiency may not be the sole criterion in climate adaptation decisions. Other objectives, including flexibility, avoiding irreversibility, equity, risk and uncertainty, political sensitivity, etc. are important. MCA essentially involves defining a framework to integrate different decision criteria in a quantitative analysis without assigning monetary values to *all* factors. HM Treasury (2003) refer to MCA as 'weighting and scoring'.

at hand. To support the decision-maker in selecting the 'best' or 'preferred' option, (or at least a good one), several option appraisal or decision-support tools can be used. When outcomes are described in money terms, option appraisal is typically performed in the framework of **cost-benefit analysis** (CBA). However, since it is not always feasible to express all relevant risks in money terms, nor is 'net benefit' always the sole criterion by which the success of an option is judged, alternative decision-support tools have been developed, which are capable of dealing with unvalued outcome descriptors; namely **cost-effectiveness analysis** (CEA) and **multi-criteria analysis** (MCA). All these tools are used to support the option appraisal component of the decision-making process. However, government departments and executive agencies should note that the Green Book recommends the use of CBA, over CEA, with supplementary tools used for weighing up unvalued costs and benefits (HMT, 2003).

2.2.4 ISSUES OF UNCERTAINTY

Decision problems may be classified according to the degree of knowledge the decision-maker has about future outcomes. In theory, there are two states of knowledge which a decision-maker can have: (1) certainty, and (2) uncertainty.

A situation of **certainty** exists if the decision-maker has complete knowledge of every element of the decision problem (e.g. the probability of an event or state of nature being realised, and the magnitude of the likely consequences arising from exposure to this event or state of nature). In this case the decision-maker is therefore certain of the outcome associated with each option. Since each option is assumed to lead to a unique outcome, the decision problem of choosing among alternative options is reduced to one of choosing among outcomes. For example, if in following the application of these costing guidelines one reduced the resource costs and associated benefits of each adaptation option to a single aggregate descriptor – net benefit – then *if* the decision-maker's sole decision criterion were maximisation of net benefit, the solution to the decision problem would be simply a matter of selecting the option with the highest net benefit. The 'best' option is the one, which leads with *certainty*, to the 'best' outcome. (Of course, solving the decision problem under certainty is not so straightforward in the presence of multiple objectives.)

Decision problems under certainty do not, however, exist in the real world. Most decision problems, especially those in the context of climate change impact and adaptation assessment, involve some degree of uncertainty about the outcomes that may result from the implementation of a given option. Uncertainty differs from certainty in that the latter involves a specified set of conditions leading to *one* outcome, while uncertainty involves a range of possible conditions which may occur, leading to the existence of *more than one* potential outcome.

Now, the decision-maker may lack some knowledge that is important to a particular climate adaptation decision. For example, the decision-maker may not know with certainty the likelihood that a particular event will occur, or the magnitude of the consequences of exposure to that event. If (s)he does not know the probability and/or the consequence, the decision-making context is one of 'uncertainty'. Uncertainty is said to exist if the decision-maker lacks knowledge as to the outcome of the decision.

All climate change related decision problems will involve uncertainty. To support the decision-maker in selecting the 'best' option in these circumstances, specialist techniques are required. These techniques are reviewed in Section 5.

2.3 Estimating outcomes for the decision problem

2.3.1 INTRODUCTION

The purpose of using the costing methodology is to populate the outcome array shown in Table 2.1, by expressing the descriptors in monetary terms. This section considers the generation of these monetary descriptors.

2.3.2 THE COSTING METHODOLOGY – AN OVERVIEW[15]

We have already shown that the costing methodology comprises two steps. Before climate change impacts can be valued they must first be identified and measured (Step One). Only once they have been quantified is it possible to determine their relative economic importance by expressing them in monetary terms (Step Two). The identification and measurement or quantification of risks is therefore a prerequisite for their valuation. The two-step nature of the costing methodology is illustrated in Figure 2.4, taking coastal zones as an example (we will return to this figure below), and summarised in Box 2.6. This two-step process is vital, as it underpins the approach to valuation prescribed in this report.

Box 2.6: The basic approach to valuation used in these guidelines

The cost (benefit) of a climate change risk to (impact on) an exposure unit (£)

equals

The expected physical impact on the exposure unit (number of units affected)

multiplied by

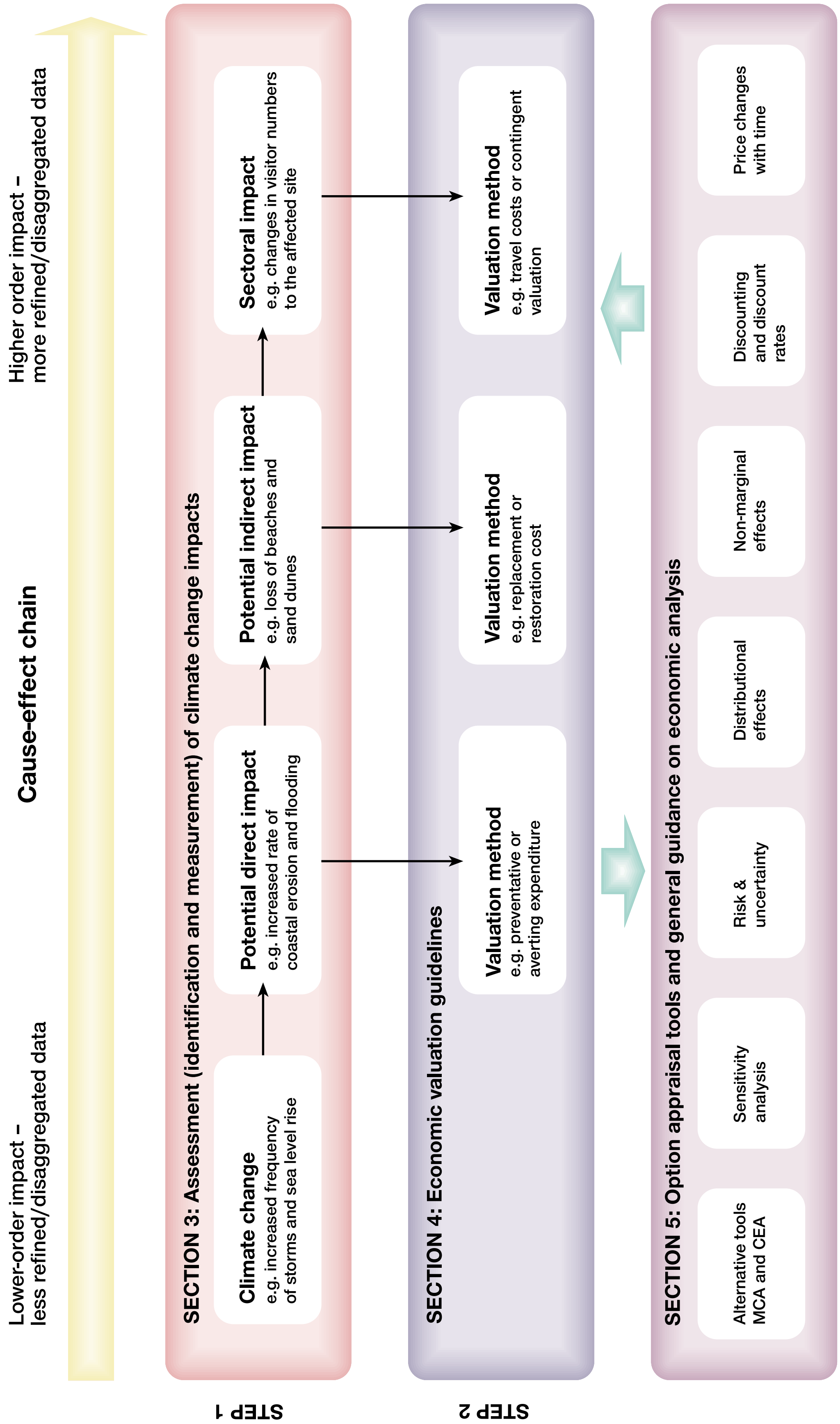
The appropriate economic unit value (£ per affected unit)

Figure 2.4 illustrates the pathway or hierarchy of cause from climate change through to specific impacts, which affect the welfare of individuals. In this report '**lower-order impacts**' refer to the direct impacts of climate change, such as coastal erosion or flooding. '**Higher-order impacts**' result from the lower-order impacts, so that given the lower-order impact of flooding, a higher-order impact could be loss of natural habitat, and a still higher-order impact is the loss of recreational and other values that people place on that habitat. Essentially, this is represented across the top of Figure 2.4, as a 'cause-effect' chain (or impact pathway). The chain starts by linking climatic change to lower-order – direct – impacts (e.g. increased rate of coastal erosion) and moves through to specific higher-order – indirect – impacts (e.g. the loss of beach area and changes in visitation rates). One problem that arises when attempting to value the impacts of climate change is that, as we move along this **cause-effect chain**, the extent to which *all* impacts can be quantified across *all* exposure units and receptors will vary considerably.

The implication of this for valuation studies is that, for certain 'cause-effect' chains, there may be more than one point along their length at which some form of valuation can be undertaken. For example, along a

15 You may realise that the potential exists for 'double-counting' the costs of specific climate change impacts (or, alternatively, the benefits of avoiding those impacts). When using the guidelines, care must be taken to ensure that such double-counting does not occur. We return to this in Section 3.2.3.

Figure 2.4: The general structure of the costing methodology – taking coastal zones as an example. The section numbers refer to sections in this report



specific 'cause-effect' chain, impact data may exist in the form of crude data on the total area of coastal zone that would be lost relative to the base case, and more detailed data on changes in visitation rates to an affected recreation site. Although, in an ideal world, impacts would be valued using the latter (since they are able to produce a more accurate measure) – that is, using detailed data relating to high order impacts – our costing methodology must be able to offer guidance on valuing lower-order impacts as well. In general this will involve using aggregate cost data to provide approximate damage cost estimates for lower-order impacts, and using data on the values individuals attach to very specific receptors, environmental or otherwise, to provide more refined damage estimates for higher-order impacts. These ideas are illustrated in Figure 2.5, which shows the pathway from climate change to the consequences for the exposure unit and receptor(s), to measures of cost and benefit. The objective is to derive detailed cost estimates for the impacts of climate change on very *specific* receptors. To this end, Step One must identify and quantify the climate change risk facing a receptor (e.g. the change in the quality/quantity of a *specific* good or service valued by society).

Clearly, for the costing methodology to be effective, valuation techniques need to be identified which can deal with the full range of impacts, as illustrated in Figure 2.5.

As the science of climate change risk/impact assessment advances, an increasing number of impacts will be quantified, and to higher levels. So while impact data may not be available for some of the higher-order impacts at present, it may become available in the future.

It is the inherent need for flexibility that has shaped the structure of these guidelines, specifically the use of the hierarchy of cause captured by the four boxes in Step One, Figure 2.4. To summarise, the flexibility is necessary in order to accommodate:

- climate change risks/impacts that are quantified at different levels and in different ways; and
- climate change risks/impacts that are likely to be quantified in the near future.

Returning to Figure 2.4, we now consider the two elements or steps which constitute the methodology for costing climate change impacts, in turn, that is: Step One – the identification and quantification of climate change impacts; and Step Two – the valuation of these impacts in accordance with standard practices in economic analysis.

Step One – Climate change impact assessment

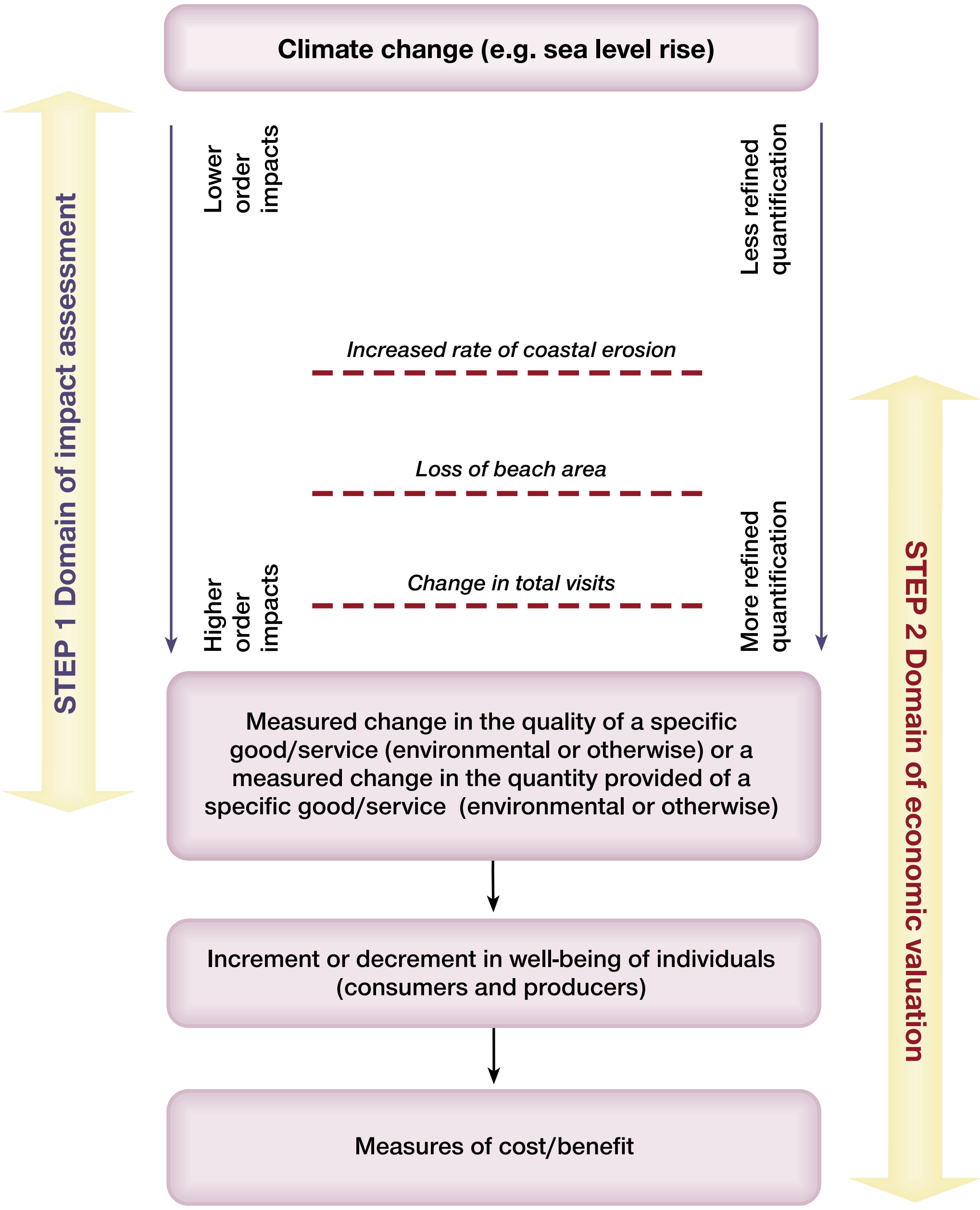
This step is based, as we have seen, on 'cause-effect' chains (or impact pathways), which link lower-order climate change risks (e.g. increased frequency of flooding) to higher-order impacts (e.g. changes in the total number of visitors to a specific beach or recreational site). As mentioned above, it is envisaged that impact data will be available at different levels along a given cause-effect chain. The cause-effect chains are presented in the form of **impact matrices**. These matrices summarise the anticipated impacts of climate change on a number of sensitive sectors.

The matrices function purely as an identifier – i.e. they link a particular impact with a valuation guideline(s). It is assumed that the reader already has undertaken a climate change risk assessment (as described in Willows and Connell, 2003) and has identified and measured impacts relevant to the decision at hand. There may well be impacts which are not shown in the matrices.

Step Two – Economic valuation of impacts

The impact matrices suggest to the reader an appropriate valuation guideline(s) for impacts of interest. Each valuation guideline provides step-by-step instructions in the application of an economic valuation technique(s) to a specific 'type' of climate change impact. The user is free to select a valuation guideline compatible with the impact data at their disposal, the level of accuracy required, and the resources available – expertise, time and money. In the situation where the user is considering a potential impact not explicitly identified in the matrices, (s)he is required to make a judgement about the appropriateness of the guideline/valuation technique to use. It is suggested that, where a similar impact has been considered in the guidelines, the user should follow that guidance. Where there is not, or the user is unsure of the relevance of other guidelines, (s)he will need to consult climate change impact and economic specialists.

Figure 2.5: Illustration of the linkage between climate change impact assessment (Step One) and economic valuation (Step Two) – using impacts on coastal zones as an example



Economic valuation techniques have varying data input requirements, and specific techniques are applicable to different order impacts. In the example shown in Figure 2.4, for instance, **preventative expenditure**[16] or **replacement cost**[17] approaches can be used to value the lower-order impacts, whereas the **travel cost**[18] or **contingent valuation method**[19] can be used to value the higher-order impacts.

Application of Steps 1 and 2 will generate monetary descriptors of the outcomes of the options considered. It is likely at this point that option appraisal tools will be employed, as shown in Figure 2.4 within the third box labelled 'Option appraisal tools and general guidance on economic analysis'. As the box label implies, the guidelines also provide advice on more general aspects of economic analysis – including adjusting cost and benefit estimates for distributional impacts and **relative price** movements over time.

It should be noted that these guidelines adopt a 'bottom-up' approach to costing the impacts of climate change. We believe that this approach represents the best way of providing a flexible costing methodology which can be used by non-experts to perform desk-top costing analyses and still yield approximate cost estimates at a local/regional/national scale, disaggregated by sector. At the same time, we recognise that in some cases, e.g. when impacts are large ('**non-marginal**') or the potential for indirect impacts is high, such a bottom-up approach may not yield accurate estimates.

The valuation approach adopted in these costing guidelines assumes that any one climate change impact under consideration is relatively small (or '**marginal**'); therefore, the value that individuals attach to affected receptors *does not* change. Subject to this assumption, the benefit/cost of a climate change impact on a receptor is valued by multiplying the anticipated physical impact on the receptor by the appropriate initial economic **unit value**. In some cases, however, climate change may result in relatively large (or 'non-marginal') impacts on a receptor, which may in turn change the current economic unit value. We are now faced with the dilemma of which 'price' to use in the costing analysis – the initial price or the price that prevails subsequent to the climate change impact? Moreover, depending on the nature of interrelationships between receptors, a change in the economic unit value pertaining to one receptor may disrupt price and quantity equilibria throughout the economy. A further question therefore arises – how many receptors must we consider in order to derive an accurate measure of the 'true' cost of climate change? In these cases some form of integrated modelling exercise or '**top-down**' **approach** may be more appropriate.

[16] The **preventative** (or **averting**) **expenditure method** is a valuation technique in which the time and money incurred by individuals to offset or mitigate an environmental or man-made hazard is indicative of the lower bound value the individual places on that hazard.

[17] With the **replacement cost approach**, the costs that an individual incurs in replacing or restoring (cleaning) a damaged asset are taken as a minimum estimate of the value of the inauspicious environmental condition(s) that caused the deterioration in asset quality.

[18] The **travel cost method** values site specific environmental resources (e.g. a national park) by estimating demand for access to the site. The total expenditure (time and money) on the travel required to reach the site is interpreted as the implicit, or the surrogate, price of the visit – i.e. the value of the experience afforded by the site.

[19] The **contingent valuation method** determines money measures of changes in the well-being of individuals through the use of survey questionnaires, which describe a hypothetical situation and elicit how much the respondent would be willing to pay either to obtain or to avoid the described situation.

3. Assessment of climate change impacts

3.1 Introduction

We stated in Section 2 that the links between climate change impacts and possible valuation guidelines are presented in the form of impact matrices. These impact matrices have been constructed, one for each of the following key (sensitive) sectors, from an extensive review of the UK climate impacts literature:

- Coastal zones sector;
- Water resources sector;
- Agricultural sector; and
- Buildings and infrastructure sector.

Note that there is not a separate matrix for the impacts of climate change on natural habitats, another key sector at risk from climate change. This is because risks to natural habitats are inevitably included in the matrices for the other four sectors.[20] An extract from the impact matrix for the Coastal Zone Sector is reproduced in Table 3.1 for illustration here. The full matrices for each sector are given in the implementation guidelines. Users should note that there may be additional impacts not shown in these matrices, and should refer to Willows and Connell (2003) for information on how to undertake a risk/impact assessment.

The matrices loosely depict the 'cause-effect' (or impact pathway) chain associated with a specific climate change event. So, for example, starting with a climate change event such as the expected rise in sea level, the matrices trace the 'cause-effect' chain through the corresponding potential direct impacts (e.g. permanent loss of territory) to the subsequent consequences of each of these direct impacts (e.g. loss of recreational sites) through to specific sectoral impacts (such as loss of species). At various points along each 'cause-effect' chain, the reader is referred to different valuation guidelines, as explained in the previous section. The applicability of a valuation guideline at any particular point depends on the type and form of impact data available, and the characteristics of the affected receptor, e.g. whether or not the value that individuals attach to it is observed in conventional markets.

This section explains how the impact matrices are used to identify the valuation guideline(s) that are appropriate for costing particular climate change impacts of interest to the user.

3.2 Using the impact matrices

As mentioned in Section 2, the impact matrices have been developed in order to accommodate two stages in climate-sensitive decision-making – namely, (1) assessment, prioritisation and ranking of risks and (2) adaptation options appraisal.

In both cases the following general procedure is applicable:

1. The relevant sector matrix(ces) should be selected.

2. The climate change risk(s), **direct impact(**s), indirect consequence(s), and/or sector level impact(s) relevant to the decision-making context should be identified and measured.

3. In the column denoted 'VG' (valuation guideline) the label should be identified (e.g. 'CO'). The VG column, adjacent to each impact category, will contain one of six possible labels, each of which denotes a particular course of action. For each of the labels, the implementation guidelines provide detailed guidance on the course of action denoted. Take, for example, the labels 'CO' and 'IG':

    - The label 'CO' (which denotes the guideline on **conventional market-based valuation techniques**) requires you to go to the decision tree shown in Figure 3.1 below, and progress along the initial 'YES' branch. (A description of how to use the decision tree is provided overleaf.)

[20] In the future it may be desirable to produce similar impact matrices for other sectors susceptible to climate change.

Table 3.1: Extract from the coastal zone impact matrix

Climate change: sea level rise

Direct impact	VG	Potential indirect impact	VG	Sector affected	Potential sectoral impact	VG	Relevant stakeholders
Permanent and non-permanent loss of territory	NT	Loss of property	CO	Domestic sector	Property loss	CO	Households, individuals, construction companies, landlords, local authorities, government, insurers
					Welfare loss	SC	
					Changes in the demand for property in the surrounding areas	NT	
		Loss of agricultural land	CO	Agriculture	Loss of productivity	IG	Local farmers, consumers of farm products
		Loss of non-agricultural (natural habitat) land	CO	Habitat	Loss of species/ecosystems	IG	General public, tourists, national interest groups, government
					Migration of species/ecosystems	IG	
		Flooding of wetlands/marshes	CO	Habitat	Loss of species/ecosystems	IG	General public, tourists, national interest groups, government
					Migration of species/ecosystems	IG	
		Loss of recreational sites	IG	Tourism	Reduction in demand at affected site	IG	Tour operators, accommodation and related businesses, general public, tourists
					Shift in demand to alternative sites	IG	
		Resettlement	CO	All sectors	Welfare loss	SC	Producers, local population, employees, local authorities, regulators, government, insurers
					Temporary losses of productivity	CO	
					Compensation	ET	
					Removal management	CO	

Notes: VG denotes valuation guidelines. The labels CO, IG, NT, SC, ET and RU (which is not shown) identify specific courses of action that the user should take in order to identify an appropriate valuation guideline. These acronyms are defined in Appendix 3. A full explanation is provided in the implementation guidelines.

- The label 'IG' (which denotes **individual guidelines** for broad receptor categories) requires you to go to the decision tree, and progress along the initial 'NO' branch.

Details of what course of action to pursue when faced with one of the other four labels in the matrices (namely 'NT', 'ET', 'SC' and 'RU') are given in the implementation guidelines, and the labels are defined in Appendix 3.

Finally, a very important component of the economic value that people derive from such resources as natural habitats, recreational sites, landscapes, objects of cultural heritage, etc., but which is completely unrelated to 'use' of that resource, is **non-use value**. Non-use values are defined as those gains/losses in welfare that arise from environmental changes *independently* of any direct or indirect use of the environment. For example, you may gain satisfaction from simply knowing that a species exists, even if you feel that you will never see this species. Non-use value is applicable to more than one of broad receptor categories covered by the individual valuation guidelines, and often represents a significant element of the total economic value of impacts on the environment. For these reasons a separate valuation guideline is provided for non-use value.

3.2.1 USING THE DECISION TREE

In this section we briefly describe the use of the decision tree shown in Figure 3.1. Specifically, we consider some of the key advice provided in the implementation guidelines to help the user determine which branch in the decision tree to follow. The decision tree is to be used once the valuation guideline(s) adjacent to the climate change impact(s) of interest has been identified in the impact matrix(ces). **The primary purpose of the decision tree is to take the user from the impact matrix to an appropriate valuation guideline**.

