Accounting for the Effects of Climate Change

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Supplementary Green Book Guidance

HM TREASURY

defra
Department for Environment
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CONTENTS

1. INTRODUCTION

The climate of the UK is changing. There will be at least 30-40 years of unavoidable climate change and further changes beyond this, dependent on the success of global mitigation efforts.

This document explains how to incorporate these changes into the development, appraisal and evaluation of policies, programmes and projects. It should be read in conjunction with the Green, Orange and Magenta Books[1]. A summary and issues filter presenting the key issues in the guidance on one page is attached.

1.1 The effects of climate change

According to the latest UK Climate Projections, UKCP09, the main changes will be:

Higher temperatures

- Hotter summers and milder winters

Changing patterns of precipitation

- Drier summers and wetter winters

Changes in extreme events

- More very hot days
- More intense downpours of rain
- Larger and more frequent storm surges

Rising sea levels

1.2 When it is important to consider climate change

Many policy, programme or projects will be directly or indirectly affected by a changing climate. It will be particularly important to consider the risks and effects of climate change if a policy, programme or project:

- Has elements affected by the weather and climate, including variability and extremes, and assumes a stable climate;
- Has long-term lifetimes, implications or implementation periods;
- Involves significant investment or has high value at stake;
- Provides or supports (critical) national infrastructure;

[1] The Green, Orange and Magenta Books are central government guidance on: the appraisal and evaluation of policies, programmes and projects (www.hm-treasury.gov.uk/greenbook); the management of risk (www.hm-treasury.gov.uk/orange_book.htm); and policy evaluation (www.nationalschool.gov.uk/policyhub/magenta_book), respectively.

- Involves decisions with significant irreversible impacts;
- Has significant interdependencies with other Government activities or the wider economy; or
- Addresses contingency planning or business continuity needs.

2. IDENTIFYING AND ADDRESSING RISKS FROM CLIMATE CHANGE

2.1 IDENTIFYING CLIMATE RISKS

2.1.1 Physical changes

Changes in extremes and anomalies – exceeding a certain threshold or climate record - are likely to be noticed before changes in average climate. For example, more frequent periods of temperatures exceeding 35°C.

Changes in the average climate will become more apparent over the next 20-30 years, visible as differences from historical norms and variability (for example, warmer, wetter winters with more intense rainfall events). These changed conditions will then become the accepted norm.

The specific context of an activity will determine how these differences in climate will be felt, and the implications they have.

Climate change projections for the UK are developed by the UK Met Office and made available through the UK Climate Impacts Programme (UKCIP). The most recent set of climate projections, UKCP09, are described in Box 1.

Box 1: The UK Climate Projections www.ukcp09.net

The UK Climate Projections 2009 (UKCP09) describe how the climate of the UK might change during the 21st century. UKCP09 attaches probabilities to different levels of future climate change, allowing users to explicitly consider the implications of uncertainties and risks.

UKCP09 provides projections of changes for a number of climate variables (such as average temperature and precipitation), for 25x25 km grid squares and for administrative regions and river basins. There are also projections for marine regions around the UK. Projections are available for different scenarios of greenhouse gas emissions.

UKCP09 also includes a tool called the Weather Generator that allows users to derive plausible daily time-series at a finer resolution, and assess relevant thresholds.

2.1.2 Effects on policies, programmes and projects

A risk assessment should be made of how climate change could affect a policy, programme or project. The depth of the assessment should be proportionate to the costs, benefits and risks involved.

The extent to which climate change will affect an activity depends on the vulnerability and adaptive capacity of the activity:

- *Vulnerability* is the extent to which an activity is susceptible to the effects of climate change, including climate variability and extremes. It is context specific, and may depend on thresholds. For example, temperatures above a certain level may damage road surfaces. However, a road surface in direct sunlight is more vulnerable to higher temperatures than a road surface in shade.

- *Adaptive capacity* is the ability to adjust to climate change risks (including climate variability and extremes). This will be constrained by factors such as the information available, and the incentives individuals and organisations face.

Risk assessment should take a structured approach. Box 2 outlines tools that can be used. Initial screening should focus on identifying potential climate factors that may pose a threat (or opportunity), and how these could affect the activity. Once these are identified, more detailed risk analysis should be undertaken to explore how the effects of climate change are transmitted and the non-climate factors that enhance or diminish these effects. The aims of the activity will need to be defined clearly enough to allow analysis, particularly for deriving forecasts in terms of parameters that affect the activity.

Box 2: Tools for climate change risk assessment

The UKCIP Adaptation Wizard is a web-based tool, designed to help assess vulnerability to current climate and future climate change, identify options to address climate risks, and develop a strategy to address identified risks. It is also a guide to the information, tools and resources that UKCIP provide.

The UKCIP Business Areas Climate Impacts Assessment Tool (BACLIAT) is a simple checklist that can be used to assess the potential impacts of climate change at an organisational level. It examines threats and opportunities from climate change for Logistics, Finance, Markets, Processes, People, Premises and Management implications.

The UKCIP report "Climate adaptation: risk, uncertainty and decision-making" has detailed guidance on the issues to consider when assessing risk. The Defra "Guidelines for environmental risk assessment and management" also outlines a framework for assessing risks.

UKCIP tools are available at www.ukcip.org.uk. Defra guidance at www.defra.gov.uk/environment/risk/index.htm

Risk assessment should consider direct and indirect effects. Many activities will be directly influenced by climate change, because their objectives or elements of their design and operation are dependent on climatic factors. Failure to allow for projected changes in climate may lead to significant future costs or missed opportunities.

Where an activity is not directly affected by climate change, it could still be affected by changes in other areas and sectors. Box 3 describes an example of direct and indirect effects of climate change on agriculture.

Important factors to be aware of include:

- Timing. Particular attention should be paid to activities that have long-term time horizons, life-times, or implications;
- Thresholds. Threshold effects may exist where risks become particularly intolerable, and these may depend on other activities or the wider economy;
- International effects. Events elsewhere in the world triggered by climate change could have effects on activities that operate solely within the UK; and
- Flexibility. Given uncertainty over the future climate, decisions that would be difficult or expensive to revise in future should receive additional scrutiny.

Box 3: The effects of climate change on agriculture

Climate change will directly affect the agriculture sector. Higher average temperatures mean that there are likely to be benefits from increased crop yields and longer growing seasons, with reduced frost damages in winter. There will also be opportunities to diversify and plant new crops. However, higher temperatures may increase the prevalence of pests and other diseases. More extreme and variable weather may lead to greater variability in yields, and increased damages from storms. These direct effects will also have implications for the benefits provided by agricultural land which help manage the broader effects of climate change on society.

There will also be indirect effects on agriculture. Effects of climate change in other sectors may be felt in agriculture. For example, irrigation needs in agriculture may increase, but water supply may become increasingly constrained. The effects of climate change elsewhere in the world may lead to changes in global markets for agricultural commodities, and these may have implications for UK agricultural producers and consumers.

These (direct and indirect) effects may vary over the short and long-term. For example, higher temperatures may initially increase yields, but beyond a certain threshold may lead to decreasing yields.

2.2 ADDRESSING CLIMATE RISKS

Taking action to reduce risks or take advantage of opportunities from climate change is called *adaptation*[2]. Adaptation will contribute to sustainable development[3].

Adaptation measures should be aimed at adjusting an activity to account for the effects of climate change, or at addressing market failures that provide barriers to individuals and organisations adapting in a socially optimal way.

2.2.1 Principles of good adaptation

Well-designed adaptation measures should be effective, efficient and equitable.

Effective

Taking account of vulnerability and adaptive capacity, effective measures will reduce the risks from climate change and not introduce perverse effects.

Effective measures will incorporate flexibility to adjust in the future to cope with a range of climate scenarios, as well as socio-economic, technical and other changes. They will not limit future adaptation actions.

Efficient

The expected reduction in social damage costs from adapting to climate change should justify the costs of implementing the measure.

Measures should be timed appropriately. Activities that are flexible or renewed and changed often can adapt over time to changes in climate. Activities – such as infrastructure - with long lead times and lifetimes are more likely to be locked into their design and performance window. Climate change should be incorporated into their design. Unanticipated climate change could lead to costs through poor performance, need for retrofitting, or early abandonment.