Impacts that affect marketed goods/services

The first question asked of the user in the decision tree is '*Does the impact directly affect a marketed good/service?*' Impacts on receptors whose price or value is observable in markets can be valued using conventional market-based techniques such as:

- the replacement (or restoration) cost-based approach; or
- changes in the input/output of market goods/services approach.

Detailed guidance on which one of these approaches should be used to value the climate change impact of interest is given the implementation guidelines, but, as Figure 3.1 shows, it depends primarily on whether the impact is on a durable (typically man-made) good or on the provision or production of a marketed good or service.

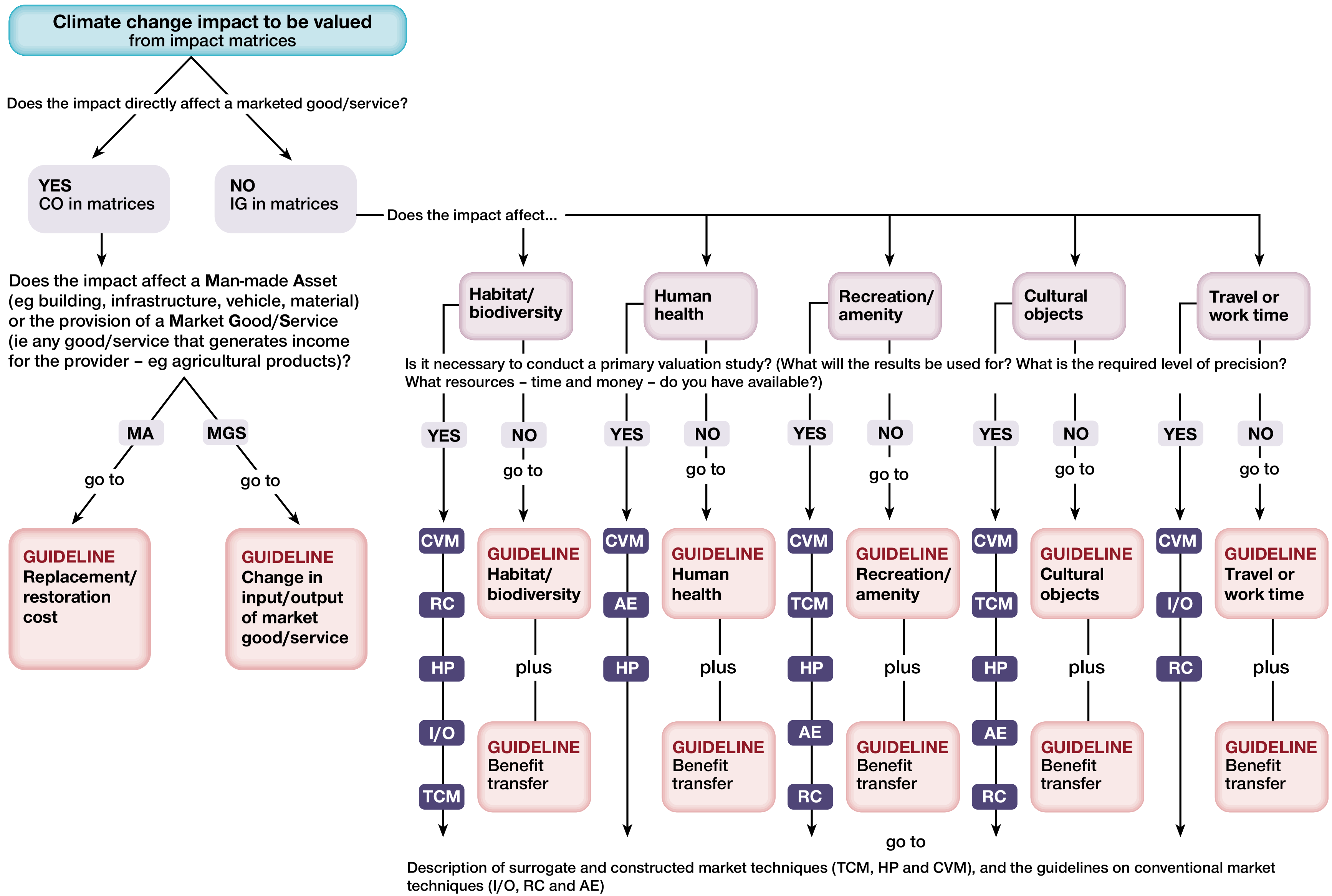
It should be noted that in some cases both valuation approaches are valid. For example, consider the loss of farmland. The market price of farmland itself reflects its value to agricultural production. Therefore, the loss of the land could be valued at the cost of its replacement, i.e. the cost of obtaining similar land that would allow a farmer to realise the same net income as before the impact. Alternatively, the value of the marketed agricultural output that would be lost along with the land could be measured using the change in input/output approach. The former approach yields a 'one-off' measure of loss, whilst the latter typically produces a 'recurring' annual measure of loss.[21]

Impacts that do not directly affect marketed goods/services

If the answer to the original question ('*Does the impact directly affect a marketed good/service?*') is 'No', the right-hand branch of the decision tree must be used. You will see that in costing impacts in any of the broad receptor categories along this branch, the analyst must choose between carrying out a primary valuation study, and using existing studies which value similar impacts at another location, to approximate the value of the impact(s) being considered. The latter approach is known as **benefit transfer**. Some of the key points to consider when deciding whether a primary study is

[21] A word of caution is warranted here. It is important to note that annual (or recurring) cost estimates cannot be added directly to non-recurring (or 'capitalised') cost estimates (e.g. changes in land values). Either the former must be converted into an appropriate capitalised value, or the latter converted into an equivalent annual value. Failure to do so will result in errors when aggregating across impacts. These issues are discussed further in the implementation guidelines.

Figure 3.1: Route map – going from the impact matrix designations to the valuation guidelines



Notes: CVM = Contingent Valuation Method; RC = Replacement Cost; HP = Hedonic Price; I/O = Input-Output; TCM = Travel Cost Method; AE = Averting Expenditures required, or whether benefit transfer is acceptable, are reviewed below. Key considerations identified in the Treasury Green Book are also summarised in Box 3.1.

"…The key question is whether the added subjectivity and uncertainty surrounding the [benefit] transfer are acceptable, and whether the transfer is still informative. If not, the alternatives are to forego a quantitative CBA [do not value the impacts] or to conduct an original [primary] study…" Desvousges, Johnson and Banzhaf (1998).

In general, the decision as to whether a particular situation requires a primary valuation study will depend on four things: the use to which the value estimates will be put; the degree of accuracy required for this use; the degree of accuracy which can be attained using benefit transfer; and possibly of greatest importance, the relative cost of the primary study.

A primary study, which directly values the impact of interest, will inevitably provide a more accurate estimate of the 'true' costs of the impact. However, primary studies are also much more costly in terms of time and resources. The user, therefore, needs to decide on the acceptable balance between the level of precision required and the relative costs of primary studies. Sometimes it may be more economical to use benefit transfer. In other words, in some cases the balance between accuracy and cost will favour benefit transfer.

To help address these issues, Desvousges, Johnson and Banzhaf (1998) provide a 'Continuum of decision settings from least to most required accuracy', which is shown in Figure 3.2 below. Along this continuum they suggest that some uses of the valuation results require higher levels of accuracy than others. Situations which require the highest level of accuracy in their continuum are those where cost-benefit estimates are used to compensate the victims of (environmental) damage, or where environmental externalities are being internalised, e.g. where firms are charged for emitting pollutants at the rate equal to the **marginal cost** of pollution to those who suffer from it. In these situations a primary study is required.

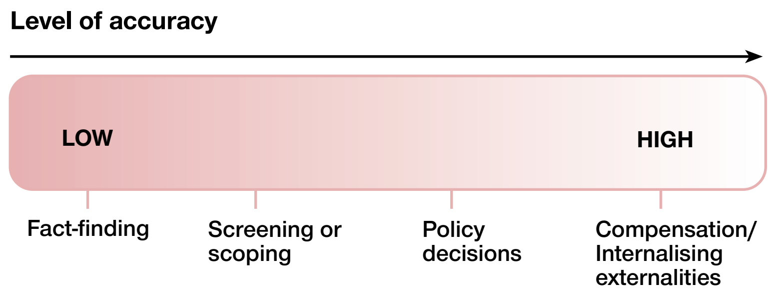
Valuation studies which inform the appraisal of policies,[22] such as cost-benefit tests of alternative adaptation options, are the next highest in the continuum. Since real economic commitments rest on the outcomes

Box 3.1: Key considerations governing the decision whether to commission primary research or use benefit transfer

- Is the research likely to yield a more robust valuation?
- Will the results of the research be applicable to a range of future appraisals?
- Is the accuracy of the valuation material to the decisions at hand?
- What is the scale of the decision at hand? (If the decision relates to a multi-million pound investment, then clearly it is worth devoting more, as opposed to fewer, resources to the valuation.)

(HMT, 2003, p.58)

Figure 3.2: A continuum of decision settings from least to most required accuracy. *(Desvousges, Johnson and Banzhaf, 1998)*



22 Note that 'policies' include decisions made at both project and programme level.

of these tests, valuation studies which serve as an input to such tests must meet a high standard of accuracy. It is often sufficient, however, for the valuation studies to obtain a 'bounded' result. For example, to pass a cost-benefit test it is often only necessary to determine whether or not an option's benefits exceed its resource costs; that is, it is not always necessary to establish the exact magnitude of the exceedance. If the resource costs of the option are already known, it is perfectly acceptable to tolerate some uncertainty in the benefit estimates, so long as they are clearly larger (or smaller) than the known costs.[23] This situation is typical of many climate change decisions that users of these costing guidelines will encounter. The additional uncertainty associated with benefit transfer may, in this case, be acceptable.

With respect to each particular climate adaptation decision, the analyst will therefore have to decide whether, given the use to which the final results will be put, it is acceptable to use benefit transfer, or if the additional costs of carrying out a primary study are justified by a need for a greater level of accuracy.

Selecting valuation techniques for a primary study – if required

It is all but impossible to supply hard-and-fast rules for selecting a valuation technique(s) to apply in a specific context. The choice of valuation technique for any specific costing exercise will depend on a number of criteria. Garrod and Willis (1999) have prepared a list of such criteria; these are outlined in the implementation guidelines. Table 3.2 below also provides some guidance on matching primary valuation techniques and specific impacts.[24] The table shows a selection of potential (environmental) impacts resulting from climate change, along with the main surrogate (or revealed preference) market-based and constructed (or stated preference) market-based valuation techniques that can be applied. A 'Y' indicates that the valuation technique can generally be applied to the corresponding impact. A question mark means that the valuation technique may apply; where no symbol is shown, this means that the valuation technique generally does not apply.

3.2.2 THE COST-SIDE OF THE EQUATION

For decision problems concerned with the net benefit of adaptation, the user should be aware that application of the impact matrices and subsequent valuation guidelines allows the construction only of the 'benefit-side' of a standard cost-benefit equation. The 'cost-side' of the equation is given by the resource costs of the adaptation option(s). Analysts in some key sectors, e.g. coastal zones and water resources, have their own guidelines for costing specific engineering projects, many of which can also be used to estimate the resource cost of adaptation measures. The implementation guidelines provide some guidance on estimating the resource costs of adaptation options. It is important when costing adaptation measures that the cost concepts outlined in the implementation guidelines are adhered to, to ensure consistency with the impact valuation guidelines.[25]

3.2.3 POTENTIAL MISTAKES TO AVOID WHEN USING THE COSTING METHODOLOGY

No matter which individual valuation guideline(s) is/are employed to estimate the value of the climate change impact(s) of interest, there are several mistakes that the user should take care to avoid when using the final results. In this section we will draw attention to two potential sources of error. The first concerns the treatment of impacts that cannot be put into monetary terms; the second relates to the aggregation of costs associated with 'higher-order' impacts in order to obtain a value for the costs of a 'lower-order' impact. We deal with each of these potential problems in turn.

The treatment of unvalued impacts

Application of the valuation guidelines depends on sufficient quantitative data being available in an

23 Adaptation options, in general, are costed using market prices, and can therefore be costed relatively accurately.

24 Note that Table 3.2 only concerns the applicability of surrogate (or revealed preference) and constructed market (or stated preference)-based valuation techniques to specific climate change impacts (i.e. it looks only at those methods most likely to be employed as primary valuation exercises in the context of these costing guidelines). Many of the impacts listed in Table 3.2 can be valued using the implementation guidelines, and a primary study is not warranted.

25 The Green Book also provides guidance on estimating 'costs' for government departments and executive agencies. The implementation guidelines are consistent with the advice provided in the Green Book.

Table 3.2: Applicability of surrogate and constructed market techniques for primary valuation studies.
(Adapted from Abelson, 1996)

Climate change impact	Surrogate market			Constructed market
	Hedonic property	Hedonic wage-risk	Travel cost	Contingent valuation
Productivity:				
Soil loss/damage	?			
Crop loss/damage	?			
Forest loss/damage				?
Habitat loss/damage			?	Y
Fisheries loss/damage				
Water quality deterioration	?	?		Y
Property loss/damage	?			
Resource loss/damage	?		?	?
Human health:				
Mortality health outcomes		Y		Y
Morbidity health outcomes		Y		Y
Amenity:				
Recreation loss	?		Y	Y
Habitat loss/damage			?	Y
Visual amenity deterioration	Y		?	Y
Noise	Y			Y
Other:				
Non-use values				Y
Occupational environment		Y		Y
Damage/loss of heritage	?		Y	Y
Access to water	?		Y	Y
Sanitation services	Y			Y
Travel time savings	Y			Y

Notes: 'Y' indicates that the valuation technique can generally be applied to the corresponding impact. '?' means that the valuation technique may apply. Where no symbol is shown, this means that the valuation technique generally does not apply.

appropriate form. It is likely that there will be many types of anticipated climate change impacts for which appropriate quantitative data are simply not available, and, therefore, the suggested valuation guideline(s) cannot be applied. For example, changes in the hydrological regime and the resulting risks to natural habitat might be considered a likely consequence of coastal erosion in an area, but there may as yet be no evidence as to the extent or implications of the impacts. It is also likely, given the state of the art of economic valuation, that it will not be possible to value certain impacts even if appropriate quantitative data are available. However, these impacts are still relevant in the appraisal of alternative adaptation strategies for coastal erosion, regardless of the fact that they cannot be valued.

Therefore, the lack of monetary estimates for specific climate change impacts *does not* mean that those impacts can be overlooked in the decision-making process.

It is important, therefore, when using these costing guidelines, to have some systematic method for identifying those impacts that are relevant, but which are not valued. This will ensure that such impacts are not ignored when

Table 3.3: Checklist for the identification of all impacts of relevance: example of permanent loss of territory from sea level rise

Potential indirect impact	Valuation		Potential sectoral impact	Valuation	
	No	Yes		No	Yes
Loss of private property		✓	Property loss		✓
			Welfare loss	✓	
			Changes in the demand for housing in the surrounding area	✓	
Loss of agricultural land		✓	Loss of productivity		✓
Loss of non-agricultural (natural habitat) land	✓		Loss of species/ecosystems	✓	
			Migration of species/ecosystems	✓	
Flooding of wetlands/marshes	✓		Loss of species/ecosystems	✓	
			Migration of species/ecosystems	✓	
Loss of recreational sites		✓	Reduction in demand at affected site		✓
			Shift in demand to alternative sites	✓	
Resettlement	✓		Welfare loss	✓	
			Temporary loss of productivity		✓
			Compensation		✓
			Removal management		✓
Loss of land with cultural heritage	✓		Loss of cultural objects	✓	
Loss of building/infrastructure (including transport)		✓	Loss of business property/infrastructure		✓
			Loss of transport infrastructure and equipment		✓

Notes: The tick-marks shown in the table are not definitive; they pertain solely to this example. In another example the tick-marks corresponding to the same impacts may appear in different columns.

making the final decision(s). One approach is to construct a simple checklist, such as the one shown in Table 3.3 above. Such a checklist allows the user to identify which of the anticipated climate change impacts falling within the scope of the decision problem have been valued. This information can then be used, for example, to inform a sensitivity analysis within a cost-benefit framework, or serve as input to multi-criteria analysis.

Aggregation – avoiding double-counting

The second potential pitfall is that of double-counting. This may arise when attempting to cost a 'lower-order' climate change impact, such as the loss of territory due to sea level rise, by aggregating the associated 'higher-order' impacts, such as the loss of habitat, of recreational sites, the need for resettlement, etc. To avoid the problem, three points should be considered when attempting to aggregate. These are:

- First, that care should be taken to ensure all of the potential 'higher-order' impacts associated with the lower-order impact have been taken into account. This relates to the discussion above, that impacts should be accounted for even if monetary values cannot be attached to them.

- Secondly, in situations where a number of direct climate change impacts will eventually be aggregated, care should be taken to ensure that the individual indirect, sector-level impacts, which comprise these direct impacts, are not repeated. For example, a permanent loss of territory might result in the loss of buildings used by the tourist industry, such as hotels. There is a danger that the loss of these buildings could be counted under both a study of the loss of private property, and a separate study to measure the effects of loss of land on the tourist industry. double-counting is also possible if care is not exercised when measuring changes in non-use values, which are then to be added to changes in use values – particularly with respect to resources that provide recreational and amenity values. Some of the non-use values reported in the literature may also capture use values, and vice versa.

- Finally, the analyst should be aware that studies which measure the cost of climate change impacts directly, e.g. a contingent valuation study of individuals' **willingness to pay** to avoid sea level rise, is unlikely to yield the same result as the aggregate of studies which directly measure individuals' willingness to pay to avoid numerous indirect, sector-level impacts of sea level rise.

4. Economic valuation guidelines

4.1 Introduction

In Section 3 we described how the decision tree shown in Figure 3.1 is used to take the user from an impact matrix to an appropriate valuation guideline. The purpose of this section is to provide an overview of the various valuation guidelines available to the user.[26] In line with the first branch of the decision tree, we group the valuation guidelines into two categories. The first category (which corresponds to the left-hand branch of the tree) contains guidelines which value the impacts of climate change on goods/services traded in conventional markets – hence these guidelines are referred to as '**conventional market-based techniques**'.

The second category (which corresponds to the right-hand branch of the tree) contains valuation guidelines tailored to specific types of receptor: (a) habitat and biodiversity; (b) human health; (c) recreation and amenity; (d) cultural objects; (e) leisure or work time and (f) non-use benefits. For the most part, impacts on these receptors will affect non-marketed goods/services.

The two types of technique used to value non-market goods/services are known in the technical literature as revealed preference and stated preference techniques, respectively. Further detail on these techniques can be found in the Treasury Green Book at: http://greenbook.treasury.gov.uk/chapter05.htm#valuing

Both categories of valuation guideline are discussed below. Each of the guidelines presented below has its own strengths and weaknesses, which must be borne in mind when using the resultant valuations. It is not feasible within the scope of this report to cover these issues; the user is instead referred to the relevant sections of the implementation guidelines.

It should be highlighted at this point that the Green Book suggests a procedure for selecting appropriate techniques, which is summarised in Table 4.1 overleaf. The Green Book is the principal source of guidance for public sector users who wish to undertake climate change impact costing work using market or non-market techniques. The guidelines presented in this report serve to present the likely physical impacts of climate change alongside the monetary valuation techniques available for these impacts and serve to steer the public sector analyst when dealing with the climate change context. The same is true for the private sector analyst, though (s)he has flexibility as to the choice of valuation technique. As a consequence, these techniques are outlined in this section and in further depth in the implementation guidelines.

4.2 Valuation guidelines using conventional market-based methods

The two main types of conventional market-based technique covered in the guidelines are: (1) changes in the inputs or outputs of marketed goods or services (including the change in productivity and production cost techniques); and (2) cost-based methods (including the replacement cost and avertive expenditure techniques). As noted above, these techniques use market price data to value climate change impacts. The guidelines for these techniques are, therefore, written to facilitate the use of primary data, since such data should be available to the user.

4.2.1 GUIDELINE: VALUATION BASED ON CHANGES IN THE INPUTS/OUTPUTS OF MARKETED GOODS/SERVICES

The environment often has a direct effect on the capacity of an economic unit (e.g. a farm) to produce a good, and/or the costs of producing that good. An example of this might be where the output of a commercial fishery depends, among other things, on fish stocks, which in turn depend on water quality. If the water quality changes as a result of climate change, and this reduces fish stock, then in order to maintain output, the operator of the fishery must allocate more resources to catching fish. If resources are not increased, then the quantity of fish harvested is likely to decrease. Either way, the operator of the fishery suffers an economic loss. This provides us with

[26] Note that this overview report largely assumes that prices remain constant, with impacts changing the quantity only. Section 5.5 of the implementation report discusses the treatment of impacts when prices change – i.e. the changes are 'non-marginal'.

Table 4.1 Hierarchy of valuation techniques. *(HM Treasury Green Book, 2003)*

PROCEDURE	SUMMARY TERMS
Determine whether:	
Impacts can be measured and quantified	
AND	
Prices can be determined from market data	
If this cannot be readily done:	
Use 'willingness to pay' for a benefit	'willingness to pay'
determined by	
Inferring a price from observing consumer behaviour	'revealed preference' or a subset of this called 'hedonic pricing'
If this does not provide values, determine whether:	
Willingness to pay can be estimated by asking people what they would be willing to pay for that particular benefit	'stated preference'
or whether	
In the case of a cost: identifying the amount of compensation consumers would demand in order to accept it	'willingness to accept'

two measures of the cost of the (climate change-induced) deterioration in water quality: (1) the cost of the additional resource inputs; or (2) the value of lost output.

In general, when we estimate the cost (benefit) of a deterioration (improvement) in environmental quality by valuing decreases (increases) in output (or the quality of that output), we are employing what is referred to as the **change-in-productivity approach**. A closely-related approach, where we estimate the cost (benefit) of a deterioration (improvement) in environmental quality by valuing increases (decreases) in resource costs, is the **production cost** (or **cost saving**) **technique**.

In valuing changes in inputs/outputs, we must distinguish between changes in quantity that are sufficient in scale to result in changes in price, and those that do not result in price changes. If the change in output or resource input is small relative to their respective total market shares, then we can assume that prices will remain constant after the change in output. In this case, we can employ any one of four methods: (1) we can calculate a **gross margin** for each unit of output, then multiply this by the projected change in output; (2) we can calculate the **unit cost** of variable factors, then multiply this by the projected change in resource use; (3) we can assess **total** (farm) **budgets** for the 'with' and 'without' cases; or (4) we can estimate changes in **land values** for the 'with' and 'without' cases. Depending on circumstances, one method may be more appropriate than others (see the implementation guidelines). It is also important to note that distortions to market prices should be corrected for – e.g. by deducting taxes from prices, or adding back subsidies.

If the change in output is large relative to the total market, this may induce changes in the price of the affected good/service. In order to value the changes in quantity or quality, we must establish the change in price likely to result. This requires us to consider the underlying supply and demand curves of the affected good/service.

4.2.2 GUIDELINE: VALUATION BASED ON PREVENTATIVE EXPENDITURE OR REPLACEMENT COST

In some cases the costs of climate impacts can be estimated using resource cost data. Estimates of the potential costs (or savings) to households and producers, for example, can be obtained by using:

- the cost of reducing or avoiding the climate impact on the susceptible good/service *before* it occurs; or

- the cost of replacing the affected good or service *after* the climate impact has occurred.

The former is known as avertive or preventative expenditures. The latter is referred to as replacement costs (restoration costs or corrective expenditures).

1. The **avertive expenditure** method is based around the premise that the money an individual spends in order to avert damage can be viewed as a 'surrogate' for the current level of environmental quality. Put another way, an individual's perception of the cost imposed by climate change is assumed to be at least as much as the amount paid to avert the impact. An example of a **preventative expenditure** in the present context is the expenditure that is made on a sea defence system in order to prevent future damaging impacts from sea level rise. The appropriateness of using the expenditure as a proxy for the impact cost is contingent on there being no ancillary benefits associated with the expenditures. If there are other, ancillary benefits the expenditure will give an over-estimate of the value of the climate change impact, since the individual incurring the expenditure may be doing so to gain the ancillary benefits as well as to avoid the consequences of the impact.

2. The **replacement cost** technique assumes that the costs incurred in replacing damaged productive environmental assets can be interpreted as an estimate of the (lost) benefits presumed to flow from the affected assets. Basically, it is assumed that you would not spend money to replace a damaged good if you did not value it, and the amount of money you spend to replace the good should be roughly equivalent to the lost benefits that good provides you. This technique is closely related to the avertive expenditure technique. The distinction between the two techniques is that if expenditure is made to avert further losses, then the avertive (preventative) expenditure technique is appropriate. Alternatively, if the expenditure is made in order to restore the environmental asset to its original state, the replacement cost is appropriate. A further distinction is that the replacement cost value can be seen as an objective valuation of the impact, since the impact has actu-

ally occurred, whereas the preventative expenditure is a subjective valuation of the impact perceived to have been avoided.

The replacement cost technique assumes that replacement costs are calculable and that, as with the avertive expenditure approach, there are no ancillary benefits resulting from the expenditure unrelated to the climate impact reversed. A weakness specific to these techniques is that they only measure willingness to pay (WTP) in so far as society is willing to devote the expenditures to prevent or replace the damage done by the impact. It is likely, however, that the resource cost of achieving these objectives will be either lower than the real WTP (in which case the expenditure is made and there exists **consumer surplus**) or higher than the real WTP (in which case the expenditure will not be made). These techniques, therefore, only provide either a lower or upper bound estimate of the true WTP.

The **relocation cost** technique is a variant of the replacement cost technique, where the actual costs of relocating (e.g. a factory or household because of environmental changes) are used to approximate the potential benefits of preventing the environmental change. The **shadow project** approach to valuation is another special case of the replacement cost technique. It attempts to estimate the cost of replacing the entire range of environmental goods and services that are threatened by climate change, by examining the costs of a real or hypothetical project that would provide substitutes for the threatened/lost good/service. The shadow project technique can be used to estimate the cost of both marketed and non-marketed climate change impacts. It can also be used to help estimate the 'social' cost of adaptation measures – that is, to include some of the externalities that arise from the implementation of selected adaptation projects.

Box 4.1: The main surrogate and constructed market-based techniques

Hedonic analysis

Environmental quality often affects the price individuals are willing to pay for certain marketed goods/services. For example, you may be willing to pay more for a house in a quiet area than for an identical house in a noisy area. Similarly, you may require a higher wage to work with a dangerous substance than you would to work with a safe substance. Statistical analysis can be used to examine the contribution of specific environmental attributes, like noise or visual amenity, to property prices – in which case we are talking about the **hedonic property value** approach. Equally, statistical analysis can be performed on wage data – e.g. to identify the wage premiums required to accept specific levels of workplace risk – in which case we are employing the **hedonic wage-risk approach**.

Travel cost

The **travel cost method** (TCM) is another technique that attempts to deduce values for non-marketed goods/services from the behaviour of individuals in actual ('surrogate') markets. The TCM is frequently used to value site-specific levels of environmental resource provision and, to a lesser extent, quality. Basically, information on visitors' total expenditure to visit a site is used to derive a demand curve for the services provided by the site. This demand curve is then used to measure the average benefits to visitors, which is subsequently aggregated over the population that can be assumed to make such visits in order to derive a measure of total benefit. It can also be used to measure the benefits/costs resulting from changes in the services (quantity and/or quality) provided by the site.

Contingent valuation

In contrast to the techniques described above, which use observed data, the **contingent valuation method** (CVM) relies on structured conversations to directly elicit the value respondents place on some, usually non-marketed, good or service. The assumption is that a hypothetical, yet realistic, market for buying or selling the use and/or preservation of a good/service can be described in detail to an individual, who then participates in the hypothetical market by responding to a series of questions. These questions relate to a proposed change in the quality or provision of the good/service. The responses to these questions are then analysed to estimate the average value the respondents associate with the proposed change. This value is subsequently aggregated over the affected population to derive a measure of total benefit (or cost).

4.3 Valuation guidelines for individual receptors

In contrast to the guidelines presented above, which value impacts on market goods/services, the guidelines below attempt to value climate change impacts on primarily non-marketed goods/services. The valuation of impacts on such goods/services is not so straightforward, and requires the application of sophisticated, and expensive, specialist economic techniques. These techniques value impacts either indirectly using the market price of surrogates for the affected good/service (e.g. **hedonic analysis** or **travel cost**), or based on values observed in hypothetical or constructed markets for the affected good/service (e.g. **contingent valuation**). Hence, they are collectively referred to as surrogate and **constructed market** techniques.

In the decision tree shown in Figure 3.1 you are asked whether it is necessary to conduct a primary study. You are also provided with advice on how to answer this question. If the answer is 'yes', then you will need to use one of these surrogate or constructed market techniques. However, in the majority of cases, your answer to this question will be 'no'. The guidance provided in this section of the guidelines has been designed accordingly. Instead of providing step-by-step guidance on how to conduct, say, a contingent valuation study, the guidelines contain only an overview of the method, and the user is advised to seek expert input. (A brief description of these valuation methods is given in Box 4.1.) The valuation guidelines presented in this section rely instead on **benefit transfer** – that is, the transfer of values from existing (contingent valuation) studies to value non-market impacts relevant to the current decision-making context. A separate guideline on benefit transfer is provided, and this *should be used in conjunction* with the guidelines for the individual receptors.

4.3.1 INDIVIDUAL GUIDELINE: VALUING LOSS OF HABITAT AND BIODIVERSITY[27]

Natural habitats and biodiversity provide society with a broad range of economic services, and economic values can be attached to these services. Natural habitats are involved in the provision of marketed goods and services, e.g. agricultural products. They also provide recreational, cultural and aesthetic values such as walking and other sporting activities. Furthermore, they provide non-use values (the valuation of these values is discussed below), including **pure existence value** and **bequest value**.

Most of the anticipated climate changes can be expected to affect natural habitats. For instance, inland water systems could be affected by changed water temperatures and changed water flows such as reduced summer flows. Likewise, increased incidence of droughts could reduce water quality and the capacity of streams to support flora and fauna. Coastal systems are vulnerable to sea level rise and possible increased frequency and intensity of **extreme events**, such as storm surges.

The general procedure for estimating the monetary value of a change in habitat or biodiversity associated with climate change impacts involves: first, quantifying the habitat change; secondly, identifying the types of economic service that are affected by the impact on habitat; thirdly, identifying the unit monetary value of the affected services; and finally, multiplying this unit value by the quantified change in the habitat.

The first step is the output of the climate change impact assessment. The second involves identifying the economic values associated with a particular habitat. For instance, if a habitat provides recreational values as well as non-use values, and constitutes an input to a marketed good, such as timber, then all these values must be accounted for.

To identify economic unit values for changes in the quality or quantity of habitats, and for the loss of species, we must first make a distinction between those habitat services which may be classified as 'marketed' and those which are 'non-marketed'. The value of habitat and biodiversity services in the production of marketed goods is generally more straightforward to estimate, since the products of those services have market prices attached to them. They can therefore be valued using either of the conventional market-based approaches described above. For example, the

[27] Note that in order to avoid double-counting in aggregation, the user of these guidelines will need to assess which values are attributable to which affected individuals. The user is referred to Section 3.2.3 on double-counting in the implementation guidelines.

input/output method can be used to measure the value of an ecosystem service in terms of its effect on the production of a marketed good; the replacement cost method can be used to value ecosystem services at the cost of the marketed inputs that would be required in their absence – e.g. expenditure on irrigation systems to replace the hydrological services to agriculture of a lost wetland falls into the latter category.

Recreational, cultural and aesthetic values are typically estimated using the primary valuation methods reviewed in Box 4.1. In the context of habitat, biodiversity and ecosystem services, the CVM is used to create a hypothetical market for the preservation or restoration of a natural habitat, from which values for these services are derived. The TCM is used to estimate the value of recreational opportunities provided by natural habitats. Hedonic analysis is used to estimate the contribution to house values of an environmental asset, such as a clean river or a wood. This approach has been used in many studies of the values of natural habitats to estimate, for example, their aesthetic value.

4.3.2 INDIVIDUAL GUIDELINE: VALUING IMPACTS ON HUMAN HEALTH

Many of the expected climate changes will affect either health, life expectancy, or both. The valuation of changes in health outcomes is, therefore, an important aspect of costing the impacts of climate change. The impacts on health expected to be associated with climate change include changes in deaths and illness from increased summer and winter temperatures and sunshine intensity, increased risk of death and illness from air pollution, and increased risk of death and injury due to extreme weather events.

Various categories of impact health status, including accidental, acute, chronic and latent mortality, and accidental, acute and chronic morbidity, are defined in the implementation guidelines. The general procedure for measuring the value of these impacts involves: first, identifying and quantifying the health impact; secondly, identifying into which of the preceding categories the health impact falls; thirdly, identifying the appropriate unit value for that category of impact; and finally, multiplying this unit value by the quantified impact.

Various techniques have been used to value the different categories of health impact. **Accidental mortality**, for example, has been valued using either the CVM, (which in this context involves surveying individuals about their willingness to pay for measures that reduce the risk of death from certain activities), or the **wage-risk approach**. The latter identifies a relationship between the risk of death in the workplace and the wage premium required as compensation to accept that risk. These methods produce an estimate of the '**value of a prevented fatality**' (VPF); the current 'best' estimate of the VPF is around £1million. **Acute mortality** affects a different population, since those affected tend to be elderly and/or ill, as opposed to members of the general population. Unit values for acute mortality are based on those derived for accidental mortality, but the VPF is usually adjusted for age. In valuing **chronic** and **latent mortality**, the process of 'discounting' (see Section 5) is used to account for the latency period between exposure to the impact and death. In the case of chronic mortality, the individual is ill for a period of time before dying. An appropriate morbidity value for this time period must therefore be included in the total impact costing. The total unit values should – in any case – include any additional resource costs associated with the incidence of premature death.

In valuing **accidental** and **acute morbidity** impacts, the full value of illness and injury is accounted for, including financial expenditure, the value of time lost, and the cost of pain and suffering. The first two components define the **cost of illness** (COI) (both to the individual and to society more generally); the third component is measured using the CVM.

Unit values applicable to each category of health impact are provided in the implementation guidelines, based on those recommended by the Treasury Green Book.

4.3.3 INDIVIDUAL GUIDELINE: VALUING IMPACTS ON RECREATION AND AMENITY

Many expected climate changes, as well as adaptation options, will have important effects on recreation and amenity. The impacts on recreation that have been identified to date include the effect of low flow in rivers on, for example, angling, the impacts on coastal recreation of coastal erosion and sea level rise, and urban disamenities arising from, for example, low water levels in canals. These impacts reduce both the quality and quantity (number) of recreational visits.

The general procedure for valuing impacts on recreation and amenity involves: first, identifying the expected climate change impact; secondly, identifying and quantifying the expected impact on recreation service provision (quantity or quality) or amenity; thirdly, identifying the appropriate economic unit value for the impact; and finally, multiplying this by the quantified change in recreation services or amenity.

Economic unit values for recreation activities have been estimated using the CVM. This typically involves asking people directly for the amount they would be willing to pay to obtain an improvement in the provision (quantity or quality) of a recreational activity. The TCM has also been used to infer the value that people place on certain recreational opportunities from the amounts that they spend in order to visit a site which provides those opportunities. Impacts on amenity have been valued by analysing the premium that house-buyers pay for a property with a certain environmental attribute, such as proximity to a forest or a pleasant view. The CVM has likewise been used, as has the avertive expenditure method. The latter involves measuring the amount that people will spend to avoid the loss of an amenity, such as tranquillity, by undertaking avertive action, such as installing double glazing.

Some unit values for various types of recreational activity, and property price premiums corresponding to specific changes in amenity, are provided in the implementation guidelines.

4.3.4 INDIVIDUAL GUIDELINE: VALUING IMPACTS ON CULTURAL OBJECTS

The UK's **built heritage** provides society with a number of economic services, and economic values can be attached to these services. The services provided by cultural objects include marketed goods/services such as living and working space, and non-marketed goods/services such as recreation, cultural and aesthetic values, as well as non-use values. Expected climate changes that could affect heritage include changes in the frequency and severity of extreme weather events, humidity and temperature. For instance, cracking of masonry could increase if subjected to regular extreme temperature and moisture variations. Increased wind speed may cause structural damage, particularly to historic roof structures. A lower level of ground water could render timber-framed foundations unstable, and coastal sites may be affected by rising sea levels.

The monetary value of impacts on built heritage can be estimated using the following general procedure: first, the climate change impact is identified and quantified; secondly, the affected economic services are identified; thirdly, the appropriate economic unit value for the predicted change in these services is identified; and finally, this unit value is multiplied by the identified change in built heritage.

Economic unit values for built heritage can be estimated using a number of methods. (In general, fewer studies have been conducted concerning cultural objects than for the other impacts addressed in this section.) The marketed services provided by historic buildings can be estimated using a variation of the input/output approach – namely the production function method, which involves estimating the annual 'rent' available from a property. Preventative and replacement cost methods can be also used to provide lower bound estimates of the value of damage to buildings. In this case primary data can be used. The non-market goods/services arising from the built heritage – i.e. recreation, cultural and aesthetic values – can be measured using any of the surrogate or constructed market techniques listed in Box 4.1, although hedonic analysis is likely to be difficult to implement in this context due to a lack of data. While no studies have used the CVM to value specifically the impacts of climate change on built heritage, several have estimated the total economic value of cultural sites. The TCM has not yet been used to value cultural heritage, therefore, few values are available for benefit transfer.

4.3.5 INDIVIDUAL GUIDELINE: VALUING IMPACTS ON LEISURE AND WORKING TIME

A number of the expected impacts of climate change will lead to time lost out of planned work or leisure activities. Two types of time impact have been identified as having potentially significant effects on individuals. These are the loss of productive, or working time, and the loss of leisure time, where in both cases time is spent travelling rather than undertaking planned activities.

The economic value of impacts on time can be measured using the following procedure: the first step is to identify and quantify the change in time availability associated with the climate change impact; the second step is to identify the category into which the change in time availability falls; and the third step is to identify the appropriate unit value for the affected time category and then multiply this by the quantified change in time availability from step one.

In terms of valuing changes in time availability, the unit value we seek is the **time cost per minute**. Various techniques have been used to value such units of time. The replacement cost method has been used to measure the additional expenditure undertaken, for example, to use an alternative, quicker mode of transport in order to save time, where the additional expenditure is taken as a proxy for the time saved. The production function variation of the input/output method has also been used to value time as its value in production activities. In this case, time is valued at an individual's wage rate. The CVM has been used to survey individuals about their willingness to pay for events that result in a change in time availability. In general, the valuation of (lost) time is problematic, since it is not always possible to identify whether the time is work or leisure. The implementation guidelines provide a number of unit values for lost working time and these themselves rely on those unit values recommended by the Department for Transport.[28]

4.3.6 INDIVIDUAL GUIDELINE: VALUING IMPACTS ON NON-USE BENEFITS

The **total economic value** (TEV) we associate with a good/service is often thought of as comprising **use value** and **non-use value**, where use value refers to all direct, indirect, and potential future uses of a good/service. Non-use value (or benefit) derives from:

- **Pure existence value** – the value the people place on an asset, such as a particular habitat or species, purely on the basis of its existence, independently of any use, or potential future use, of the asset.
- **Bequest value** – the value that people place on an asset due to the fact that the current generation will be able to pass the asset on to future generations.

In the context of climate change, impacts that are most likely to affect non-use values are those that damage habitats and species, in particular those that are unique, well-known or well-frequented. Cultural assets such as ancient buildings and monuments are also likely to be associated with non-use values.

The general process for measuring the value of a change in non-use values involves: first, identifying and quantifying the impacts associated with the expected climate change effect; secondly, identifying the impacts to assets (natural or man-made) that have non-use values; thirdly, identifying the appropriate monetary value for the changes in non-use value; and finally, multiplying this unit value by the quantified changes from the first step.

Monetary values for non-use benefits can only be made using the CVM, since all other valuation methods, such as the TCM and hedonic analysis, involve inferring values from individuals' behaviour when using marketed goods/service. Use of the CVM in this context involves asking individuals, who may or may not derive any form of use value from an asset, hypothetical questions about their willingness to pay to avoid the loss of that asset. Selected non-use unit values are provided in the implementation guidelines.

4.3.7 INDIVIDUAL GUIDELINE: THE PRACTICE OF BENEFIT TRANSFER

Estimating the cost of climate change impacts on receptors where there is no market 'price', as discussed above, requires values to be derived from studies that use surrogate (revealed preference) or constructed (stated preference) market-based techniques. However, as stated earlier, such studies are very expensive to conduct. More often than not, the user will not have the resources necessary to design and implement primary studies of these types, and indeed it may not be worthwhile to do so, for instance if the level of accuracy required is relatively low (see further details in Section 3.2.1). A cost-effective alternative is to apply the results from existing studies (undertaken at a '**study site**') to new valuation contexts or locations (known as the '**policy site**'). This process is known as **benefit transfer.**

[28] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504932.pdf

A general protocol for benefit transfer is provided in the implementation guidelines. The objective of this protocol is to ensure that the general valuation procedures recommended within each of the individual guidelines are applied in a rigorous and consistent manner. The benefit transfer protocol consists of the seven steps listed below. Note how each of these steps relates to the general valuation procedures described above.

Step 1: Define the value(s) to be estimated at the policy site – the specific receptor(s) damaged by the climate change impact of interest must be identified.

Step 2: Conduct a thorough literature review to identify valuation data relating to the specific receptor(s) identified in Step One.

Step 3: Assess the relevance (suitability) of the study site values for transfer to the policy site, considering the similarity of the policy site to the study site, the similarity of impacts considered, baseline environmental quality, the affected populations, etc.

Step 4: Assess the quality (i.e. scientific soundness and richness) of information available at the study site, accounting for data collection procedures, sound practices, the use of appropriate statistical methods, etc.

Step 5: Select and summarise the data from the existing valuation studies for transfer to the policy site. In general, if there is only one study this is relatively straightforward; if several relevant studies are available, the selection process is more complex.

Step 6: Transfer the benefit measures from the study site(s) to the policy site. This can be done using the **benefit value approach**, which involves transferring a 'best' estimate, often the **mean** WTP, or an adjusted version to account for differences between the study and policy sites. An alternative is the **benefit function approach**, which involves specifying a function relating the specified unit value to characteristics of the affected population and the resource being assessed, and transferring the entire function to the policy site, making adjustments to the function where deemed necessary.

Step 7: Determine the 'market' over which impacts at the policy site are aggregated in order to obtain a measure of **total cost** or benefit. This can account for the geographical extent of the effect, the number of affected individuals/households residing in the geographical market, and possible substitutes for the affected receptor(s) in question.

How good are benefit transfers?

There are two general sources of error in the values estimated using benefit transfer: (1) errors associated with estimating the original measures of value at the study site(s); and (2) errors arising from the transfer of these study site values to the policy site. There are various sources of these types of error, so care must be taken when undertaking benefit transfer. Indeed, it may well be judged to be the case that no study values of sufficiently good quality are identified – in which case the analyst will be forced to decide whether a primary study is needed or whether to include the impact in the analysis in non-monetary terms. If however the data quality/suitability checks listed in the implementation guidelines (in particular, during Steps 3 and 4) are fully adhered to, then these potential sources of error can be limited. However, as with all types of decision-support tools, transfer studies are most useful to the end-user when sources of uncertainty are identified and, where possible, quantified. Several methods for dealing with uncertainty in transfer studies are presented in the implementation guidelines, including **inferential statistics** (e.g. the use of confidence intervals), **interval analysis** and **Monte Carlo simulation** techniques. The last two are briefly described in Section 5. As a general rule, when using benefit transfer a central estimate along with a plausible maximum and minimum estimate should be provided.

Sources of benefit transfer data

Several good databases of valuation data are available, two of which have been developed with benefit transfer in mind – namely the Environmental Valuation

Reference Inventory (available at the EVRI website at http://www.evri.ec.gc.ca/evri/) and the Environment Agency's Register of Environmental Values. A list of UK valuation studies is also available at http://www.defra.gov.uk/environment/economics/evslist/index.htm. (The Green Book also provides suggested values and references for valuing selected non-market items, and the most up-to-date information can be found at the Green Book homepage.[29]) Each of the individual guidelines in the implementation report also provides economic unit values for selected receptors.

[29] See http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm

5. Options appraisal

5.1 Introduction

Once the climate impacts have been quantified, and where possible valued, and the resource costs of alternative adaptation options assessed, the various outcomes need to be compared, so that the decision-maker can identify the 'best' (or preferred) course of action to take. To assist the decision-maker in selecting the best way forward there are many 'decision-support' tools that can be used. In this section, however, we only consider those tools commonly used in economic analysis, since this is the focus of these guidelines. An overview of the full range of decision-support tools for option appraisal is provided in Willows and Connell (2003).

When the consequences of alternative courses of action are described in money terms, option appraisal is typically performed in the framework of **cost-benefit analysis** (CBA). Indeed, we recommend that CBA is used, with supplementary techniques (discussed below) used for taking account of unvalued risks.[30] Before we look at CBA, however, two points are worth stressing to the user:

- First, economic value will seldom be the sole decision criterion for selecting among options. Decision-makers may have other criteria in addition to economic value, including flexibility, equity, avoiding irreversible impacts, political sensitivity, etc. In this case the economic consequences of the various options being considered only represent one input to the decision-making process, albeit an important one. While it is possible to explicitly incorporate, for example, equity into CBA, it may be necessary to employ CBA within a broader decision-support tool such as multi-criteria analysis, in order adequately to account for multiple decision objectives.

- Secondly, decision-making in the context of climate change inevitably involves large uncertainties. When using CBA the user should therefore employ the option selection criteria advocated for making decisions in the presence of uncertainty. To allow further for the considerable uncertainties surrounding the range of possible outcomes, the user should test the key factors that underpin the estimated outcomes, using one of the techniques suggested below.

In short, it should never be assumed that a single 'correct' measure of net benefit will result from the application of these guidelines. Moreover, any measure of net benefit, no matter how reliable it is, will not necessarily provide a solution to the problem confronting the decision-maker.

5.2 Cost-benefit analysis

Cost-benefit analysis (CBA) is designed to show whether the total advantages (benefits) of a project or policy intervention, e.g. an adaptation option, exceed the disadvantages (costs).[31] As far as practical, all advantages and disadvantages should be valued. This essentially involves "*listing all parties affected by the option and then valuing the effect of the option on their well-being as it would be valued in money terms by them*" (Layard and Glaister, 1994). The affected parties should include not only the project/policy participants and consumers, but also third parties who experience so-called **external effects**. The basic approach to CBA may be divided into three main activities or steps, as shown in Table 5.1.

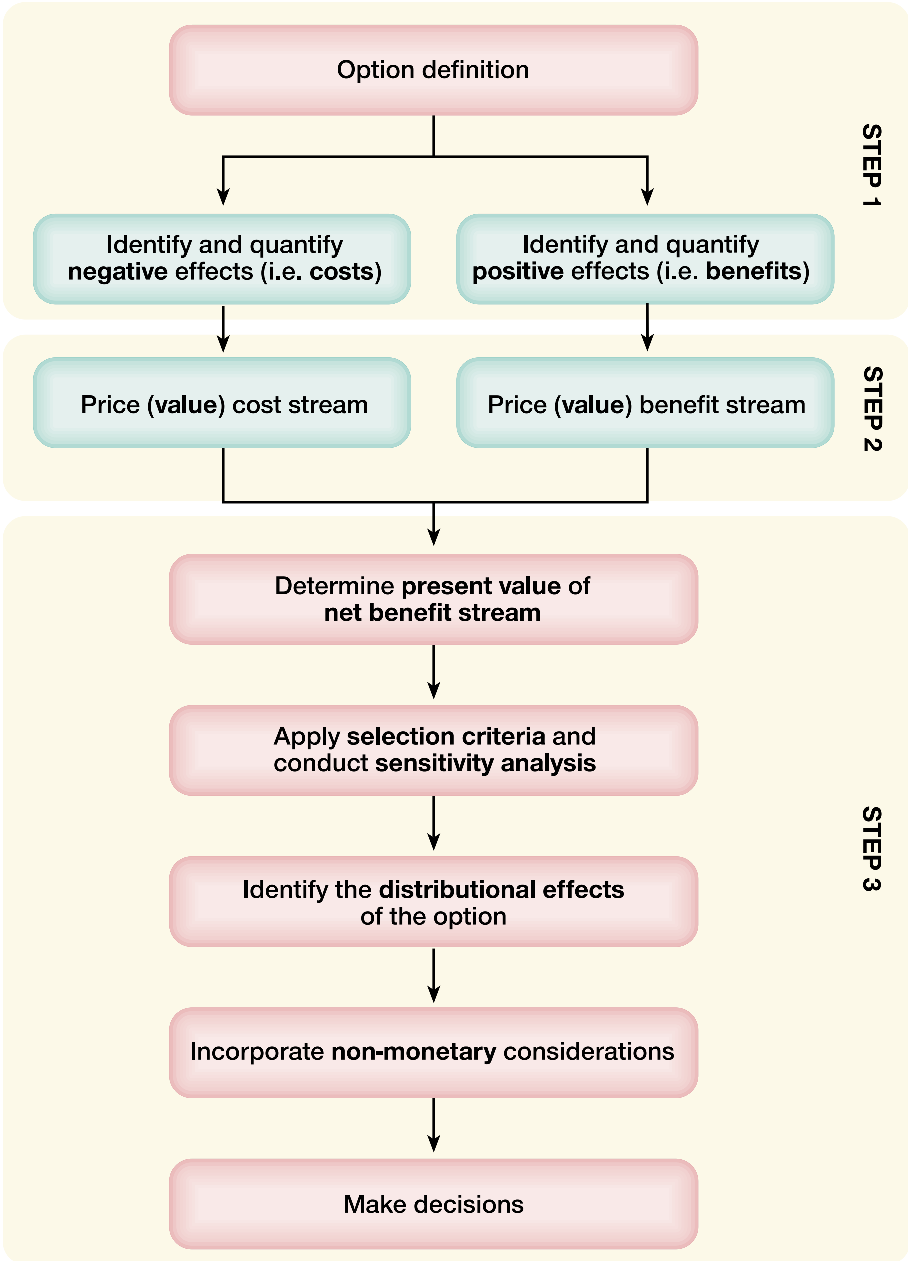
The three main steps in CBA are:

Step 1: **Risk (impact) assessment** of the adaptation option – the process of identifying all exposure units and receptors affected by the option(s) and quantifying the 'incremental' impact of the climate adaptation decision on these exposure units and receptors. By 'incremental' we mean the difference between the relevant **reference scenario** and the **policy scenario** being evaluat-

[30] See Sections 2.2.2 and 2.2.3 on limits to CBA applicability in the climate change context.