Equitable

Some of the groups most vulnerable to the effects of climate change may also be least able to adapt to the effects of climate change.

It will not be possible to avoid all of the costs imposed by climate change. The distributional consequences of different options should be

[2] In comparison, *mitigation* relates to reducing the emissions of carbon dioxide and other greenhouse gases that cause climate change.

[3] The Government Economic Service is currently undertaking a review of sustainable development and policy appraisal; more information can be found at www.defra.gov.uk/evidence/economics/susdev

analysed to inform decision makers of the effects of the activity on different groups.

2.2.2 Addressing uncertainty

Three approaches can help address uncertainty over future climate change:

- Incorporate flexibility: allow for the possibility of adjustment in the future to cope with effects that are more or less severe than anticipated, or to adapt incrementally. For example, building a flood barrier that can be extended in the future (see Box 5).

- Increase resilience: design the activity to tolerate a wider range of climate conditions, while retaining the same basic structure and functioning. For example, by building a bridge higher than otherwise would be done.

- Identify low-regrets and win-win measures: Low-regrets options have relatively low costs, and relatively large benefits (that are mainly realised under projected future climate change). Win-win measures address climate change risks, but also deliver other benefits. For example, insulating and flood-proofing buildings will provide benefits under the current climate, as well as in the future.

2.2.3 Adaptation options

Adaptation measures should be flexible. They can be aimed at helping others to adapt in the right way, as well as delivering adaptation actions. Helping others adapt in the right way means creating the underlying framework to deliver adaptive actions.

The options outlined below are not mutually exclusive – a mix of measures may be appropriate. For example, a flood defence strategy may include built flood defences to make buildings more resilient (preventing losses), insurance against any flood damage (sharing losses) and allowing some areas to flood (bearing losses).

Helping others adapt in the right way by:

Setting the right underlying framework for effective adaptation

Individuals and organisations take decisions within the regulatory and institutional framework they face. This framework should address market failures and give the correct incentives for effective adaptation. This might be by amending existing, or creating new, instruments to account for climate risk and adaptation. These could be regulations,

standards, codes or guidance. Market based instruments may also be appropriate.

Creating information needed to make effective decisions

It is important that individuals and organisations are informed about the likely consequences of climate change, so they can assess the potential impacts and risks they face. Using education, information, or training can help communicate the effects of climate change. Research can help improve knowledge of the effects of climate change, and how this will affect an activity, as well as key thresholds and interdependencies. Learning from experience will be a source of information by monitoring progress, collecting data and evaluating outcomes.

Delivering adaptation actions by:

Bearing losses and managing impacts

- When the benefits of taking adaptive action do not justify the costs, accepting the risk and bearing any consequences and costs that result from climate change may be appropriate
- Devising strategies to manage impacts that arise
- Repairing damages might be viable, particularly if the impact is small and infrequent.

Sharing risks

- Insurance can spread risk and losses across society
- Diversifying can help reduce dependency on any one outcome
- Ensure incentive structures and contracts accurately reflect risk
- Where there are cross-cutting effects and interdependencies across activities or the wider economy, co-ordinated action can help reduce costs and spread risks.

Preventing losses or reducing consequences

- Structural or technological methods to reduce the probability of damage occurring, such as building flood defences
- Measures to enhance resilience to reduce consequences and impacts, and shorten recovery time
- Avoiding impacts by changing location of an activity
- Legislative, regulatory or institutional changes, such as amending building standards
- Increasing the range of climate conditions under which activities remain viable
- Emergency, contingency or disaster planning to deal with extremes – such as the Department of Health Heatwave plan.

Exploiting opportunities

- Taking advantage of positive effects of climate change
- Identifying win-win adaptation measures that provide additional climate and non-climate benefits

Box 4: Responding to Climate Change – DH Heatwave Plan www.dh.gov.uk

Climate change means heatwaves - periods of very high temperatures - are likely to become more common. Because the effects of excessive heat on health can be severe (including death), the Department of Health introduced an annual Heatwave Plan to ensure the country is prepared for future heatwaves.