[31] A review of the extent to which CBA is used in environmental policy analysis in the UK and the EU is provided in Pearce D. (1998).

Table 5.1: Methodological framework for cost-benefit analysis. *(Adapted from Boyd, 2000)*



ed (see Figure 2.3 above). In other words, we seek to measure the net impact of the decision, rather than the gross impact.

Step 2: **Valuation** – the process of attaching an appropriate 'price tag' to all relevant impacts. Net impacts (i.e. gross climate impacts minus those averted by adopting an adaptation measure) should, as far as practical, be expressed in monetary terms. At this stage, it may also be necessary to adjust the valuations for movements in relative prices and/or distributional considerations.

Step 3: **Weighing up and deciding** – the process of discounting (at an appropriate **discount rate**) to adjust for the time incidence of costs and benefits, so that the present value net benefit of the option(s) can be determined, and ultimately a decision can be made on the relative economic merits of the option. This involves the application of some form of (social) decision rule. However, before this decision rule can be applied, uncertainty should be factored into the analysis (e.g. through sensitivity analysis). Moreover, before a final decision is reached, all unvalued impacts should be considered, either through sensitivity analysis or some form of weighting and scoring.

In Section 5.2.3 we will look in detail at the more important aspects of Step Three of CBA. Before doing so, however, we first consider two issues vital to Step Two, which has not been discussed so far, namely prices and distributional impacts.

5.2.1 CHANGING PRICES WITH TIME

The **general price level** and the **relative prices** of individual goods and services in the economy change with time. Therefore, the cost of individual goods or services affected by climate change, and in turn the overall total cost of climate impacts, will also change with time. This presents two potential problems for climate change costing studies:

- expressing cost data in the prices of a common base year; and
- the price basis for future costs.

When making cost comparisons between, say, two adaptation responses, it is important to ensure that all cost data are expressed on an equivalent price basis, i.e. in the prices of a 'common' year. Failure to do this would render any such comparison meaningless. Also, if the cost data are to be used in economic analysis, it is advisable that the 'common' year corresponds to the **base year** of the analysis,[32] this being the year from which all future projections are made.

The effect of **inflation** on future prices can be removed if we work with so-called **constant** (or **real**) **prices**. In fact, the Green Book recommends that future costs and benefits be expressed in such prices. In this way, only relative price changes are reflected in the analysis – i.e. where the value of an impact is anticipated to increase/decrease more or less than the general price level.[33]

5.2.2 EQUITY CONSIDERATIONS

Once the selection criteria have been applied, the distribution of costs and benefits may be evaluated, since knowledge of how these impacts are allocated among affected parties is often of interest to decision-makers. The **distributional effects** of climate change impacts and adaptation options are important because they may affect the achievement of equity-related social objectives that a public decision-maker may have. The burden of the benefits and costs on different groups within society may well also determine the political acceptability of alternative options. The costing analysis therefore needs to consider two things. First, how equity, and particularly the effect of impacts and adaptation on income distribution, is incorporated. This is because the potential exists for climate impacts to be borne disproportionately by poorer sections of society. For example, those at risk from flooding might not be able to afford to move to avoid this risk. Similarly, it is possible that the net costs of adaptation may also be disproportionately borne by low-income groups, thereby increasing the welfare disparity that already exists between high- and low-income groups. One way of displaying the distributional effects of various courses of action is to construct a **distributional matrix.**[34]

The second aspect that the costing analysis must consider is the procedure adopted which allows identification of affected groups more generally. In other words, the acceptability of an adaptation option may depend on the relative influence of the different stakeholder groups who are bearing the benefits and costs of such an action. A method of assessing this is **stakeholder**

[32] A procedure for converting cost data to a common base year is presented in the implementation guidelines.

[33] Note that over future time periods, the general price level and structure and nature of the economy may be expected to change according to the socio-economic scenarios adopted in the analysts' study. See Section 5.2.3 in the implementation guidelines.

[34] A distributional matrix displays the costs and benefits of a policy option, and shows how they are distributed among different socio-economic groups.

analysis. The aim of a stakeholder analysis is to identify those whose interests will be, or are being, affected by the planned option, and to assess the potential influence they may have on the decision problem.

5.2.3 DISCOUNTING AND DISCOUNT RATES

Having considered prices, we can now turn our attention to the first part of Step Three, which requires the **present value** of the net benefit stream to be determined. Costing of climate impacts and adaptation measures necessitates consideration of the treatment and reporting of economic values that are forecast to occur in the future. **Discounting** is the technique generally used to add and compare costs and benefits that occur at different points in time. There is, however, significant disagreement about the discount rate(s) that should be used in the context of climate change analysis. This section briefly highlights the main factors that should be considered when discounting in the present context, and derives a range of discount rates that may be adopted in **sensitivity analysis**.

Box 5.1: Rationale for discounting and choice of discount rate

Discounting is necessary because individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now. Impatience, or '**pure time preference**', is one reason why the present is preferred to the future and this is a component of the **social rate of time preference** (SRTP). The second reason is that, since capital is productive, a pound's worth of resources now will generate more than a one pound's worth of goods and services in the future. Hence, an entrepreneur is willing to pay more than one pound in the future to acquire one pound's worth of these resources now. This argument for discounting is referred to as the '**marginal productivity of**, or **opportunity cost of capital**' (OCC) argument; the use of the word 'marginal' indicates that it is the productivity of additional units of capital that is relevant.

In the context of these guidelines, discount rates need to be applied to both climate impact costs, and climate adaptation costs, that are borne, or avoided, over future time periods. In order to aggregate these impact/adaptation costs in terms of today's value it is necessary to calculate the **present value** (PV) of the future cost streams. The PV of a future cost which is incurred in year *t* is:

$$\textbf{Present Value} = 1 \,\big|\, (1 + \text{discount rate})^{t}$$

The recommended discount rate for the public sector is given in the Treasury Green Book as 3.5%. For the longer time periods over which climate impacts and adaptation should be considered, the Treasury's Green Book suggests the following discount rate profile over future years: for years 0-30, use a real annual discount rate of 3.5%. For the period from 31 to 75 years use a discount rate of around 3%. For the period from 75 to 125 years, a rate of 2.5% should be used. For the period from 126 to 200 years, a rate of 2% should be used. For 201 years to 300 years, the rate should be 1.5%, whilst for 301 years and more a rate of 1% should be adopted.

5.2.4 INTRODUCTION TO OPTION SELECTION CRITERIA

Once the valuation step is complete, the next step in the CBA is to apply selection criteria and conduct a sensitivity analysis. In this section we will consider how the decision-maker can be supported when selecting the 'best' (or preferred) option under conditions of **certainty**. As stressed throughout the guidelines, these conditions will rarely prevail in the context of climate change. However, since the same decision rules described below can also be used under conditions of uncertainty, we explain them here. (Decision-making made under conditions of uncertainty is considered below, as is sensitivity analysis.)

The decision rule embodied in CBA can be tested through the application of one of the following option selection criteria: net present value, **internal rate of return** or benefit cost ratio. These criteria are *only* applicable when the 'worth' of an option is gauged solely in terms of economic value. Multi-criteria techniques are required when options are compared on the basis of multiple objectives.

The **net present value** (NPV) of an adaptation option is given by the present value of the estimated benefits net of costs. For an independent option, i.e. one which is not in any way a substitute for another course of action, the NPV decision rule is to '*accept the option if its NPV is greater than zero*', since this indicates that the incremental benefits of adaptation exceed the incremental resource costs. If the decision-maker must choose among competing ways of adapting to the same impact (i.e. the options are mutually exclusive), (s)he should select the option(s) with the largest NPV. An alternative to NPV is the **internal rate of return** (IRR), which is the discount rate that equates the present value of an option's benefits with the present value of its cost, and so makes the NPV equal to zero. If the IRR exceeds the discount rate, the option generates net benefits. Care must be taken in using the IRR criterion to rank mutually exclusive options since, in some cases, the IRR criterion will produce different rankings from the NPV criterion.[35]

The other main alternative to NPV is the **benefit-cost ratio** (B/C), which is simply the ratio of the present value benefits to the present value costs. When the B/C ratio is greater than one, the present value of the option's benefits must be greater than the present value of its costs. This implies that the option must also have a positive NPV, and consequently it should be accepted. As with the IRR, caution is required when ranking options according to their B/C (a higher B/C being preferred to a lower B/C), since it is possible to produce different rankings to the NPV criterion. This inconsistency when ranking options using the IRR or B/C criterion is one of the reasons why the Green Book recommends that NPV is the primary criterion for deciding whether government action is justified. Readers in government departments and executive agencies should note this.

5.2.5 OPTION SELECTION CRITERIA UNDER CONDITIONS OF UNCERTAINTY

Above, we presented option selection criteria for making decisions under conditions of certainty, but in the context of climate change, decision-making under certainty is rare. In this section we consider the techniques available to support the decision-maker in selecting the 'best' option(s) under conditions of uncertainty. The user is also referred to Section 2.6 on uncertainty in Willows and Connell (2003) for further detail on this issue.

Making decisions in the presence of uncertainty: knowledge of probability is still good

Most climate adaptation decisions involve some degree of uncertainty about the possible range of outcomes for a given option (e.g. either the likelihood of an event or state being realised is unknown, and/or the consequences of that event or state for exposure units and receptors is unknown). Although not certain, the decision-maker may nonetheless have good knowledge of the probability of occurrence of each event/state. The main selection criteria commonly used to aid decision-making in these circumstances are the expected (monetary) value criterion, the expected **utility** criterion, and expected value-risk analysis.

The **expected value** criterion involves ranking options according to the expected value of the outcome, given the range of possible events/states and consequences that could emerge. By 'expected' we mean the probability or likelihood that a particular outcome will be realised. Consider a simplified example in which the

Table 5.2: Example outcome array – NPV of adaptation options under five flow regimes (£ million)

Options	Flow regime (future states of nature)				
	S_1	S_2	S_3	S_4	S_5
Probability	0.10	0.20	0.40	0.20	0.10
A_1	2.0	6.0	10.0	14.0	18.0
A_2	9.0	9.5	10.0	10.5	11.0
A_3	10.0	12.5	14.0	15.5	18.0

35 Since discussion of these concerns, and recommended corrective actions, is beyond the scope of this report, the interested reader is referred to any good text on capital budgeting, e.g. Bierman H. and Smidt S. (1993).

decision-maker has to choose from three adaptation options, where the net present value of each depends on the anticipated future flow regime in a river. Suppose that the decision-maker is relatively confident about the probability of occurrence of each of five predicted flow regimes, and knows with certainty the consequences associated with each flow regime. This situation is shown in Table 5.2 above.

Since the decision-maker is able to assign a probability distribution to the likely flow regimes, (s)he can calculate the **expected net present value** (ENPV) of each option. (Note that the Green Book refers to this as the **risk adjusted NPV**.)

The ENPV of each of the adaptation options listed in Table 5.2 is given in Box 5.2 below.

Box 5.2: ENPV of adaptation options

E (A_1)
= 0.1 x £2.0m + 0.2 x £6.0m + ,..., + 0.1 x £18.0m
= £10.0 million

E (A_2)
= 0.1 x £9.0m + 0.2 x £9.5m + ,..., + 0.1 x £11.0m
= £10.0 million

E (A_3)
= 0.1 x £10.0m + 12.5 x £10.0m + ,..., + 0.1 x £18.0m
= £14.0 million

Since the outcomes in this case are described in terms of NPV, the decision-maker should select the option with the largest **ENPV**[36] – that is, option A_3.

Ranking options based on the ENPV criterion, however, ignores the 'riskiness' (or the 'dispersion' of expected outcomes) of each option. For example, adaptation options A_1 and A_2 (above) have the same ENPV, but different distributions of possible outcomes; A_1 is 'riskier'[37] than A_2. Preferences regarding risk can be addressed by using the **expected utility criterion**. In terms of risk preferences, a decision-maker may be described as **risk-averse**, **risk-loving**, or **risk-neutral**.

Using specialist methods, it is possible to capture a decision-maker's preference to risk. Basically, these methods measure the 'utility' a decision-maker associates with specific uncertain outcomes. It is then possible to estimate the expected utility of each course of action, and select the option with the highest expected utility.

An alternative to the expected utility criterion, which still accounts for the decision-maker's preference to risk, is to use **expected value-risk analysis** (or **risk-benefit plotting**). This technique involves comparing the ENPV and 'riskiness' of each option under consideration, where one indicator of 'riskiness' is standard deviation. ENPV has positive value whereas, if the decision-maker is risk-averse, increased dispersion of outcomes has negative value. That is, a higher ENPV is preferred to a lower one for the same dispersion of outcomes, and a smaller degree of dispersion is preferred to a higher one for the same ENPV. If the decision-maker can identify the rate at which (s)he is willing to accept increased 'riskiness' for the compensation of increased ENPV, then options with different levels of ENPV and 'riskiness' can be ranked, and the most desirable one identified.

Making decisions in the presence of uncertainty: knowledge of probability is poor

Various decision-support techniques have been developed which do not require knowledge of, for example, the likelihood of an event/state occurring, in which case the determination of an expected value would not be possible. These so-called 'non-probabilistic' criteria simply involve the application of predefined rules to the outcome arrays. These are likely to be particularly relevant in the climate change context since our state of knowledge is not currently sufficient to assign probabilities to a particular climate change scenario.

The **maximin criterion**, for example, requires the decision-maker to identify the 'lowest' NPV that could result from each adaptation option, and then to select the largest of these 'lowest' outcomes, i.e. **maxi**mise the **min**imum NPV. This criterion is clearly 'pessimistic' as it focuses on the worst possible outcome associated with each option. Indeed, it is the most risk-averse criterion.

36 NB this is the same as employing the NPV selection criteria, except we are basing the decision on expected values as opposed to deterministic values.

37 That is, the distribution of outcomes is more dispersed around the mean.

Other 'non-probabilistic' criteria, such as the **minimax (regret) criterion** and the **maximax criterion**, are outlined in the implementation guidelines.

Assessing the effect of future uncertainty on the outcome estimates[38]

The estimates which the analyst arrives at essentially determine the choice of the 'best' option, and as such *the decision-maker will want to know how sensitive the future estimates are to the input data and modelling approach used by the analyst, as well as the key assumptions adopted*. Several techniques exist for testing the key factors which underpin the estimated outcomes in a decision problem, including: (a) sensitivity analysis; (b) (Monte Carlo) simulation; and (c) interval analysis.

Sensitivity analysis focuses on assumptions that have a potentially significant effect on the study's results. It should always be applied in the context of climate adaptation decisions. The method involves recalculating the NPV for different values of major variables, one at a time. It involves selecting variables to which the estimated NPV may be sensitive, determining the extent to which they may vary, calculating the effect of different values on the NPV, and interpreting the results, in particular regarding whether or not certain combinations of variables may result in the NPV switching from positive to negative, or vice versa.

Monte Carlo simulation (or **simulation** for short) provides a rigorous approach to the treatment of uncertainty; in fact it is probably the most common approach used to evaluate the impact of uncertainty on inputs to quantitative modelling. It involves generating a large number of sample outcomes, using the underlying probability functions of the variables, in order to build an accurate picture of the distribution of possible outcomes, from which expected values and measures of dispersion can be estimated.

Interval analysis involves taking the (absolute) lower value of the range of estimates for each model input, and combining them to define the *lower bound* of the final result. Likewise, the (absolute) upper value of the range of estimates for each model input can be combined to define the *upper bound* of the final result. Since the probability of all the lower (upper) values occurring simultaneously is relatively small, the **confidence interval** for the final result is wider than those corresponding to the individual inputs.

5.2.6 TREATMENT OF UNVALUED IMPACTS

Environmental impacts are often dislocated in time and space, making cause and effect difficult to establish, and the severity of an impact frequently depends on an accumulation of problems. Furthermore, many environmental goods and services do not enter markets, which presents difficulties for valuation, compounded by the fact that the available data are often scarce or of poor quality. Hence, it is highly likely that, for many of the impacts of climate change on receptors in the UK, appropriate quantitative data will simply not be available, making economic valuation extremely difficult. It is also likely, given state-of-the-art economic valuation, that it will not be possible to 'price' certain impacts even where quantitative data are available. Nevertheless, **the lack of a monetary estimate for specific climate impacts does not mean that those impacts can be overlooked in any decision-making process.** The penultimate step in Step Three of CBA is the incorporation of unvalued impacts into the CBA framework.

The first step in ensuring that these impacts are not overlooked is the construction of a simple checklist, which can be used to identify all potential impacts relevant to the decision problem at hand, and to indicate whether or not they can be valued. A decision-support tool is then required, which brings both valued and unvalued impacts into a common framework of analysis. One possibility is to use a variation of **sensitivity analysis**. A second more rigorous option is to use **multi-criteria analysis** (MCA). Since MCA also allows objectives other than economic value to influence the decision-making process, it is considered in a separate section below (Section 5.4).

38 Note that the optimal timing (and nature) of adaptation options might be dependent on whether new information about likely climate impacts becomes available in the future. The value of this new information is known as quasi-option value (see Section 5.7.6 in the implementation guidelines).

Variation of sensitivity analysis

Above we presented **sensitivity analysis** as a technique for assessing the vulnerability of options to future uncertainties. A variation on sensitivity analysis, which allows us to take the unvalued impacts into account, albeit subjectively, is to calculate the magnitude of the unvalued impacts necessary to make an 'unfavourable' NPV 'favourable', or vice versa. Once we have determined the magnitude of the unvalued impacts necessary to switch the NPV from positive to negative, or vice versa, we can then make a judgement as to whether or not the unvalued impacts are likely to amount to this value.

For **independent** options, this approach provides a means to assess the likely influence of unvalued impacts on the selection decision. It is, however, not appropriate for assessing **mutually exclusive** alternatives (this is best done using MCA).

5.3 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is the main alternative economic decision-support tool to CBA, and is also used to evaluate trade-offs between benefits and resource costs. In contrast to CBA, however, the benefits are measured in units other than money. CEA can be used to find, e.g., the least-cost way of achieving a predetermined goal or the policy that yields the greatest benefit subject to a budget constraint. In contrast to CBA, CEA has the advantage that it does not require the desired outcome (benefits) to be expressed in money terms. Only the resource inputs (costs) of the adaptation option are valued. The benefits can be expressed in physical units, e.g. volume of water delivered per year. This is particularly advantageous when valuation of the option deliverables is impractical, controversial, uncertain, or any combination thereof. However, CEA does not work so well when each option under consideration yields several deliverables that are measured in different units, and therefore cannot be aggregated into a single measure of 'benefit'. For similar reasons, CEA cannot be used to compare options that provide different outputs; CEA compares the costs of alternative options for providing the same, or similar, outputs.

In the context of these guidelines, CEA serves two purposes. Firstly, CEA may be used to identify the least-cost adaptation response to provide a specific level of climate risk management, and by extension, it can be used when considering cost-based approaches to valuing the economic benefits foregone through damage caused by climate change.

5.4 Multi-criteria analysis

We have seen above that impact quantification and valuation problems are likely to restrict the economic analysis of adaptation options. A further factor to take into account is that economic value is not the sole criterion for making climate adaptation decisions. Other decision criteria, including flexibility, avoiding **irreversibility**, equity, minimising uncertainty, political sensitivity, etc., may also be important to the decision-maker. Recognition of the importance of these issues has led to the development of so-called **multi-criteria analysis** (MCA) techniques (sometimes referred to as 'weighting and scoring'). MCA differs from conventional economic analysis in three ways:

- it does not restrict the decision-making process to **economic efficiency** criteria;
- it allows climate impacts to be measured in units other than monetary ones; and
- it does not require the use of economic valuation to accommodate climate impacts in the decision-making process.[39]

MCA embodies a vast array of analytical techniques, which cannot be covered in this overview, or for that matter, in the implementation guidelines.[40]

In general, MCA proceeds in four steps:

1. Problem definition, which involves specifying overall **objectives** and feasible **alternative courses of action** (adaptation options).

[39] At the same time it does not exclude economic valuation from the decision-making process.

[40] An introduction to MCA (weighting and scoring) is available from the Office of the Deputy Prime Minister website (www.odpm.gov.uk) (see the DTLR archive).

2. Selecting **decision criteria** and assessing alternative options, in which qualitative and/or quantitative information on each alternative option is summarised by using the assignment of a **rank**, **rating** or **scale value** relative to each decision criteria.[41]

3. Specifying stakeholder preferences, which involves the **weighting** of decision criteria relative to one another.

4. Aggregation, where an overall **composite index** or **total score** is calculated for each alternative. The total score of an alternative is given by the product of the importance weighting assigned to each decision criterion and the ranking, rating, or scale of each alternative with respect to that decision criterion, summed over all decision criteria.[42]

The basic idea behind MCA is to define a framework that allows the integration of different objectives (or decision factors) in a quantitative analysis without assigning monetary values to all of them. In short, MCA provides systematic methods for comparing these decision factors, some of which are expressed in money terms and some of which are expressed in other units. CBA should still be used within the MCA framework, however, to value rigorously those impacts that can be expressed in monetary terms. MCA cannot be used instead of CBA; its purpose is not to replace valuation.

[41] **Ranking** involves ordering alternatives, from best to worst, in terms of their likely impact on each identified decision factor. **Rating** involves the use of a pre-defined rating scheme. **Scaling** refers to the assignment of algebraic scales or letter scales to the impact of each alternative being assessed on each identified decision factor.

[42] **Weighting-scaling** or **weighting-rating** methodologies embody the assignment of relative importance weights to decision factors, and impact scales or ratings for each alternative relative to each factor. **Weighting-ranking** approaches involve the assignment of importance weights, and the relative ranking of all alternatives from best to worst in terms of their impact on each decision factor.

Appendices

Appendix 1: case studies

A1.1 Introduction

In this section we present four case studies that demonstrate how the costing methodology presented in the implementation guidelines can be used to derive cost estimates for selected climate change impacts. These cost estimates could be used to provide a monetary indicator of the importance of the impact in question, or a measure of the potential benefits of alternative adaptation options. Specifically, the case studies aim to illustrate the mechanics of applying the implementation guidelines: how a user, confronted with a specific climate change decision problem, can work through the document in order to undertake a rigorous costing exercise in different contexts. The four case studies are:

- increasingly stringent effluent standards for dischargers to a river in SW England;
- irrigation bans on agriculture in East Anglia;
- the changing costs and impacts of flood alleviation in Shropshire; and
- short-term disruption to rail transport systems in Scotland.

The case studies relate to a range of ‘sensitive’ sectors that are likely to be affected by climate change in the UK, and also provide a wide geographical coverage across the UK. The case studies therefore illustrate the application of a range of different costing guidelines.

It should be emphasised that these case studies are purely illustrative: **they do not purport to give actual cost estimates**. Indeed, the climate impacts considered in some of the case studies are not based on real data. Also, the case studies generally focus on one climate change impact among the many that would be relevant to the type of decision problem being considered.

A1.2 Water resources: the cost of increasingly stringent effluent standards

A1.2.1 CONTEXT OF CASE STUDY

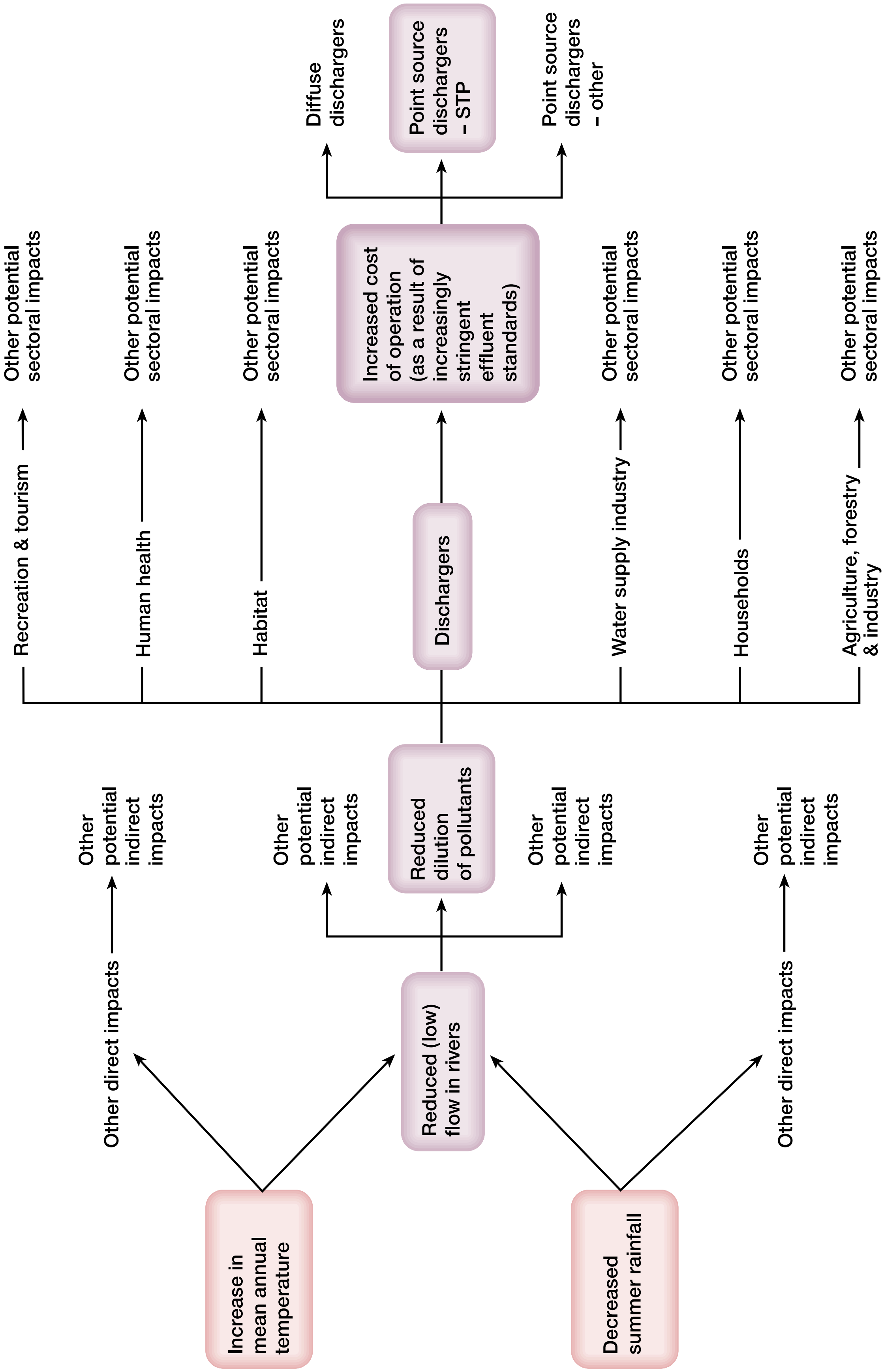
One of the potential impacts of predicted decreased summer rainfall, or rise in mean annual temperatures and the subsequent increase in evaporation, is the increased incidence of low flow in rivers. This in turn is likely to result in, among other things[43], a reduction in water quality, since there is less volume to dilute pollutants in the water course. Low flows directly (and indirectly through deterioration in water quality) adversely affect recreation activities and associated tourism, habitat, amenity, agricultural production, industrial processes, public water supply, and waste water discharge. The future impacts of climate change will be more problematic in those rivers already adversely affected by low flow.

It is the responsibility of the Environment Agency (EA) to maintain, and where appropriate improve, the quality of water for all those who use it. In general, this is done by setting Water Quality Objectives (WQO) based on: a) quality targets to protect recognised uses, and b) standards laid down in EU Directives. The quality targets used in rivers are known as River Quality Objectives (RQO), and they are based on the River Ecosystem (RE) classification system. The RE classification system consists of five classes in order of decreasing quality, from RE1 to RE5, which are used to establish WQOs under the 1991 Water Resources Act.

In future, as climate impacts intensify, the increased future incidence of low flow in susceptible rivers could present the EA with a ‘decision problem’ in that preemptive action could be required in order to ensure that the relevant WQOs are maintained. Note that this is an illustrative future decision context that does not reflect actual intended action by the EA. Some of the possible courses of action that the regulatory authorities could consider pursuing are:

[43] As seen in the impact matrix below, low flows can also have impacts on recreation and tourism, habitat, water industry supply, etc.

Figure A1.1: Scope of the case study — relevant cause-effect chains from the water resource impact matrix



Note: STP = sewage treatment plant

- Revoking or modifying existing abstraction licenses, or declining applications for new licenses on the affected river.

- Undertaking major engineering works to support the flow regime in the affected river.

- Imposing more stringent effluent standards on significant discharges along more problematic reaches of the affected river. (Of course, this option only addresses water quality and does not alleviate low flow.) This involves lowering the numerical conditions in the discharge consent for specific contaminants of concern.

As part of its duty, the EA must consider the costs and benefits of any statutory actions taken. Other stakeholders will also be interested in the costs and/or benefits of proposed actions (e.g. the holders of discharge consents in respect of more stringent effluent standards), and therefore may wish to participate in the decision-making process.

The context of this case study is one in which the EA evaluates various options to mitigate the impact of climate change on water quality in a river susceptible to low flow – we have chosen the River Tavy in south-west England. The full set of impacts relevant to this decision problem, identified in the Water Resource impact matrix in the implementation guidelines, are depicted schematically in Figure A1.1. (An extract of the relevant portion of the Water Resource impact matrix is shown in Table A1.1.) It is not feasible within the scope of this case study to 'cost' all these impacts, where they are applicable. This case study focuses on the potential impact on holders of discharge consents, if the numerical conditions on these consents were to be tightened. Specifically, **this case study estimates the increase in treatment costs at a sewage treatment plant (STP) if the permitted concentration of biochemical oxygen demand (BOD) in the effluent were decreased in order to maintain the long-term RQO immediately downstream of the discharge point.**[44] The resulting cost estimate represents one piece of information that the EA can use to construct an outcome array from which to solve their water quality decision problem. (The other potential sector impacts shown in Figure A1.1 and Table A1.1 also need to be 'costed' to complete the outcome array.) Of course, the operator of the STP is primarily interested in the impact of increased effluent standards.

The River Tavy

The River Tavy rises on the western slopes of the upland area of Dartmoor, within the boundary of the Dartmoor National Park, and flows south-west before joining the Tamar estuary north of the city of Plymouth. The Tavy has a reputation of being one of England's fastest flowing rivers. Over the 28 km from its source to the tidal limit at Lopwell, it drops over 560 m at an average gradient of 15.9 m km^{-1}. Upstream of the tidal limit it drains an area of 235.5 km^2. Within this catchment area there are 15 licensed surface water and 75 licensed groundwater abstractions, with a total authorised volume of 122 million m^3 $year^{-1}$ (as of 1997). There are also 50 licensed 'consents' to discharge.

The RQOs for the Tavy are shown in Table A1.2. The STP considered in this case study is located on the reach of river between West Bridge and the River Lumburn confluence. The long-term RQO for this reach is RE 2, and the corresponding criterion for BOD is 4.0 mg l^{-1}. It is assumed that this criterion is to be maintained under the following (fictitious) predicted climate change upstream flow rates in the year 2020: 3.4 m^3s^{-1} (with a probability of occurrence of 0.3); 3.5 m^3s^{-1} (with a probability of occurrence of 0.6); and 3.2 m^3s^{-1} (with a probability of occurrence of 0.1). These represent the expected flow rates at some point in the future under particular climate change scenarios. It is assumed that in the absence of climate change, the average daily flow upstream of this reach is predicted to be 3.7 m^3s^{-1} during the same time period (this is taken as the baseline flow rate for the case study).

A1.2.2 APPLICATION OF THE COSTING GUIDELINES

Impact assessment: using the matrices and decision tree

In working through the Water Resource impact matrix for the part of the decision problem we are considering in this case study (see Table A1.1), the relevant terminal impact is labelled 'increased cost of operation'. In the column denoted 'VM' (valuation method), which is

[44] Note that – in reality – many other courses of action could be followed in response to this impact.

Table A1.1: Scope of the case study – extract from the water resource impact matrix

Climate change: decreased summer rainfall

Direct Impact	**VG**	**Potential Indirect Impact**	**VG**	**Sector Affected**	**Potential Sectoral Impact**	**VG**	**Relevant Stakeholders**
Low flow in rivers	NT	Silting up of, and collection of material in, water channels (continued)	CO	Water transport	Change in operational costs	CO	Transport operators, waterways authorities, emergency services
					Change in risk of accidents	IG	
				Households	Loss of amenity	IG	Local population
		Lack of water supply in river	CO	Water supply	Increased abstraction costs (increased depth of pumping)	CO	Water supply companies, consumers, government, regulators
					Reduced groundwater quality – increased risk of saline intrusion (increased treatment costs)	CO	
				Autonomous abstractors	Increased abstraction costs (increased depth of pumping)	CO	Autonomous abstractors
					Reduced groundwater quality – increased risk of saline intrusion (increased treatment costs)	CO	
		Reduced dilution of pollutants	NT	Human health	Increased risk of mortality	IG	Regulators, government, local population, NHS
					Increased risk of morbidity	IG	
				Habitat	Loss of species	IG	Local population, national interest groups
					Damage to habitat/ecosystems	IG	
				Tourism and recreation	Decrease in demand or decrease in enjoyment per visit	IG	Tourists, recreational users or water resource
				Households	Amenity losses	IG	Property owners, general public
				Dischargers	**Increase cost of operations**	**CO**	**Waste water treatment companies**
				Angling	Change in fishery class	IG	Recreational and commercial fisheries
					Loss of productivity (or increased costs)	CO	
					Increased risk of catching unhealthy fish – human health risk	IG	
				Water supply	Increase in water treatment costs	CO	Water suppliers, autonomous abstractors
				Agriculture, forestry, manufacturing	Decreased water quality – loss of productivity (or increased costs)	CO	Farmers, forestry companies, autonomous industrial abstractors

Notes: NT = No technique recommended; CO = conventional market technique; IG = individual guideline

Table A1.2: River quality objectives for the River Tavy				
River reach			Approx. distance (km)	RE Class
Source	➔	Hill Bridge	>7.5	RE 1
Hill Bridge	➔	Cholwell Brook	3.6	RE 1
Cholwell Brook	➔	River Burn confluence	2.0	RE 1
River Burn confluence	➔	Kelly School	0.7	RE 2 [1]
Kelly School	➔	West Bridge	1.6	RE 2
West Bridge	➔	River Lambourne confluence	3.0	RE 4 [2]
River Lambourne confluence	➔	Quarry Wood	1.3	RE 2 [1]
Quarry Wood	➔	River Walkham confluence	0.9	RE 1
River Walkham confluence	➔	Denham Bridge	2.6	RE 1
Denham Bridge	➔	Tidal Limit (Lopwell Dam)	3.7	RE 1

Notes: 1 '[ ]' denotes a long-term River Quality Objective (RQO). *(Adapted from EA, 1996)*

adjacent to the terminal impact, you will find the label 'CO'. The appropriate valuation methods in this case are the conventional market-based techniques. According to the instructions given, you should **go to** the decision tree shown in this overview of guidelines (Figure 3.1), and progress along the initial 'YES' branch. (If we were evaluating the entire decision problem we would also need to progress along the initial 'NO' branch, in order to value the other relevant impacts, including non-use value.)

The next node on the decision tree asks whether:

- The affected market good/service is a man-made asset, which is lost or damaged as a result of the impact; in which case you should **go to** the guideline on (replacement/restoration) cost-based approaches.

- The impact positively (or negatively) affects the provision or production of a market good/service; in which case you should **go to** the guideline on changes in inputs/outputs (of marketed goods/services).

Since the impact under consideration potentially increases the cost of providing the affected service (i.e. waste water treatment), the latter branch of the decision tree is the appropriate one to follow.

Economic valuation: change in input/output of a marketed good or service

In many cases, environmental quality, or the availability of a natural resource such as water, may have a direct (or indirect) effect on:

- the capability of an economic agent to provide a service; and/or

- the costs that the agent incurs in providing that service.

For example, in the context of this case study, the waste assimilation capacity (WAC) of a river is directly related to water availability (or more precisely, water flow); other things being equal, a decrease in flow rates leads to a proportional decrease in WAC. As the WAC declines, the dilution that the river flow provides to 'dischargers' is affected, with the consequence that a greater burden of achieving set water quality criteria such as RQOs for the affected stretch of river must now be borne by the discharger.

Since, in this case study, we are dealing with a situation in which a reduction in river flows and the subsequent reduction in the river's WAC leads to an increase in

Figure A1.2: Diagrammatic representation of the mass balance approach used

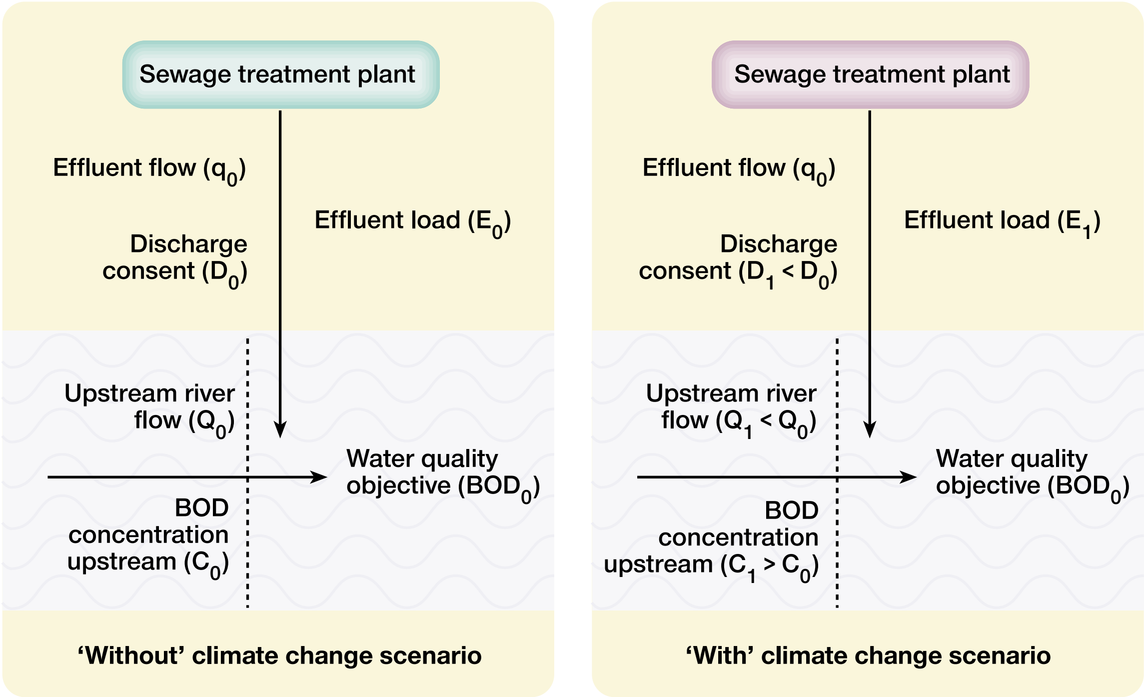
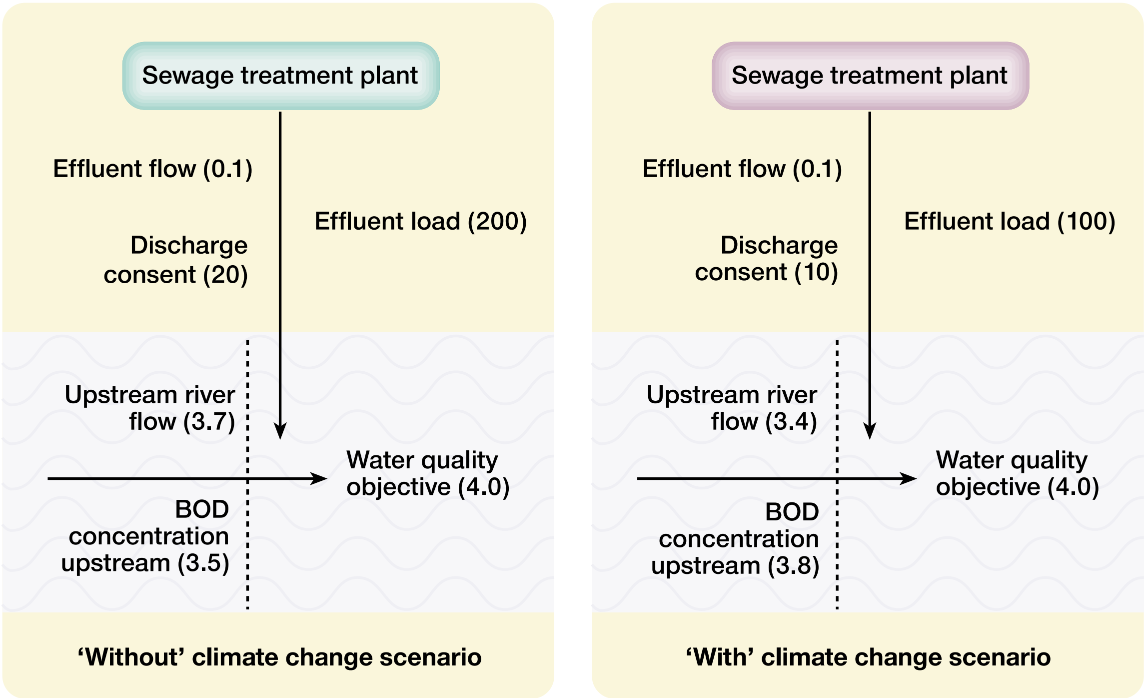


Figure A1.3: Example calculation of change in BOD loading



Box A1.1: Version of the 'unit cost' approach applied in this case study

The economic value of an increment in sewage treatment costs (arising from a improvement in BOD removal efficiency) can be determined by multiplying the unit cost of removing an additional kg of BOD from the influent stream (which reflects the total cost of those resource inputs consumed in doing so) by the projected total change in resource use (a proxy for which is the total kg of BOD that must be removed) – that is:

$$V_{BOD} = \underbrace{mc_{BOD} \times \triangle E_{BOD}}_{\text{Step 2}} = mc_{BOD} \times \overbrace{(E^1_{BOD} - E^0_{BOD})}^{\text{Step 1}}$$

Specifically,

V_{BOD} = the economic value of an increment in sewage treatment costs (arising from a improvement in BOD removal efficiency),

mc_{BOD} = the unit cost of removing an additional unit of BOD from the influent stream,

E^0_{BOD} = the projected BOD loading in the *without* climate change case, and

E^1_{BOD} = the projected BOD loading in the *with* climate change case.

resource costs for dischargers, as opposed to a change in productivity, you should use one of the **production cost** (or **cost saving**) **techniques**. The techniques given involve either:

- Calculating the **unit cost** of the relevant resource inputs, and then multiplying this by the projected change in resource use, which is defined as the difference between the *with climate change* (i.e. the permitted (consent) concentration of BOD under reduced flow conditions) and the *without climate change* (i.e. the permitted (consent) concentration of BOD under baseline flow conditions) case.[45]

- Using **Total Budgets**, or similar accounting frameworks, to value changes in net income accruing to the operator of the STP for the *with* and the *without* cases.

Implementation of the second ('net income') approach requires relatively more data than the 'unit cost' approach. Moreover, these data must be obtained from the plant operator. Hence, the 'unit cost' approach is used in this case study.

In the guidelines the 'unit cost' approach is performed in two steps. These steps are considered in turn below, and illustrated in Box A1.1.

Step One

As shown in Box A1.1, Step One involves determining the reduction in BOD loading (kg BOD day^{-1}) required to maintain the long-term RQO for the river reach under consideration. Put another way, we must estimate the additional mass of BOD that needs to be removed from the influent to the STP, other things being equal, in order to comply with the more stringent discharge consent. This requires that we first determine the 'new'

[45] In contrast to the agriculture case study (Section A1.3), where we would expect the climate impact to induce price changes, the estimated change in resource inputs in this case study is insignificant relative to the market for such inputs; hence, we do not expect their price to change. This allows us simply to multiply the expected change in resource inputs by prevailing market prices to derive a measure of the cost of the projected change. Also, it is unlikely that the markets in which inputs to waste water treatment are traded are distorted, so no adjustments to market prices are required.

discharge standard that is required to ensure that the water quality criterion for that river reach is still met under the *with* climate change case (i.e. reduced flow). For the purpose of this case study we performed these calculations using a simple mass balance equation; the model is illustrated in Figure A1.2.

Figure A1.3 shows the results of applying the model to one of the predicted flow rates. As one can see from the figure, if the predicted flow rate is 3.4 $m^3 s^{-1}$, then a 'new' discharge consent[46] of 10 mg BOD l^{-1} must be imposed on the STP in order to maintain the RQO for BOD of 4 mg l^{-1}. Given the effluent flow of 0.1 m^3 s^{-1}, the BOD loading under the *with* case is about 100 kg BOD day^{-1}. Hence, relative to the *without* case, where the BOD loading is about 200 kg BOD day^{-1}, an additional 100 kg BOD day^{-1} must be abated. This is the measure of $\triangle \boldsymbol{E}_{BOD}$ that we seek as an input to Step 2. Similar calculations have been performed for the other two predicted upstream flow rates (see Table A1.3 below).

Step Two

A sewage treatment plant (STP) is essentially a combination of separate unit processes[47] designed to produce an effluent of a specified quality from a waste water (influent) of known composition and flow rate. By combining these unit processes in various ways it is possible to produce an effluent of specified quality from virtually any type of influent waste water, since each unit process, or combination of processes, has different removal efficiencies. Each unit process, or combination of processes, also has different total cost structures. Hence, the response of the STP operator to the more stringent discharge consent can be characterised by specific unit cost comprising two elements: 1) a measure of 'effectiveness' (kg of BOD removed); and 2) a measure of total cost (£), which together provide a measure of cost-effectiveness (£ kg^{-1} BOD removed).

For the purpose of this case study, it is assumed that the unit **abatement cost** for BOD ranges from £2.5 to £5.2 kg^{-1} BOD removed (in 2000 prices). This provides us with a 'low' unit cost and 'high' unit cost scenario. (If the exact response of plant operator, and the resulting changes in removal efficiency and total costs, are known, then the cost-effectiveness guideline could be used to generate appropriate unit costs in terms of £ per kg BOD removed from the influent.) We can now apply these unit costs to the estimated additional mass of BOD that must be abated under the *with* case. For the flow scenario shown in Figure A1.3 for example, the estimated annual cost of complying with the new BOD effluent standard, under the low unit cost and high unit cost scenario, is given as:

£2.5 kg^{-1} BOD x 100kg BOD day^{-1} x 365 days $year^{-1}$ = £91,000 $year^{-1}$

£5.2 kg^{-1} BOD x 100kg BOD day^{-1} x 365 days $year^{-1}$ = £190,000 $year^{-1}$.

Similar calculations have been preformed for the other two predicted future flow rates. These are shown in Table A1.3, which summarises the main outputs of applying the 'changes in input/output' guideline in the context of this case study.

A recurring theme in these guidelines is that most decision problems in the context of climate change impact and adaptation assessment involve some degree of uncertainty about the possible outcomes of a given course of action. In this case study, one is assumed to have good knowledge of the probability of occurrence of each of the predicted upstream flow rates (states of nature), and thus the decision-making context is one of 'risk'; for example, we know that the probability of a future flow rate of 3.4 m^3 s^{-1} is 30% (or 0.3).

Since we are able to assign a probability distribution to the possible states of nature, we can calculate the

[46] That is, the 'new' permitted concentration of BOD in the effluent.

[47] These unit processes are typically classified into four groups: (1) **Primary (Mechanical) Treatment**: removal and disintegration of gross solids, removal of grit, oil and grease (if present in large amounts); separation of storm water; and removal of settable solids (SS), which are separated as sludge. (2) **Secondary Treatment**: used as a minimum treatment requirement in typical receiving water situations. Biological or chemical treatment processes are used to further purify waste water; the biological processes remove more organic matter while the chemical processes remove more phosphorous. (3) **Tertiary Treatment**: further treatment of biologically treated effluent to remove remaining BOD, SS, bacteria, specific toxic compounds and nutrient to enable the final effluent to comply with standards more stringent than can be achieved with secondary treatment alone. (4) **Sludge Treatment**: thickening, dewatering, stabilisation and disposal of sludge (Gray, 1999).