The thresholds at which the effects of excessive heat become apparent vary across the country: they are higher in urban areas and the south. Certain groups of people are more vulnerable during a heatwave – for example, because they are at higher risk physically, or they are less able to adapt their behaviour.

One of the main barriers to taking timely preventative measures is recognising that a heatwave is occurring, and having access to information on what action to take. The Heatwave Plan addresses these barriers by setting out what needs to happen before and during a heatwave. The core elements of the plan are:

- A heat-health watch operating between June and September. Based on regional temperature thresholds, there are four levels of response:
  - Level 1 – Summer Preparedness and Long-term Planning
  - Level 2 – Alert and Readiness. Triggered when temperatures forecast to exceed thresholds.
  - Level 3 – Heatwave Action. Triggered when temperature thresholds are exceeded.
  - Level 4 – Emergency. If a heatwave lasts for four or more days in two or more regions, or if a severe or prolonged heatwave affects sectors other than health.
- Advice and information issued direct to the public and health and social professionals on health effects and how to treat them;
- Long-term planning to adapt and reduce the impacts of climate change for each level of severity; and
- Annual evaluations to review the effectiveness of the plan.

2.2.4 Real Options Analysis

Uncertainty over the future impacts of climate change means the ability to use and value flexibility is critical. Real Options Analysis provides a framework to incorporate the uncertainty of climate change and the value of flexibility into decision making.

A "Real Option" is an alternative or choice that becomes available through an investment opportunity or action. For example, designing

an activity with the flexibility to upgrade in the future provides an option to deal with more (or less) severe climate change.

Real Options Analysis recognises that information about uncertainty changes over time (for example, from learning or research). With sufficient flexibility the activity can be amended in the light of new information. But this flexibility does not detract from performance if it is not needed. When the value that this flexibility creates is not incorporated, the "true" value of the options Net Present Value (NPV) will be systematically underestimated.

2.2.5 When can Real Options Analysis make a difference?

A Real Options approach will be particularly suitable for policies, programmes or projects which have three core features: uncertainty, flexibility, and learning potential.

Uncertainty surrounding the effects of climate change highlights the importance of flexibility as a part of an adaptation strategy. Where flexibility is limited, the benefits of acquired information cannot be realised.

Potential for learning will arise as knowledge about the effects of climate change improves over time: from improved modelling and scientific understanding, and from experience of how the climate is actually changing[4].

[4] Further information on how climate scenarios for the UK have evolved can be found at www.defra. gov.uk/adaptation

Box 5: Incorporating climate change into decision making – TE2100

Thames Estuary 2100 (TE2100) is an Environment Agency project to develop a tidal flood risk management plan for the Thames estuary for the next 100 years. It will recommend what measures will be required, where, and when. As such, the implications of future sea level rise and increasing frequency of storm surges from climate change are critical considerations.

The Thames estuary floodplain contains 1.25 million people (one sixth of London's population), about £200bn of property, and key transport and infrastructure assets, including the London Underground, 16 hospitals and eight power stations. The value of assets at risk and the long lead times involved in developing solutions emphasise the need to plan in advance for the effects of climate change.

The TE2100 strategy incorporates flexibility to account for uncertainty in the effects of climate change. The project identified options to cope with different levels of sea level rise, and the thresholds at which they will be required. The options were designed to implement the small incremental changes common to all options first, leaving major irreversible decisions as far as possible into the future to make best use of the information available.

The project includes a monitoring and evaluation strategy. If monitoring reveals that climate change is happening more quickly (or slowly) than predicted, the implications for decision points are established. The strategy can be reappraised in light of the new information and options can be brought forward (or put back). This helps ensure adaptation decisions are made at the right time.

For further information, Annex 1 contains a full case study illustrating the approach taken to developing the TE2100 project.

3. APPRAISING AND EVALUATING POLICIES, PROGRAMMES AND PROJECTS

3.1 APPRAISING OPTIONS

The standard Green Book approach to option appraisal should be followed for adaptation measures, giving consideration to section 3.1.5 on specific issues. If an activity has uncertainty, flexibility and learning potential, a Real Options approach may be appropriate.