Table A1.3: Outcome array – expected increase in resource costs under three predicted flow rate scenarios in 2020 (2000 prices)

	State of nature (predicted flow rate)		
	S_1	S_2	S_3
Probability	0.3	0.6	0.1
'With' discharge consent (mg l^{-1})	10.0	15.0	5.0
Upstream flow rate (m3 s^{-1})	3.4	3.5	3.2
Change in effluent loading (kg BOD d^{-1})	100	50	150
Increase in treatment costs (low) (£ $year^{-1}$)	91,000	46,000	137,000
Increase in treatment costs (high) (£ $year^{-1}$)	190,000	95,000	285,000

expected cost of the proposed increase in the STP's discharge consent. The expected annual cost of the low and high unit cost cases listed in Table A1.3 below is:[48]

E (low) = 0.3 x £91,000 + 0.6 x £46,000 + 0.1 x £137,000 = £68,600 per year;

E (high) = 0.3 x £190,000 + 0.6 x £95,000 + 0.1 x £285,000 = £142,500 per year.

As a consequence of reduced river flow and the desire of the EA to maintain the long-term RQO on the relevant reach, the expected cost to the operator of the STP who now faces a more stringent discharge consent for BOD ranges from £68,600 to £142,500 per year. Note that these estimates are annual (recurring) values, and not capitalised (or present) values. When integrating these expected cost estimates into, say, cost-benefit analysis, they should be treated as costs that will recur over the time horizon of the analysis, in this case the year 2020.

A1.2.3 SUMMARY

One of the potential impacts of predicted decreased summer rainfall, or rise in mean annual temperatures and the subsequent increase in evaporation, is the increased incidence of low flow in rivers. This in turn is likely to result in, among other things, a reduction in water quality, since there is less volume to dilute pollutants in the water course. In future this could present the EA with a 'decision problem' in that pre-emptive action could be required in order to ensure that relevant WQOs are maintained subject to increased low flow. One of the courses of action open to the EA is to impose more stringent effluent standards on significant discharges along more problematic reaches of the affected river. This involves lowering the numerical conditions in the discharge consent for specific contaminants of concern. In this case study we estimated the increase in treatment costs at a sewage treatment plant, if the permitted concentration of BOD in the effluent were decreased in order to maintain the long-term RQO immediately downstream of the discharge point, under three predicted climate change flow rates. Using the relevant parts of the implementation guidelines, the **expected cost** to the operator of the STP (who faces a more stringent discharge consent for BOD relative to the base case), ranges from £68,600 ('low' unit cost case) to £142,500 ('high' unit cost case) per year. These cost estimates represent one piece of information that could be used by decision-makers managing water quality.

48 These cost estimates, in contrast to those given above, represent the expected cost across all three predicted flow rates, as opposed to the estimated cost under a single flow rate.

A1.3 Agriculture: the cost of not meeting irrigation need

"Even small changes in precipitation will have profound consequences for plant production… Decreased spring and summer rainfall would have serious implications, decreasing crop water supply, especially in light soils, increasing moisture stress and reducing growth. The impact on horticultural crops would be severe. Demand for irrigation would probably increase." MAFF (2000, p.18).

A1.3.1 CONTEXT OF CASE STUDY

In 1997/8 agriculture accounted for 1%-2% of the total volume of water abstracted from surface and groundwater sources in England and Wales.[49] Over 70% of the 618 Ml day^{-1} that was abstracted for agriculture was used for the purpose of spray irrigation. This may not seem significant relative to the volume of water used for public water and electricity supply, which respectively account for 45% and 32% of total abstractions. However, it can be significant in selected river basins. This is especially true in the drier regions in eastern England, where nearly half of all the irrigation water used in England and Wales is consumed (250 Ml day^{-1} in the EA Anglian Region).

Since irrigation in the UK is supplementary to rainfall, demand for irrigation is seasonal, with irrigation typically needed between May and October when rainfall is lowest. In general, if summer rainfall decreases (as a result of climate change) irrigation needs for existing crops increase, *ceteris paribus*.[50] Already, during the summer months in a 'dry' year, irrigation demand is relatively high and there is sometimes not enough irrigation water to meet needs. Evans (1994) notes that irrigation demand on a 'peak' summer's day in East Anglia can exceed the volume collectively demanded by the water utilities. Peak irrigation demands also happen to correspond to the times when water resources are most scarce. Indeed, "*climate change may well reduce available resources in precisely those regions and at those times when agricultural irrigators most need it*" (MAFF, 2000, p. 21). Peak irrigation needs can, therefore, place significant demands on available resources, in turn leading to conflict between competing uses.

Between 1982 and 1995, the underlying growth rates in the total area irrigated, and the total volume of irrigation water applied, was +1% and +3% respectively. Continued growth is expected, with actual volumetric demand under the 'most likely' scenario predicted to increase between +2.5% and +2.8% per annum from 1995 to 2001, and then averaging about +1.5% per annum from 2001 to 2021 (Weatherhead *et al.*, 1997).[51] Actual irrigation volumes are, therefore, predicted to rise by nearly 50% by 2021. The demands that irrigation needs place on available water resources are, therefore, set to worsen.

Faced with increasing irrigation demand and reduced water resources, the decision-maker must decide whether the available water is 'best' left in the river (or aquifer) in order to provide environmental (non-extractive) services, allocated to non-agricultural abstractors such as public water supply or industry, or used to meet the increasing irrigation need. For illustrative purposes we may assume that it is the responsibility of the Environment Agency (EA) to allocate water resources so as to balance the needs of abstractors with the need to maintain the water environment. Note that this is an illustrative decision context, and does not represent a real set of decisions that the EA has to make. As part of its duty, the EA must consider the costs and benefits of any statutory actions taken, e.g. restricting direct water abstraction for the purpose of spray irrigation.

The purpose of this case study is to use the costing guidelines to estimate the cost of not meeting predicted actual irrigation needs in 2001 in the EA Anglian Region of England. The baseline for the analysis is defined by the predicted irrigation needs shown in Table A1.4 below. The impact of climate change will be the extent to which these irrigation demands are not met (see Table A1.9 below). The specific scenario considered

[49] Estimated total abstractions from all surface and groundwaters in 1996 was 56,181 Ml day^{-1}; abstractions for agricultural and horticultural purposes amounted to 618 Ml day^{-1} (EA, 2001).

[50] Equally, if temperature and evapotranspiration increase and summer rainfall remains unchanged, irrigation need on existing crops will increase. Increases in irrigation need are exacerbated if increased evapotranspiration and decreased rainfall are accompanied by extra sunshine hours and lower relative humidity (MAFF, 2000).

[51] These predictions do not allow for the influence of climate change. Irrigation needs may well increase above current predictions as a result of climate change. As the authors note, the actual influence of climate change will depend on complex interactions between changes in cropping patterns, irrigation economics and water availability.

assumes that, as a result of climate change, water resources under baseline conditions in the Anglian Region are predicted to be insufficient to meet future demands. In this illustrative case study this presents the EA with a 'decision problem' in that action is required to allocate available water resources so as to balance the needs of abstractors with the need to maintain the water environment.[54] One of the many options that would be available to the EA is to restrict direct abstractions. The impact under investigation is thus defined as the volume of irrigation water demanded which is not provided as a consequence of these restrictions on abstraction (in turn, farmers will lose the additional income that they accrue from irrigation).

This case study approximates the cost, in terms of irrigation benefits foregone, of restricting abstraction of raw water for irrigation purposes. The resulting cost estimate represents one piece of information that the EA can use to construct the outcome array from which to solve this hypothetical resource allocation decision problem.

It should be noted that more than one climate change 'cause-effect' chain can lead to reduced water supply during periods when irrigation water is most needed. This case study does not revolve around a specific cause-effect chain, and therefore the methodology can be applied in many contexts. Also, as is clear from the above discussion, climate change may well increase

Table A1.4: Predicted actual irrigated area and volumes in the EA Anglian region (2001) for a 'design' dry year

Crop category	Distribution	Irrigated volume	
	(%)	Rates of change A (10^3 m^3)	Rates of change B (10^3 m^3)
Main crop potatoes	48%	45,949	46,519
Early crop potatoes	6%	5,744	5,815
Sugar beet	14%	13,402	13,568
Orchard fruit	2%	1,915	1,938
Small fruit	1%	957	969
Vegetables	15%	14,359	14,537
Grass	3%	2,872	2,907
Cereals	4%	3,829	3,877
Other crops	7%	6,701	6,784
Total	**100%**	**95,727**	**96,915**

Notes:
- Derived from predicted actual total irrigated areas and irrigation volumes reported in Weatherhead *et al* (1997) and the distribution of irrigation between the eight major crop categories, by area and volume, in the Anglian Region (MAFF, 1997, and in Knox *et al*, 2000).
- 10^3 m^3 is thousand cubic metres of irrigation water demanded.
- 'A' are based on Weatherhead *et al* (1994) rates of change assumptions; 'B' are based on underlying rates of change between 1982 and 1995. For the purpose of this case study, it is assumed that the distribution of irrigation between the eight crop categories, which relates to 1995, is applicable in 2001.
- Irrigation requirements in a 'design' dry year are defined as the need equalled or exceeded in 20% of years (i.e. demand with a 20% probability of exceedance).
- Predicted irrigated area and volumes are derived under current pricing conditions; changes in the price of water will modify these predictions.

[52] Of course, the EA is not the only decision-maker that may initiate action to address the decision problem.

Table A1.5: Scope of the case study – extracts from the agriculture impact matrix

Climate change impact: increase in mean temperatures

Direct impact	VM	Potential indirect impact	VM	Sector affected	Potential sectoral impact	VM	Relevant stakeholders
Impact on arable crop	NT	Increased need for irrigation for crops and vegetables	CO	Water resources	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, general public, water companies, regulators
					New water supply sources needed	CO	
Warming of water temperatures	NT	Requirement of aquaculture for improved oxygenation, aeration or lower stocking densities	CO	Agriculture	Loss of productivity (or increased costs)	CO	Aqua-farmers, consumers of farmed fish products, wholesalers/retailers, Defra, EA
		Requirements of aquaculture for better parasite control strategies	CO	Health	Loss of productivity (or increased costs)	CO	Aqua-farmers, consumers of farmed fish products, wholesalers/retailers, Defra, EA
					Human health risks	IG	Consumers of farmed fish products, NHS, regulators

Climate change impact: decrease in moisture availability

Direct impact	VM	Potential indirect impact	VM	Sector affected	Potential sectoral impact	VM	Relevant stakeholders
Increased risk of drought in summer	NT	Crop failure/yield reduction	CO	Agriculture	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, food wholesalers/retailers, Defra
					Change in cropping type/pattern	CO	
		Increase in irrigation demand	CO	Water resources	Loss of productivity (or increased costs)	CO	Aqua-farmers, consumers of farmed fish products, wholesalers/retailers, Defra, EA
					New water supply sources needed		
		Increased risk of pest and disease outbreak	NT	Health	Loss of productivity (or increased costs)	CO	Farmers, consumers of farm products, general public, water companies, regulators
					Change in cropping type/pattern		
					Human health risks	IG	Consumers of farm products, NHS, regulators

future demand for irrigation water – e.g. existing irrigated crops may require more water, or farmers may opt to irrigate new or existing crops currently not irrigated. Analysis of this scenario, which would require the specification of a different baseline, is not undertaken here. However, the cost calculations illustrated below would, in general, be quite similar.

A1.3.2 APPLICATION OF THE COSTING GUIDELINES

Impact assessment: using the matrices and decision tree

As mentioned above, this case study is applicable to several cause-effect chains associated with specific climate impacts. Regardless of which cause-effect chain one follows in the Agriculture (or Water Resource) impact matrix, the relevant terminal impact is labelled 'loss of productivity'. (Extracts from the Agriculture impact matrix, which contain the cause-effect chain of interest to this case study, are shown in Table A1.5.) In the column denoted 'VM' (valuation method), adjacent to the terminal impact, you will find the label 'CO'. This means that the appropriate set of valuation methods in this case are the conventional market-based techniques. According to the instructions given, you should go to the decision tree shown in Figure 3.1 of this overview of guidelines and progress along the initial 'YES' branch. (Since non-use value is not directly relevant to the impact under consideration here, you do not need to go to this guideline.) The next node on the decision tree asks whether:

- The affected market good/service is an asset/durable good, lost or damaged as a result of the impact; in which case you should **go to** the guideline on replacement/restoration cost-based approaches.
- The impact positively (or negatively) affects the provision or production of a market good/service; in which case you should **go to** the guideline on changes in inputs/outputs (of marketed goods/services).

Since the impact under consideration potentially decreases the output of agricultural products, the latter branch of the decision tree is the appropriate one to follow.

Economic valuation: change in input/output of a marketed good or service

Environmental quality, or the availability of a natural resource such as water, will directly affect:

- the capability of an economic agent to produce a good; and/or
- the costs that the agent incurs in producing that good.

For example, the application of irrigation water allows the farmer to realise increases in crop yield (♣ $t\ ha^{-1}$) and improvements in crop quality, which manifest themselves in the form of higher prices (♣ $£\ t^{-1}$) over and above those realised through rain-fed production.[53]

As water availability for irrigation purposes is restricted, these additional combined benefits, which are multiplicative rather than additive, are lost to the farmer.

Since, in this case study, we are dealing with a situation in which a reduction in the availability of a natural resource leads to a reduction in productivity – as opposed to an increase in resource costs, we can employ one of the suggested **change-in-productivity approaches.**[54] These involve:

- Calculating a **gross margin** ($£\ t^{-1}$) for each unit of affected output (crop) and then multiplying this by the projected change in output ($t\ ha^{-1}$), which is given by the *with* irrigation and the *without* irrigation cases.
- Using **total** (farm) **budgets**, or similar accounting frameworks,[55] to value changes in net income for the *with* irrigation and the *without* irrigation cases.

53 Irrigation may well lead to other benefits such as facilitating effective use of herbicides and fertilisers, permitting a wider range of crops to be grown, and enabling multiple cropping (Weatherhead *et al*., 1997).

54 It is therefore implicitly assumed that the farmer will not switch to mains water supply in order to continue irrigating those crops that require it.

55 For example, the accounting framework presented in MAFF (1999b) could be adapted to perform this type of costing analysis.

- Estimating changes in **land values** (£ ha-1) for the *with* and *without* cases.[56]

The second ('net income') approach is the most appropriate in this case study. First, it is more suited to dealing with combined changes in quantity and quality, and multi-product/multi-input situations than the 'gross margin' approach. Secondly, since we are not considering permanent bans on abstraction for irrigation, but rather temporary bans during part of or for the entire irrigation season in a given year, the 'net income' approach is also preferred to the 'land value' approach.

To generate a measure of the change in net income for the *with* irrigation and the *without* irrigation cases, the 'net income' approach proceeds as follows:[57]

Step One

Determine the increment in net income attributable to irrigation, for each irrigated crop. This is computed per m^3 of water applied (or per hectare irrigated) to facilitate aggregation (see Step 2). An example calculation for the main crop, potatoes, grown near Mepal, Cambridgeshire on medium available water content (AWC) soil is shown in Table A1.6.[58, 59]

Step Two

Generate an aggregate measure of the increment in net income attributable to irrigation for the EA Anglian Region. This involves taking the product of the range of predicted irrigation volumes for 2001 given in Table A1.4 ('000 m^3 $year^{-1}$), and the range of unit net benefits given in Table A1.7 below (£ m^{-3}). The resulting incre-

Table A1.6: Example calculation: average 'combined' net benefit from irrigation, for main crop potatoes grown in Mepal, Cambridgeshire (medium AWC soil) (1996/97 prices)

Item	With irrigation case	Without irrigation case
1. Gross revenue:		
a) Projected yield (t ha^{-1})	50	40
b) Projected price (£ t^{-1})	95.0	66.5
c) Projected revenue (1a * 1b) (£ ha^{-1})	**4,750**	**2,660**
2. Variable costs: (£ ha^{-1})		
a) Non-irrigation	1,979	1,840
b) Irrigation (0.15 to 0.17 m^{-3} applied net)	188 to 213	0
c) Total variable costs (2a + 2b)	**2,167 to 2,192**	**1,840**
3. Net income:		
a) Net Income per hectare (1c – 2c) (£ ha^{-1})	**2,558 to 2,583**	**820**
b) Change in net income (£ ha^{-1})	1,738 to 1,763	
c) Water applied (m^3 ha^{-1})	1,250	
d) Change in net income (£ m^{-3}) (3b ∣ 3c)	**1.39 to 1.41**	

Notes:

- Data are from Weatherhead *et al*. (1997) and Nix (1997).
- The assumed net depth of application is 125 mm.
- The combined yield and quality net benefits represent average values, and are likely to be higher in a dry year. Also, the combined net benefits vary considerably depending on whether the irrigated crop is grown on low AWC or high AWC soil (see Knox *et al.*, 2000). Table A1.7 contains low and high estimates of the average combined net benefit for selected crops grown in Mepal, Cambridgeshire.

ment in net income attributable to irrigation in 2001 (£ million year^{-1}) is shown in Table A1.8. It is assumed that the increment in net income attributable to irrigation in Mepal is representative of the increment in net income to be expected across the Anglian Region. Furthermore, it is also assumed that the total irrigated area in the Anglian Region comprises medium AWC soil.

Step Three

Determine the cost of restricting water abstraction for irrigation use. The aggregate increment in net income attributable to irrigation in the Anglian Region represents the maximum potential loss to farmers in 2001, if a total ban on abstraction for irrigation is enforced throughout the entire irrigation season – that is from April to September. If a total ban were not implemented until the beginning of July, however, a fraction of the net irrigation benefits would still be realised – the increment in net income resulting from water application between April and the end of June. The percentage of the total aggregate increment in net income that would be lost, for each crop grown on medium AWC soil, if a total irrigation ban were to be imposed from the beginning of a specific month to the end of the season, is given in Table A1.9.

Taking main crop potatoes as an example, if a total irrigation ban were imposed in the Anglian Region, say at the beginning of July for the remainder of the season, then 47 per cent of the increment in net income attributable to irrigation would be lost – the cost of the ban is thus £64-£66 million x 0.47, equivalent to £30-31 million. Similar calculations have been performed for each crop and period over which the total ban on irrigation is

Table A1.7: Average 'combined' net benefit from irrigation, for selected crops grown in Mepal, Cambridgeshire (medium AWC soil) (1996/97 prices)

Crop category	Combined net benefit	
	Low	High
	(£ / m^3)	(£ / m^3)
Main crop potatoes	1.39	1.41
Early crop potatoes	2.53	2.55
Sugar beet	0.35	0.37
Orchard fruit	1.51	2.59
Small fruit	2.24	6.81
Vegetables	1.29	4.50
Grass	0.08	0.16
Cereals	0.02	0.04

56 It is assumed that the value of irrigation is capitalised into the price of land with access to irrigation water. One can then compare the price of similar land with and without access to water. This alternative assumes that land values depend entirely on physical productivity, and not on other factors.

57 Note that we have assumed that commodity prices will not change as a result of the climate impact. This is unlikely to be the case. However, it would not be feasible to illustrate the analytical methods required to model price changes in the context of these case studies.

58 Since the affected crops in this case study are sold in relatively 'free markets', it is assumed that market prices do reflect real opportunity costs, and correction of these prices for distortions due to the presence of indirect taxes, support prices, and other subsidies is, therefore, not necessary.

59 As a means of 'bounding' the effect of uncertainty on the final outcomes we have used interval analysis. This involves taking the (absolute) lower value of the range of estimates for each model input, and combining them to define the lower bound of the final result. Likewise, the (absolute) upper value of the range of estimates for each model input is combined to define the upper bound of the final result. We only considered medium AWC soil, however. If the analysis were expanded to cover low and high AWC soil, the bounds to the final outcomes would be considerably wider.

enforced. The aggregate results, which represent the potential cost of not meeting irrigation demand in the EA Anglian Region in 2001, are shown in Table A1.10.

Similar calculations have been performed for England and Wales – the results are shown in Table A1.11. Note that errors associated with extrapolating the estimated increment in net income derived for Mepal (on medium AWC soil) across the Anglian Region are extenuated further when extended to all irrigated land in England and Wales.

The estimates contained in Table A1.10 and Table A1.11 are representative of the likely costs arising from total bans, where the farmer is given little or no opportunity to mitigate losses. Total bans on abstraction are usually a last course of action, however. A more likely course of action involves the imposition of partial bans. Morris *et al.* (1997) estimate that the potential increment in net income attributable to irrigation is reduced by 8 per cent for every 10 per cent reduction in water abstracted. If we apply this relationship to the aggregate increment in net income attributable to irrigation in the Anglian Region in 2001 (£107-162 million), we derive the curves shown in Figure A1.4 below. So, for example, if a partial abstraction ban is imposed, whereby 40 per cent of predicted actual irrigation demand is not met in the Anglian Region, farmers lose between £36 and £55 million in net income.

A1.3.3 SUMMARY

The aim of this case study is to illustrate the use of the implementation guidelines to estimate the cost of not meeting predicted actual irrigation needs in 2001 in the EA Anglian Region. It is assumed that as a result of climate change, water resources under baseline conditions in the Anglian Region are not sufficient to meet future demands. We assume for illustrative purposes that this presents the EA with a 'decision problem' in that action is required in order to allocate available water resources so as to balance the needs of abstractors with the need to maintain the water environment. One of the many options available to the EA in this situation would be to restrict direct abstractions (e.g. partial or total bans). The estimated cost of such restrictions, in terms of the increment in net farm income foregone, represents one piece of information that the EA can use to construct an outcome array from which to solve their resource allocation decision problem.

Table A1.8: Aggregate increment in net income attributable to irrigation for the Environment Agency Anglian Region in 2001 (1996/97 prices)

Crop category	Annual combined net benefit	
	Low	High
	(£ 10^6 yr $^{-1}$)	(£ 10^6 yr $^{-1}$)
Main crop potatoes	64	66
Early crop potatoes	15	15
Sugar beet	5	5
Orchard fruit	3	5
Small fruit	2	7
Vegetables	19	65
Grass	<1	<1
Cereals	<1	<1
Total	**107**	**163**

Notes: Column totals are subject to rounding errors.

Applying the guidelines we estimate that the cost of total bans on direct water abstraction for irrigation use in the Anglian Region in 2001 would range from less than £1 million to just over £160 million (1996/97 prices), depending on when during the irrigation season the ban is imposed. The purpose of this case study is purely to illustrate the application of certain aspects of the implementation guidelines to a potential climate impact, and in doing so many assumptions have been made. Consequently, the final results should not be interpreted as an accurate indicator of the true cost of total irrigation bans in the Anglian Region. Nevertheless, the approach outlined in this example could be adapted to accommodate more realistic assumptions,[60] thereby providing a more accurate cost estimate.

Table A1.9: Monthly distribution of irrigation net benefits forgone (%) as a result of total irrigation bans in a 'design' dry year (medium AWC soil)

	April	May	June	July	August	September
Main crop potatoes	100%	100%	88%	47%	17%	0%
Early crop potatoes	100%	88%	8%	0%	0%	0%
Sugar beet	100%	100%	100%	60%	20%	0%
Orchard fruit	100%	100%	90%	70%	41%	13%
Small fruit	100%	100%	77%	40%	7%	0%
Vegetables	100%	100%	73%	46%	10%	0%
Grass	100%	96%	71%	36%	4%	0%
Cereals	100%	100%	100%	100%	10%	0%
(Knox *et al.*, 2000)						

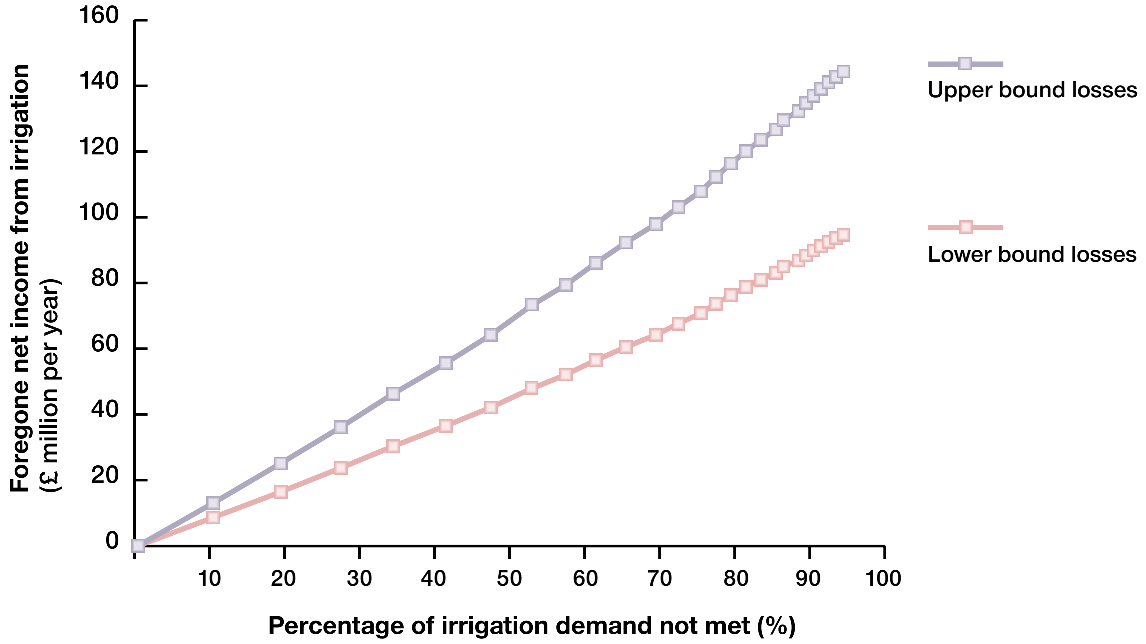
Table A1.10: The potential cost of not meeting irrigation demand in the EA Anglian Region in 2001; the imposition of total abstraction bans from the beginning of the month to the end of the season (1996/97 prices)

Month when ban is imposed	Foregone net benefit	
	Low ($£\ 10^6\ yr^{-1}$)	High ($£\ 10^6\ yr^{-1}$)
April – October	107	163
May – October	105	161
June – October	80	122
July – October	44	70
August – October	15	21
September – October	>1	>1

[60] For example, looking at the increment in net income attributable to irrigation by soil type and location, and taking into account the actual distribution of soil type and micro-environments during aggregation.

Table A1.11: The potential cost of not meeting irrigation demand in England and Wales in 2001; the imposition of total abstraction bans from the beginning of the month to the end of the season (1996/97 prices)		
Month when ban is imposed	**Foregone net benefit**	
	Low ($£ 10^6 yr^{-1}$)	**High ($£ 10^6 yr^{-1}$)**
April – October	213	386
May – October	210	383
June – October	159	286
July – October	88	164
August – October	28	45
September – October	>1	>1

Figure A1.4: The potential cost of not meeting irrigation demand in the Environment Agency Anglian Region in 2001; the imposition of partial abstraction bans (1996/97 prices)



A1.4 Flooding: the changing costs and impacts of flood alleviation

A1.4.1 CONTEXT OF CASE STUDY

Climate change predictions for the UK suggest that higher winter precipitation is likely (Hulme *et al.*, 2002). A greater frequency of higher winter precipitation may be expected to result in an increased risk of flooding. One consequence of this is an increased risk of damage to property that is privately or publicly owned, e.g. residential and commercial buildings. Clearly, even where there are existing preventative measures such as flood defences, as long as there remains a residual risk of flooding then that risk will increase in the climate change context, compared with the baseline of no climate change. Similarly, certain cost elements might be expected to change. For example, when using demountable flood defence elements, the total costs associated with their use will be expected to rise since they will be used more often in the climate change context.

This case study develops a hypothetical context for a town in Shropshire vulnerable to flooding by the River Severn. The use of the case study allows us to illustrate the effects on flood damage costs and flood defence operational costs on an existing flood defence system. In estimating the flood damage costs associated with climate change we demonstrate how the costing guidelines might be used in this context.

The case study allows us to emphasise that for a number of potential climate adaptation options there are pre-existing sector-specific guidelines that public sector analysts should use. In this case, the *Flood and Coastal Defence Project Appraisal Guidance* series, (FCDPAG), produced by Defra, is directly relevant and provides the basis for the flood defence analysis.

The structure of the remainder of the case study is as follows: first, the method by which the flood impacts of climate change can be estimated is outlined; second, these new impacts – together with changes in operational costs – are considered in relation to a decision-making framework; finally, the treatment of uncertainty in this context is considered.

A1.4.2 APPLICATION OF THE COSTING GUIDELINES

Impact assessment: using the matrices and decision tree

In this section we show how the costs associated with flooding under a climate change scenario may be estimated. Note that our primary purpose is to illustrate how the methodology developed in these costing guidelines can be used to achieve this end.

Section 3 of the implementation report is the starting point for relating climate change impacts to costing techniques. We assume that the cost analyst identifies

Table A1.12: The impacts of increased frequency of storms and winter rainfall

Potential direct consequence	VM	Potential indirect impacts	VM	Sector affected	Potential sectoral impact	VM	Relevant stakeholders
Direct physical impact	NT	Damage to buildings and infrastructure	CO	Residential	Loss of property and infrastructure	CO	Property owners, insurers, construction contractors, local authorities
					Damage to property and infrastructure	CO	
				Commercial, industrial and agriculture	Loss of infrastructure and equipment	CO	Business operators, farmers, construction contractors, general public, local authorities and insurers
					Damage to infrastructure and equipment		

the property damage effects of flooding as the impact that (s)he is interested in costing. This impact is identified in Table 3.7 (buildings and infrastructure sector) in the implementation report, where the initial climate impact is the increased frequency of storms and flooding. This table is one of a series of matrices that aims to help to relate the physical impacts often associated with climate change to techniques that can express these impacts in monetary terms. The relevant section of the matrix is replicated above in Table A1.12 for illustration.

The matrix in Table A1.12 above identifies, by the notation 'CO', that conventional market-based valuation techniques are most relevant to the costing of this impact. To identify the appropriate guideline, we refer to Figure 3.1 of the implementation report, which is entitled 'Route map – going from the impact matrix designations to the valuation guidelines'. This figure is in the form of a decision tree that the guideline user is encouraged to navigate. The decision tree picks up the notation for a conventional market based guideline (CO) in the 'YES' answer to the question, 'Does the impact directly affect a man-made asset?'

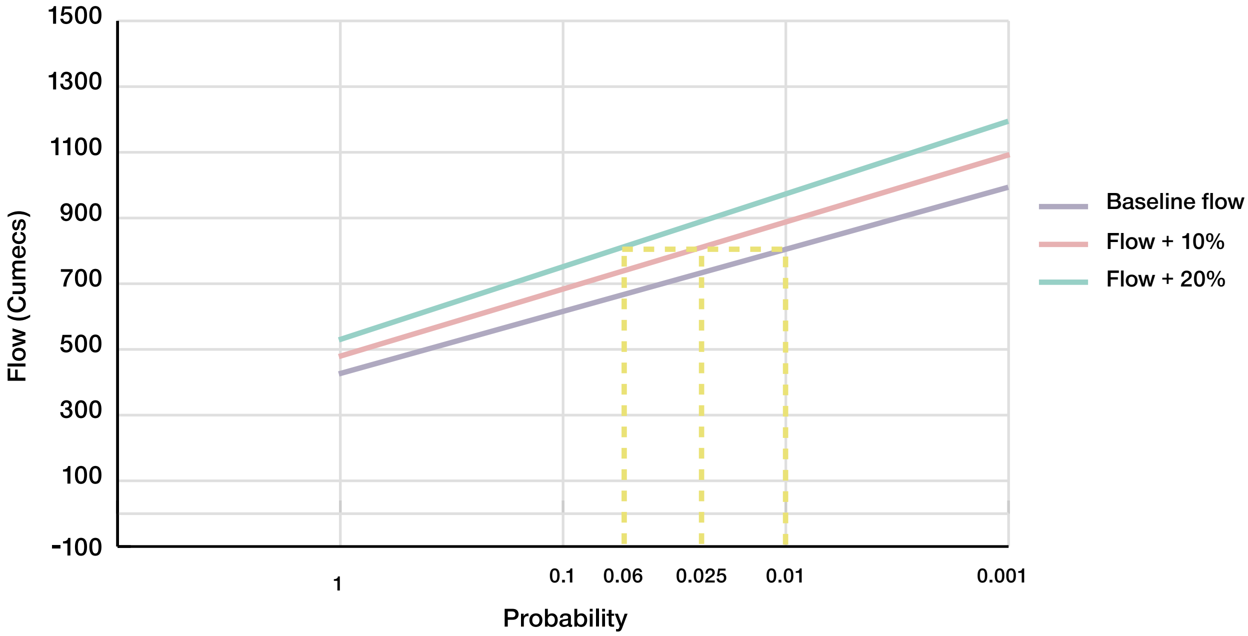
The user is then directed towards the 'Preventative expenditure and replacement cost' guideline in Section 4.3 of the implementation guidelines. The use of this guideline is described in the following section.

Before outlining the procedure used to monetarise the property damage impact of flooding from climate change we must, however, quantify the impact in physical terms. In this instance we assume that the impact of climate change on flood risk will be assessed over a period of 50 years – coinciding with the length of the existing flood defence lifetime.

Figure A1.5 below shows a hypothetical example of the effect on river flow volumes in the River Severn when climate change effects are considered.

In this instance, we assume that future flood flows increase in line with the guidance on climate sensitivity given in Defra's FCDPAG series. The frequency with which flood events of given severities occur – flood return periods – are then approximated for future years by assuming that flood flows increase above those existing in the period 1961-1990 (the no

Figure A1.5: Climate change effects on the River Severn flow volumes



climate change baseline), by 10% and 20% in the 2020s and the 2050s respectively. Probabilities of events of a given severity are assumed to become greater in future decades.

Figure A1.5 above can be explained in the following way: the thick purple line that slopes upwards and to the right describes the flow volumes associated with given probabilities of flood events in the baseline (historic) context based on the last 30+ years of records. So, the lower probability events on the right of the X-axis are associated with higher flow volumes. The pink line shows the flow volumes associated with event probabilities in the 2020s, when flows are assumed to be 10% higher than in the baseline. The green line shows the flow volumes associated with the event probabilities in the 2050s, when flows are assumed to be 20% higher than in the baseline.

Since the physical performance of the works is dependent on flow volume, the graph is used for the evaluation by identifying levels of event severity and estimating how the frequency of each such event changes in the future time periods considered. So, we can read the graph across to the left, and then down to the new probabilities, from a point such as that where the broken yellow vertical line meets the thick purple line, i.e. the flow volume associated with a 1 in 100 year event in the baseline period. According to this graph, this flood severity occurs as a 1 in 40 year event (probability of 0.025) in the 2020s and a 1 in 17 year event (probability of 0.06) in the 2050s.

We use these data in the following section to derive monetary values for the additional flooding costs associated with climate change.

Economic valuation: estimation of flood damage costs

As noted above, the decision tree identifies the preventative expenditure and replacement cost guideline as the most appropriate in monetarising the impacts of flooding on property. This guideline provides an outline of the different techniques that can be used to calculate the value of marketed assets, together with their requirements and strengths and weaknesses. The guideline also points the public sector analyst in the direction of pre-existing official guidance that might be relevant. In this case, the Flood and Coastal Defence Project Appraisal Guidance (FCDPAG) series is clearly appropriate to adopt. Guidance for economic appraisal is given in FCDPAG3. In the paragraphs below we outline the procedure in line with FCDPAG3.

The damage costs of climate change-related flooding are estimated as the change in the expected value of annual flood losses – known as the Annual Average Damage (AAD) cost in the FCDPAG3 guidance – resulting from the change in flood frequencies under climate change.[61] Thus the AADs summed over the 50-year period under the climate change flood frequency scenario should be compared with the same summed total calculated under the baseline in which no climate change is assumed. The difference between the two is therefore the flood damage cost that can be attributed to climate change. In order to calculate the AADs for the baseline case and climate change scenario, a number of steps (detailed in FCDPG3) are taken. Below, we identify the steps to be taken to calculate building property damages. An equivalent estimation procedure is used to calculate components of the AAD from other forms of property damage (such as damage to parked vehicles).

Step 1: The physical number and character (residential or commercial) of building properties in the area threatened by flooding need to be estimated.

Step 2: The amount of damage (in cost terms) caused by each flood return period per property is modelled on the basis of the Flood Hazard Research Centre at Middlesex University depth-flood damage database (Penning-Rowsell *et al.*, 2003). (Property damage is estimated on the basis of repair and replacement costs associated with property flooded to differing depths.) Our analysis considered current 3, 5, 10, 25, 50, 100 and 150-year flood return periods. It is assumed, for example, that in a 100-year event, 79 properties are affected and suffer damage.

[61] It is assumed that the defence consists of a fixed bank with an overtopping threshold of 1 in 20 (in 2000) and demountable defences with an overtopping threshold of 1 in 100 (also in 2000). Thus, the total residual damage will consist of the sum of the probability of not deploying the demountable defences with the damage at the lower threshold and the probability that the demountable defences are deployed but overtopped at the higher threshold.

Table A1.12: Flood damage calculations for the baseline year									
Average waiting time (yrs) between events	**1**	**3**	**5**	**10**	**25**	**50**	**100**	**150**	**Infinity**
Frequency per year	**1**	**0.333**	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.007**	**0**
Damage category	**Damage £'000s**								
Residential property	0	5	12	78	98	188	326	352	352
Industrial/commerical (direct)	0	7	146	376	570	1217	1514	1558	1558
Industrial/commercial (indirect)									0
Traffic related									0
Emergency services									0
Other	**0**	**12**	**153**	**285**	**292**	**304**	**367**	**385**	**385**
Total damage	**0**	**23**	**310**	**738**	**960**	**1709**	**2207**	**2295**	**2295**
Annual average damage cost (damage x frequency £'000)	**0**	**8**	**22**	**52**	**51**	**27**	**20**	**8**	**15**
Total annual average damage cost (£'000s)	202								

Step 3: The probability of each flood return period is then multiplied by the sum of the number of properties identified as being flooded to given depths in each return period, and the associated total damage costs, to give the expected value of annual flood losses. The totals for each return period are then summed together to give the annual average damage cost.

An example of these calculations for the baseline years is set out in Table A1.12 above.

Table A1.12 shows, in the first row, the different flood return periods. In the second row these are converted into event frequencies. The following rows – labelled from 'Residential property' down to 'Other' – are the total damage costs calculated for these property damage categories in Steps One and Two of the procedure outlined above. The total costs associated with each flood return period are summed in the 'Total damage' row. As dictated by Step Three, these cost totals are then multiplied by the frequencies of each event (averaging between the return periods specified) and presented in the following row. For example, the damage costs of £8,000 in the penultimate row are derived by taking the average of 1 and 0.33 for one-[62] and three-year events respectively (0.666) and multiplying by the average damage over these events (0 + 23,000)/2). The totals for each return period are then summed to give an AAD of £202,000.

The AADs for each year over the 50-year time period are the same in the baseline (no climate change) scenario since the probability of flood events of given severities remains constant.

Under the climate change scenarios, the AADs will change, as a result of the shorter flood event return periods implied by the higher flood flows. In this case, our method is to calculate the AADs for the 2020s and

[62] Note that the zero values given in the first column – where the flood return period is one year – are due to there being no flood damages associated with a flood event of this frequency. Inclusion of this frequency event ensures that the annual damages are averaged over the entire range of damage occurrences – to the point of being zero damages.

2050s before simply interpolating the AADs for the years inbetween these periods. Thus, as climate change impacts increase over time, the associated AADs also increase. An example of the AAD calculations in the climate change scenario for the 2050s is given in Table A1.13 below. Note that whilst the severity of the events has remained unchanged (i.e. the damage costs for each property category are assumed to be the same in real terms), the probabilities of these events in the second row have increased compared with those under the original return periods, as presented in Table A1.12 above. The original annual frequencies are presented above the new frequencies in this table. Note that the new frequencies are derived from reading Figure A1.5 above. Therefore, the values in the row labelled 'Annual average damage cost' are higher than under the baseline, as is the resulting total AAD (£780,000 under the climate change scenario, compared with £202,000 for the baseline scenario).

Before we can compare the streams of AADs over the 50-year period to derive climate change-attributable flood damages, we need to account for the practice of valuing future impacts relative to the way present day impacts are valued – that is, by applying discount rates to the future values. This is described in the following section.

Discounting

In this case study we are considering the flood damage costs over a 50-year period that corresponds with the lifetime of the existing flood defence system. The treatment of values (costs and benefits) over future time periods is outlined in some depth in the guideline on discounting and discount rates (Section 5.4 of the implementation guidelines). The FCDPAG guidance as revised in the 2003 supplementary guidance adopts the UK Treasury Green Book rate of 3.5% for time periods of up to 30 years in the future. The rate recommended for 31-75 years is 3%. It should be emphasised that the recommended discount rates of 3.5% and 3% are only applicable for the public sector analyst, and do not have to be adopted by the private sector analyst, who is free to adopt a rate(s) appropriate to his/her objectives.

Table A1.13: Damage calculations for the climate change scenario

Average waiting time (yrs) between events	**1**	**3**	**5**	**10**	**25**	**50**	**100**	**150**	**Infinity**
Original annual frequency	**1**	**0.333**	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.007**	
New annual frequency	**2.5**	**1.3**	**0.7**	**0.4**	**0.18**	**0.1**	**0.06**	**0.04**	**0**
Damage category	**Damage £'000s**								
Residential property	0	5	12	78	98	188	326	352	352
Industrial/commerical (direct)	0	7	146	376	570	1217	1514	1558	1558
Industrial/commercial (indirect)									0
Traffic related									0
Emergency services									0
Other	**0**	**12**	**153**	**285**	**292**	**304**	**367**	**385**	**385**
Total damage	**0**	**23**	**310**	**738**	**960**	**1709**	**2207**	**2295**	**2295**
Annual average damage cost (damage x frequency (£'000)	**0**	**14**	**100**	**157**	**187**	**107**	**78**	**45**	**92**
Total annual average damage cost (£'000s)	780								

Applying the public sector discount rates to the quantified AADs identified for the 'baseline' (no climate change) case and the 'with climate change' case, both with the existing flood defence scheme, we derive the results expressed in present value terms as summarised in Table A1.14 below. These results show that incorporating the climate change scenario into the analysis implies a more than 30% increase in the residual damages predicted under the existing flood defence scheme. So, the difference between the two scenarios of £150,000 can be attributed directly to the impact of climate change, under the scenario used.

Table A1.14: Summary of flood event damage analysis (£'000, 2001 prices)

Scenario	Cost (£'000s)
Flood damages (NPV) baseline without climate change	475
Flood damages (NPV) with climate change	625

Note that the analysis has assumed that the estimates remain constant in real terms (year 2001 prices) over the 50-year time period being considered. Consequently, inflation is ignored and no adjustment is made for changes in relative prices. This is in accordance with the Treasury Green Book guidance and FCDPAG and constitutes common practice in public sector project appraisal using cost-benefit analysis. The issue is discussed in more general terms in Section 5.2 of the implementation guidelines: 'General issues in costing analysis: making adjustments for relative price movements.'

Scheme costs

We noted earlier that, as well as affecting the damage cost element within flood defence cost-benefit analysis, climate change will impact upon the cost of the flood defence system itself when demountable defences are used, as in this case. The implementation guidelines explain the derivation and common procedures for the treatment of project costs in Section A1.2.A1. In the flood defence context, the FCDPAG3 guidelines specify the precise treatment.

In this instance, the operational costs for the baseline (no climate change) are estimated at £10,400 per annum. In the climate change context, these costs increase annually reflecting the increased frequency with which the demountable barriers must be deployed. Once these costs have been identified for the 50-year period, they are discounted according to the same rates that were applied to the flood damage costs. The summed present value costs are presented in Table A1.15 below. They show that the climate change scenario chosen here results in an 80% increase in operating costs over the 50-year period.

Table A1.15: Summary operational cost anaylsis (£'000, 2001 prices)

Scenario	Cost (£'000s)
Operational costs without climate change (PV)	255
Operational costs with climate change (PV)	460

Option appraisal: using the guidelines to establish a decision-making framework

The revised estimates of residual flood damages and operational costs derived under the adopted climate change scenario should be used to assess the sensitivity of the cost-benefit analysis on which the flood defence scheme was originally based (using the baseline 'no climate change' scenario).

Uncertainty

Sensitivity analysis (explained in detail in Section 5.8 of the implementation guidelines) can be undertaken on the benefit and cost elements within the analysis in order to account for the uncertainties in their derivation. For example, the impact on B/C ratios of varying these elements provides the decision-maker with information as to whether the original option choice is robust.

Whilst we do not undertake any further quantitative sensitivity analysis in this simplified case study, it is worth highlighting the variables that may form the basis of sensitivity analysis. These are:

- Rainfall/flooding incidence variation under alternative climate change scenarios;

- Alternative damage cost estimates for flood events of given severities with particular attention to major sources of potential damage, e.g. major commercial sites or infrastructure; and

- Variation in operational costs, particularly ongoing operational costs.

Non-monetised impacts

For simplicity, this case study has considered only a limited range of costed impacts. In practice, any analysis of costs and benefits may not fully consider a number of other impacts; in particular, some environmental and social costs and benefits. FCDPAG3 notes that a decision should be based on all significant impacts, so further consideration must be given where these are not reflected in economic values. As the guideline on **non-monetised impacts** shows (Section 5.9 of the implementation guidelines), it is implicit in a decision based on cost-benefit analysis that the non-monetised impacts are not of the magnitude necessary to make the 'favourable' net cost 'unfavourable', or vice-versa.

A1.4.3 Summary

This simplified case study has outlined how the adoption of a climate change scenario in the analysis of flood defence provision can impact on two elements of a cost-benefit analysis – the residual flood damage estimates and the operational costs. The context is hypothetical but the issue of increased flood risk from climate change is real. This example has illustrated how the costing guidelines might help to quantify the impacts and costs associated with climate change as an input to the decision-making process in flood management.

A1.5 Time losses: short-term disruption to transport systems

A1.5.1 CONTEXT OF CASE STUDY

One consequence of the predicted increased frequency of storms and flooding in the UK is the expected short-term disruption to transport systems as a result of damage to transport infrastructure (road, rail, air or sea). In turn, this imposes welfare costs on transport users through loss of productivity, and therefore income, if work-time is lost, or through loss of leisure activity time.

This case study uses evidence supplied by a rail infrastructure company in Scotland on the extent of disruption to rail services caused by high winds, flooding and land-slips – features of climate change-related weather events. The costs estimated below relate to: i) the time lost due to flooding at Muirhouse Junction, on the track between Glasgow Central and Busby Junction caused by the storm on 28 November 1999; and ii) the disruption to rail services for Scotland as a whole as a result of this storm, which caused all three types of weather event. The disruption of rail services is measured by the number of minutes by which the train is delayed in reaching its final destination.

The purpose of this case study is to illustrate the use of the guideline on valuing impacts on leisure and working time in the implementation guidelines. The cost estimates that arise from this exercise can be seen as an input into a cost-benefit analysis as part of an option appraisal when, for instance, new drainage systems are considered for stretches of track that are particularly susceptible to flooding and land-slips.

The decision context: using the guidelines to establish a decision-making framework

A pay-off matrix is presented in Figure A1.6 below that combines possible states of nature (e.g. possible climate change event frequencies) and possible options (e.g. investment in a new railway drainage system) to produce outcomes that may be expressed in monetary terms.

The illustrative assumption here is that the combined incidence of flooding, land-slips and high winds will be 50% higher in 25 years' time because of climate change, with lower and upper bounds of 30% and 70% respectively. This information would have been generated from a climate change impact assessment of the rail infrastructure, using climate scenarios data. The cost estimates are therefore presented for the year 2025. The baseline (i.e. without climate change) is assumed for simplicity to be equivalent to the 1961-1990 incidence.

The methodological framework for a CBA of this sort is presented in the implementation guidelines. The remainder of this case study will work through the three steps – impact assessment, valuation and weighing up/deciding – that are relevant to the benefit stream (the time costs avoided as a result of improved rail drainage).

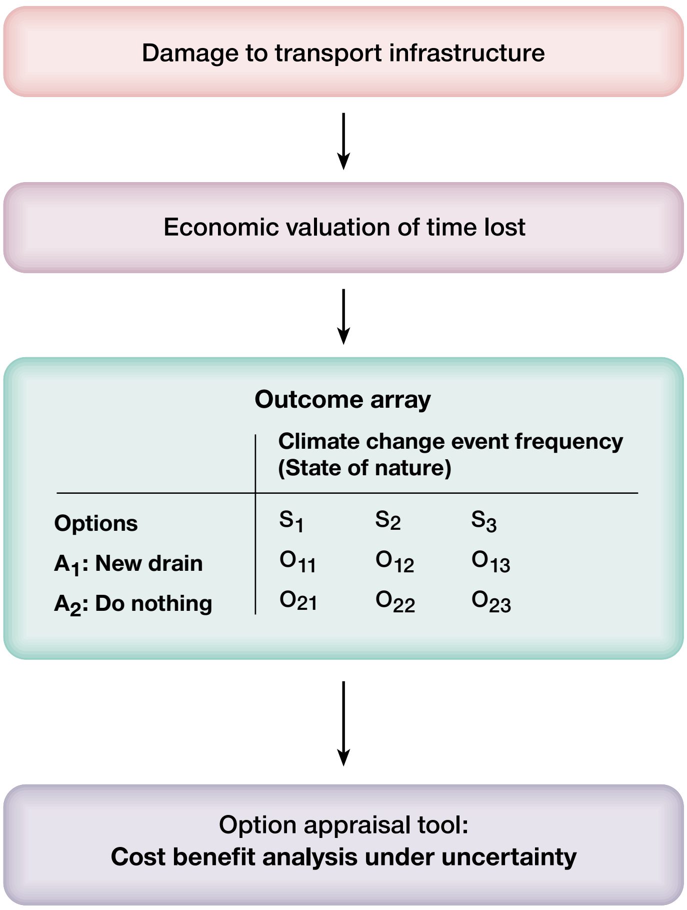
A1.5.2 APPLICATION OF THE COSTING GUIDELINES

Using the matrices and decision tree

The user in this case study has already identified the transport disruption effects of extreme weather events as the impact that (s)he is interested in costing. This is located in the matrix on the coastal zones sector where the initial climate change factor is the increased frequency of storms and flooding. A condensed version is presented in Table A1.16.

The matrix identifies that there is an individual guideline that is relevant to costing this impact. To identify the appropriate guideline we refer to Figure 3.1 in this overview of guidelines, which is in the form of a decision tree. The decision tree picks up the notation for an indi-

Figure A1.6: Contextual decision framework for investment in new railway drainage system



vidual guideline (IG) in the 'NO' answer to the question 'Does the impact directly affect a marketed good/service?'. The decision tree then asks, 'Does the impact affect… Travel or work time?' to which the answer is 'Yes'. We assume, in this case, that it is not necessary to conduct a primary valuation study – since we assume that a large number of studies have previously been undertaken to value precisely this impact – which leads us to the guideline on valuing impacts on leisure and working time.

Economic valuation

The guideline on valuing impacts on leisure and working time presents a general procedure for measuring the value of a change in time availability. The procedure comprises three steps, which we now follow.

Step One:
Identify and quantify the change in time availability associated with the expected climate change impact. The flooding at the Muirhouse junction, on November 28, 1999, resulted in the trains on the Glasgow Central – Busby Junction line running 20 minutes late.

Step Two:
Identify the category into which the change in time availability falls. Three categories are relevant here: work time-rail user; leisure time (in vehicle), and late time. It was estimated that 1950 (55%) of the passengers were travelling to work and therefore categorised as work time rail users. Also, 1618 (45%) of the passengers were categorised as leisure time users. The late time category applies to work time users.

Step Three:
Identify the appropriate economic unit value for the change in time availability and multiply this by the quantified change in time availability from Step One. The relevant unit values are those recommended by DfT[63] and are presented in the guideline on valuing impacts on leisure and working time.

We have estimates of the number of people affected and can apply these to derive total costs, which are presented in Table A1.17.

The total costs of the storm to the railway infrastructure company have been estimated using this costing methodology. In other words, the three sources of disruption that arose from this storm – flooding, land-slips and winds – have given rise to quantifiable time delays in services on this day that can be costed using the unit values presented in the guideline on valuing impacts on leisure and working time in the implementation guidelines. This methodology can be applied to estimate the total cost of all such incidents in Scotland on this day. These costs are summarised in Table A1.18.

Again, applying the same methodology to all such incidents in 1999 in Scotland, the total cost of short-term (time delay) disruption in Scotland for 1999 can be estimated at £599,857.

Risk and uncertainty

We assume that the three climate change scenarios, for which we are costing the impacts predict a 30%, 50%

Table A1.16: The impacts of increased frequency of storms and flooding on transport

Potential direct consequence	VM	Potential indirect impacts	VM	Sector affected	Potential sectoral impact	VM	Relevant stakeholders
Direct physical impact	NT	Short-term disruption	NT	Transport	Increase in travel cost – work time	IG	Local population, transport users (including tourists), transport operators, businesses, local authorities
					Increase in travel cost – non-work time	IG	

63 http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504932.pdf

and 70% increase in storms in Scotland that result in flooding, high winds and land-slips by the year 2025. The estimates for this year, without discounting, are presented in Table A1.19.

Discounting

The costs derived above are assumed to result from increased storm frequency in the year 2025. The guideline on discounting and discount rates in the implementation guidelines discusses the treatment of costs over a time period. From this guideline, we identify that the costs included in the present analysis should be based on the current UK Treasury discount rate of 3.5%. Using the methodology outlined in the guideline on discount rates, the 3.5% rate gives total present value costs for the total impacts of £254,000, £339,000, £381,000 and £423,000 for the baseline, 30%, 50% and 70% increased incidence assumptions, respectively.

Table A1.17 Total cost of rail network disruption: Glasgow Central – Busby Junction

Category	**Time loss** (hours/person)	**Number of persons**	**Unit value** (pence/hour)	**Total value** (£)
Work time rail users	0.33	1,950	3,043	19,760
Non-work time users	0.33	1,618	452	2,435
Total				**22,195**

Table A1.18: Rail disruption time costs in Scotland: 28/11/99

Climate change event/consequence	**Cost (£)**
Wind	620
Land-slips	16,460
Floods	53,900
Total	70,980

Table A1.19: Time-loss cost estimates for railways in Scotland under three scenarios (£ million)

States of nature	**Baseline** (£ million)	**30% increase** (£ million)	**50% increase** (£ million)	**70% increase** (£ million)
Total impact cost	0.6	0.8	0.9	1.0
Climate change-induced cost	–	0.2	0.3	0.4

Appendix 2: Glossary of terms

Abatement cost. The cost of abating, or reducing, environmental pollution.

Adaptation. Measures taken to reduce harm, or risk of harm, associated with climate change. Examples include the building of sea walls to prevent damages from sea level rise and the installation of chilled ceilings in the case of increased mean temperatures.

Amenity. Benefit derived from living near a certain (environmental) attribute. May be positive, e.g. in the case of woodland, or negative, e.g. in the case of a landfill site.

Ancillary impacts. External effects which have an impact on policy goals unrelated to climate change policy.

Benefit transfer. Benefit transfer is not a **valuation** method *per se*, but involves the use of existing estimates of non-market values derived in one context/location to estimate values in a different context/location. The site for which the original estimates were obtained is often referred to as the study site; and the site to which the original estimates are now to be applied is known as the policy site. Benefit transfer is therefore the practice of adapting available estimates of the economic value of changes in the quality or provision of a **non-marketed** good/service at a study site(s), to evaluate a change in quality or provision of a similar resource at a policy site(s).

Benefit-cost ratio. The ratio of an option's present value benefit to its present value costs.

Bequest value. The value that an individual places on having an environmental resource or general environmental quality available for his or her descendants to experience. Bequest values are considered as a **use value** of a resource, even though the value derived results from future rather than present use of the resource.

Built heritage. All types of man-made structures and remains that are thought to have value in addition to any functional worth, due to historical, artistic or other cultural factors.

Cause-effect chain. Links climatic variation to **lower-order impacts** through to specific **higher-order impacts**.

Certainty. When the decision-maker has complete knowledge of every element of the decision problem and thus can predict which state of nature will occur, in which case the decision-maker is certain of the outcome associated with each alternative action.

Change-in-productivity technique. Market prices can often be used to value the output from a productive process, and environmental conditions often affect such processes. In these circumstances, values for a change in the environment can be derived from the associated change in productivity. An increase in output due to the change is a measure of an increase in benefit, and a decrease in output is a measure of an increase in cost.

Confidence interval. A quantitative estimate of the degree of uncertainty associated with a statistic or other estimate. For example, the range of values within which some percentage (say, 95 per cent) of repeated estimates would fall. In other words, a confidence interval provides a range of values within which the 'true' value would actually fall with 95 per cent certainty.

Constant (real) price. Real or constant price variables adjust current price variables for changes in the general level of prices – that is, they are **inflation**-adjusted prices.

Constructed market. A hypothetical situation in which individuals are asked to assume that they can exchange money for an environmental benefit or to avoid an environmental loss. This technique is used to estimate the value of non-market costs and benefits in the **contingent valuation method**.

Consumer surplus. The consumer surplus is essentially the **net benefit** accruing to the consumer from consuming a good, given the good's current price. Formally, consumer surplus is the excess that consumers would be willing to pay over actual expenditure at the current price.

Contingent valuation method (CVM). CVM directly elicits the values that respondents place on some, usually **non-marketed**, goods and services. This is done by either employing an experimental approach, based upon simulations or game analysis, or, more commonly, by using data derived from questionnaire or survey techniques. It derives people's preferences for public goods by asking them how much they would be willing to pay for specified improvements or to avoid specified deterioration or losses. Alternatively, respondents to CV surveys might be asked what level of compensation they would be **willing to accept** (**WTA**) to take a loss, or for not getting an improvement in environmental quality.

Cost-benefit analysis (CBA). Analysis which quantifies in monetary terms as many of the costs and benefits of a project as possible, CBA is designed to show whether the total advantages (benefits) of a project or policy intervention exceed the disadvantages (costs). This essentially involves listing all parties affected by the policy intervention and then valuing the effect of the intervention on their well-being as it would be valued in money terms by them. It may include items for which the market does not provide a satisfactory measure of economic value.

Cost-effectiveness analysis (CEA). A tool with which to minimise the cost of achieving a specified environmental or economic objective. For example, in the acid deposition field the objective might be to meet a target loading of sulphur at minimum cost over a large region, taking into account that control costs vary from industry to industry, and that the cost of control increases with increasing severity of control. Cost-effectiveness analysis ignores the benefit side of **cost-benefit analysis** but concentrates on the cost side.

Cost-of-illness. An objective **valuation** approach, which places an economic value on illness caused by environmental damage. The **financial costs** of illness caused by, e.g., air pollution can be calculated by adding the costs of treating an illness to the costs of lost work time. The full cost of the illness would then require a measure of the value that the individual places on the suffering that it causes, but this must be measured using a technique such as the **contingent valuation method**, which is not an objective valuation approach.

Decision-maker. A person or institution dissatisfied with the prospect of a future state, and who possesses the desire and authority to initiate actions designed to alter this state.

Demand curve. The relationship between the demand for a good and its market price. For most goods, more will be demanded at lower prices.

Direct impact. See **lower-order impact**.

Direct use value. Value that derives from the use of goods that can be directly extracted, consumed or enjoyed. This includes consumption value, altruistic value, and **bequest value**.

Discount rate. The rate at which, when **discounting**, costs and benefits are valued in present terms, as the time at which they occur moves further into the future.

Discounting. Discounting is the technique used to add and compare environmental costs and benefits that occur at different points in time. It is the practice of placing lower numerical values on future benefits and costs as compared to present benefits and costs. It arises because individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now.

Distributional effects. The way in which a decision/policy affects different income groups, and thus affects the distribution of income or welfare.

Economic efficiency. An allocation of resources in production and consumption so as to achieve the maximum total benefit. This means that no person could be made better off without making someone else worse off. A condition for economic efficiency is that the environmental costs of production should be accounted for, and included in the total costs of production.

Economic (opportunity) cost. The economic cost of a good is the full value of the scarce resources that have been used in producing it. These resources, in turn, are measured in terms of the value of the next best alternative which could have been produced with the same resources (i.e. the value of the opportunity foregone).

Environmental externality. Where an activity affects a third party (either positively or negatively) without this effect being accounted for by the agent responsible for the activity.

Expected monetary value decision rule. A rule that leads to the selection of options so as to maximise the expected monetary value (EMV), where the EMV is the weighted average of all possible values of a variable, where the weights are the probabilities.

Expected utility decision rule. A decision rule that involves selecting adaptation options so as to maximise expected **utility** – choosing the option with the highest expected utility.

Externality. See **environmental externality**

Extreme events. Events such as hurricanes, storms, high temperatures and other naturally occurring phenomena. The likelihood of such events is expected to increase with climate change.

Financial cost. The common accounting notion of cost expressed through market prices.

Fixed baseline. Within the fixed baseline approach current climatological, environmental and socio-economic conditions are assumed to prevail in the study region into the future. Therefore, a fixed baseline is usually a horizontal curve.

General price level. The general price level is given by the weighted average price of a representative 'basket' of consumer goods and services traded in the economy, relative to the price of that basket at some fixed date in the past. As such, the general price level shows what is happening to consumer prices on average, and not what is happening to the price of individual consumer goods and services. Consequently, increases in the price of a specific good or service over time do not necessarily imply that the general price level has changed. For example, subject to the weights assigned to two items in the basket of consumer goods and services, increases in the price of one item may be offset by decreases in the price of another item, to the extent that the average price level remains unchanged. Therefore, for the general price level to move upwards, the prices of a majority of items in the basket must increase.

Gross benefit. The total benefit of a project or other activity. Deducting the costs of the project from the gross benefits gives a measure of **net benefit**.

Hedonic techniques. Hedonic pricing is a market-based **valuation** method that is used to value non-market, often environmental, assets. The method can be used to infer the value of **non-marketed** goods by analysing the prices of **marketed** goods to which the non-marketed goods are related. Houses are often used in hedonic pricing studies to infer the values of environmental characteristics, using the hedonic property price function.

Hedonic wage differential. The hedonic wage-differential (or **wage-risk**) approach estimates the relation between the wage rate in each occupation and the qualifications of worker, job attributes (unionisation, desirability, etc.) and workplace risk (e.g. risk of death). This is one of the most commonly used **hedonic valuation techniques**.

Higher-order impact. An indirect climate change impact that results from a **lower-order** (or direct) **impact** of climate change. For instance, loss of habitat may result from the lower-order impact of sea level rise. Also known as indirect impact.

Hurwicz α-rule. Decision-support criterion under conditions of uncertainty in which the decision-maker should select the alternative option with the largest α-index.

Impact assessment process. The process of identifying all parties affected by a policy intervention, and quantifying the 'incremental' impact of the intervention on these parties.

Indifference curves. Curves that link combinations of two commodities, for instance **expected monetary value** and **risk**, among which a person (e.g. a decision-maker) is indifferent. If both commodities are desirable, then for a decision-maker to be indifferent between any two combinations, less of one commodity must be compensated by more of the other, and vice versa.

Indirect use value. Indirect use value, also referred to as non-extractive use value, derives from the services that an environmental resource provides. Its definition lies between those of **use value** and **non-use value**, and can be used to refer to two main types of situation. The first is where a person makes direct use of an environmental resource, for example a fishery, but where that fishery benefits from the services of another environmental resource, such as a freshwater spawning ground. In this case, the person derives indirect use value from the freshwater spawning ground. The nature and extent of this type of indirect use value is clearly very uncertain, since scientific knowledge of the complex relationships within and between ecosystems is incomplete. The second situation in which indirect use values accrue is where a resource is used in a way that does not involve depleting the resource, for example recreation.

Indirect impact. See **higher-order impact**.

Inferential statistics. Analysis that uses information on a sample in order to infer information about the attributes of a general population.

Inflation. Inflation refers to increases in the **general price level** over time. The inflation rate defines the rate at which the general price increases over a specified time period – e.g. monthly or yearly.

Internal rate of return. Internal rate of return is the discounted cash flow rate of return or yield. It is usually defined as the discount rate that would make the present value of a project's profit stream equal to the initial investment expenditure.

Interval analysis. Identifies the extreme lower and upper estimated outcomes for a given set of input variables, modelling assumptions, etc.

Irreversibility. Where a decision, e.g. to convert a natural habitat into farmland, cannot be reversed. This is usually when a decision involves the loss of an irreplaceable asset that might subsequently be preferred for a more important later use.

Lower-order impact. A direct impact of climate change, such as sea level rise, which results in **higher-order impact** (or indirect impact) such as loss of natural habitat.

Marketed impacts. Marketed impacts refer to damages/benefits to goods and services that are traded in markets – e.g. infrastructure, buildings – and have an observable price.

Marginal cost. The contribution to total cost of the last unit of a good produced.

Marginal productivity. The marginal productivity of a factor of production, e.g. labour or capital, is the contribution to total output of the last unit of the factor used.

Maximax rule. An optimistic decision-support criterion under conditions of uncertainty in which the decision-maker should opt for the option with the highest possible outcome.

Maximin rule. A pessimistic decision-support criterion under conditions of uncertainty in which the decision-maker should maximise the minimum outcome.

Mean. The average outcome.

Meta-analysis. A meta-analysis is a study that estimates the value of an environmental cost or benefit by analysing statistically the information gathered from all previous studies on similar costs or benefits.

Minimax regret rule. A cautious approach to decision-support criteria under conditions of uncertainty in which the decision-maker should minimise the maximum regret.

Monte Carlo analysis. A way to estimate the likely outcome of an uncertain event, it can be used to analyse risk. It involves simulating the possible outcomes of an uncertain event by varying the factors that affect the outcome, thus gaining a picture of the distribution of possible outcomes.

Net benefit. Net benefit is the difference between total benefits and **total costs**.

Net present value (NPV). The net present value of a project is the difference between the discounted benefit (or impacts cost avoided) stream and the required investment and annual costs.

Non-marginal impacts. Impacts where adaptation measures lead to changes in the market conditions, meaning that partial or general equilibrium analysis may need to be applied to assess the total impacts of a given climate change impact or adaptation strategy.

Non-marketed impacts. Refer to damages/benefits to goods and services for which no market exists – e.g. most environmental resources – and which therefore have no observable price.

Non-monetised impacts. Impacts of climate change for which it is not possible to estimate a monetary value. This may be because physical data on the impact are not available, or because existing environmental valuation techniques cannot value a particular impact.

Non-use value. Non-use value is defined as those welfare gains/losses to individuals that arise from environmental changes independently of any direct or indirect use of the environment.

Option appraisal. Comparing the costs and benefits of possible decision options using criteria such as **economic efficiency**.

Opportunity cost. The economic cost of using a resource as represented by the benefit it could have generated in its most efficient alternative use.

Outcome array. A matrix that shows the outcomes (or consequences) associated with particular combinations of specific options and specific states of nature.

Policy site. In the context of **benefit transfer,** the policy site is the location to which the original estimates are now to be applied.

Preventative expenditure. These are expenditures aimed at averting the damages associated with pollution and other externalities. Estimates for these are sometimes used as measures of the lower bound of the costs of the environmental damages. Expenditures to mitigate damages to the environment can be seen as a **surrogate** demand for environmental protection.

Price elasticity of demand. Measures the percentage change in quantity demanded associated with a percentage change in price.

Primary studies. Valuation studies (e.g. CVM, TCM) that require primary research, as opposed to those using techniques such as benefit transfer to derive values for environmental attributes and assets.

Production cost technique. Values the cost (benefit) of deterioration (improvement) in environmental quality by valuing increases (decreases) in the resource costs of production.

Production function. A mathematical relation showing the maximum output that can be produced by each combination of inputs.

Projected baseline. Projected baseline is based on estimated predictions of future climatological, environmental and socio-economic conditions in the study region in the absence of climate change. It is then used as a reference case against climate change mitigation and adaptation policies. This is a more realistic approach than application of a **fixed baseline**.

Property value approach. A type of a **hedonic pricing technique** where analysis is conducted on housing data. It measures the welfare effects of changes in environmental goods or services by estimating the influence of environmental attributes on the value (or price) of properties.

Pure existence value. Relates to the value that people attach to an environmental good or service, which is completely unrelated to current or future use of that commodity by themselves, their descendants, or by others. These values are intrinsic in nature.

Pure time preference. The preference for consumption now rather than later.

Relative price. As the term implies, this defines the price of a particular good or service relative to other goods and services in general. If the price of any good or service is expected to change relative to the **general price level**, then it is said to have changed in real terms.

Relocation cost. The relocation cost technique is a variant of the **replacement cost** technique. Here, the actual costs of relocating a physical facility – because of changes in the quality of the environment – are used to evaluate the potential benefits of preventing the environmental change.

Replacement cost. The replacement cost technique assumes that the costs incurred in replacing productive environmental assets that have been damaged through climate change can be measured and interpreted as an estimate of the benefits presumed to flow from the assets. Expenditure actually incurred on replacement is a measure of the minimum **willingness to pay** to continue to receive a particular benefit. It gives only a minimum estimate because more may have been spent had it been seen to be necessary to do so. This technique is closely related to the **preventative expenditure** technique.

Risk. When the decision-maker does not know which state of nature will occur, but is reasonably confident of the proportion of the total number of occasions on which each state of nature will occur if the situation frequently recurs.

Risk-averse. A person (or decision-maker) who would pay to avoid risk, as represented by an actuarially fair gamble.

Risk-lover. A person (or decision-maker) who would pay to participate in a risky decision, as represented by an actuarially fair gamble.

Risk-neutral. A decision-maker who is indifferent to all actuarially fair gambles.

Sensitivity analysis. Sensitivity analysis shows the extent to which changes for different values of the major variables affects an appraisal.

Shadow project. The shadow project **valuation** measure can be seen as a particular type of **replacement cost**. It attempts to estimate the cost of replacing the entire range of environmental goods and services that are threatened by climate change by examining the costs of a real or hypothetical project that would provide substitutes.

Social cost. The total social cost of a project or intervention includes the private costs of all resources used by the provider(s) of the project over some predefined time horizon (usually the useful life of the project), plus any costs imposed on third parties (i.e. the externalities).

Stakeholder analysis. This form of analysis identifies those whose interests will be or are being affected by the planned project/policy, and assesses the potential influence they may have on the project.

Standard error. This is used to construct a **confidence interval** that reflects the variability of an observed response relative to the variability of the explanatory variable(s).

States of nature. Variable factors that are beyond the control of decision-makers, but which will affect the outcome of a decision problem, for example the climate change impacts that will actually occur.

Study site. In the context of **benefit transfer**, the study site is the location in which the original estimates were obtained.

Supply curve. A function that shows the amount of a good which producers are willing to supply for each level of the good's price. Producers are generally willing to supply more of a good the higher is its price.

Surrogate market. A market for a good that is associated with a non-marketed cost or benefit. Such markets, an example being the market for housing, can be analysed using **hedonic techniques**.

Top-down approach. This is a modelling approach widely used in the analysis of climate change. Top-down models evaluate a system using aggregate economic variables. Modellers using this technique apply macroeconomic theory and econometric techniques to historical data on consumption, prices, incomes and factor costs to model final demand for goods and services. Supply is modelled using data from major sectors like the energy sector, transportation, agriculture and industry. Critics of this technique suggest that aggregate models applied to climate policy do not contain adequate detail, and they recommend the use of bottom-up modelling techniques.

Total cost. Total cost of a climate change impact or an adaptation measure is the sum of all cost components over time.

Total economic value (TEV). The economic concept of value has been broadly defined as any net change in the welfare of society. The total economic value approach breaks down an impact on an environmental resource into a number of categories of (foregone) value, some of which are tangible and readily measured, while others are less tangible and thus more difficult to quantify. The total value of the good or service, however, is given by the sum of all categories of value, and not simply those that are easy to measure. TEV is generally divided into three categories: (1) **direct use value**; (2) **indirect use value**; and (3) **non-use value**.

Travel cost. Travel cost technique attempts to deduce values from observed behaviour in **surrogate markets**. Information on visitors' total expenditure to visit a site is used to derive their demand curve for the services provided by the site.

Uncertainty. When the decision-maker has poor knowledge of the likelihood with which each state of nature will occur and so cannot attach probabilities to each possible outcome.

Unit cost. The total economic cost of producing a unit of output.

Unit value. Value placed on a unit change in the level of an environmental attribute.

Use value. See **direct use value** and **indirect use value**.

Utility. The benefit that consumers derive from consuming marketed goods, from enjoying non-marketed goods such as environmental benefits, and from other factors that contribute to their overall well-being. In most economic analysis, consumers are assumed to be 'utility maximisers'.

Valuation. The process of attaching an appropriate 'price tag' to all economically relevant impacts. The effects of potential projects should, as far as possible, be expressed in monetary terms.

Value of a prevented fatality (VPF). This is a measure of the value that people place on a small change in the **risk** of dying. Such measures are often used as an estimate of the amount that people are willing to spend to increase safety and are therefore used in decisions on public spending on safety.

Wage-risk approach. See **hedonic wage differential**.

Willingness to accept (WTA). The minimum amount of money that an individual is willing to accept as compensation for suffering a loss, or forgoing a benefit. It can also be the maximum payment that the owner of a resource is willing to accept to allow its use by others.

Willingness to pay (WTP). The maximum amount of money an individual is willing to pay to obtain a benefit or to avoid a loss.

Appendix 3: Acronyms and abbreviations

A	‘Option’ or ‘course of action’ in a decision problem
B/C	Benefit-cost ratio
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CO	Conventional market-based valuation techniques
COI	Cost of illness
CV	Contingent valuation
CVM	Contingent valuation method
Defra	Department for Environment, Food and Rural Affairs (UK)
EA	Environment Agency (UK)
EMV	Expected monetary value
ENPV	Expected net present value
ET	Either technique
EVRI	Environmental Valuation Reference Inventory
FWR	Foundation for Water Research
IG	(Refer to) Individual Guideline
IPCC	The Intergovernmental Panel on Climate Change
IRR	Internal rate of return
MCA	Multi-criteria analysis
NPV	Net present value
NRA	National Rivers Authority
NT	No technique
O	‘Outcome or ‘consequence’ in a decision problem
PV	Present value
PVB	Present value benefit
PVC	Present value cost
RE	River Ecosystem classification system
RQO	River Quality Objective
RU	(Go to guideline on) risk and uncertainty
S	‘State of nature’ in a decision problem
SC	Surrogate or constructed market-based valuation technique
SD	Standard deviation
TCM	Travel cost method
TEV	Total economic value
UKCIP	The UK Climate Impacts Programme
VPF	Value of a prevented fatality
WAC	Waste assimilation capacity
WQO	Water Quality Objective
WTA	Willingness to accept payment
WTP	Willingness to pay

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