3.1.1 Using Real Options Analysis

The initial risk assessment (section 2.1.2) should examine the suitability of a Real Options approach. Consider the sensitivity to uncertainty, the potential for learning, and the degree of flexibility.

Flexibility to respond to new information can be valuable. However, waiting for new information should not be used to justify delaying action. Decisions should be taken with the best available information, recognising that this may change in the future.

3.1.2 Using Real Options Analysis qualitatively

A decision tree can be used to map out and understand the sequence of actions, decision points and events along an activity's path[5]. It is not a substitute for quantified appraisal. It should consider the range of options available (now and in the future), how information is likely to be acquired, and should incorporate monitoring and evaluation of progress (see section 3.2).

3.1.3 Real Options Analysis as a quantitative tool

A quantitative Real Options appraisal follows the same principles as a Green Book cost-benefit analysis. Streams of costs and benefits should be compared over time and discounted to generate a Net Present Value (NPV). The additional step in a Real Options appraisal is to account for the value of flexibility in the structure of the activity.

Assessing options quantitatively should build on qualitative analysis. The decision tree can be populated with information on costs, benefits, and probabilities associated with different options. Sensitivity analysis

[5] See Chapter 5 of the Green Book.

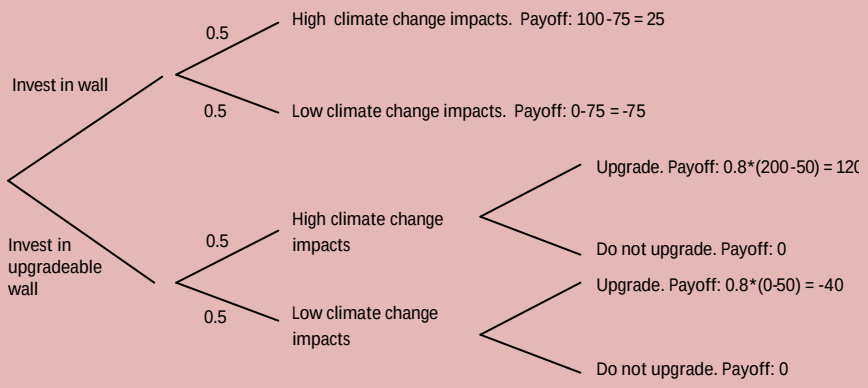
can be used to examine the implications of alternative climate change scenarios.

Box 6 outlines how a Real Options approach, using a decision tree, could be used to calculate the NPV of a proposal. It shows that valuing flexibility and the potential for learning from new information can give a different outcome. With sufficient flexibility, the option to stop the investment if it turns out not to be worthwhile has inherent value, and this is reflected in the NPVs.

Box 6: Appraisal using a Real Options approach

Consider a proposal for investing in infrastructure protecting against the impacts of flooding due to climate change. There are two options: invest in a wall, or invest in a wall which has the option to upgrade in the future. There is an equal probability of high or low climate change impacts in the future. The standard wall costs 75, and has benefits of 100 from avoided flooding. The upgradeable wall costs 50, the upgrade costs 50 and would give benefits of 200 from avoided flooding.

The information can be set out in a decision tree:



Simplifying assumptions: residual damages under the "do not invest" strategies have been ignored; the discount factor is 0.8.

The expected value of investing in the standard wall is a simple NPV calculation, calculating the expected costs and benefits of the investment. The NPV is (0.5*25) + (0.5*-75) = -25. This suggests the investment should not proceed.

Flexibility over the investment decision allows the possibility to upgrade in the future if the impacts of climate change are high. The expected value of this option can be calculated.

If the impacts of climate change are high enough to warrant upgrading, then the value of the investment is 120. If the impacts are low, then upgrading is not justified since the payoff is negative (-40). Since the investment costs of the upgrade are not realised in practice in the low outcome, they are therefore not incorporated into the NPV. The expected value of investing now with the option to upgrade in the future is (0.5*120) – 50 = +10.

Comparing the two approaches shows an NPV of -25 for the standard approach, and +10 for the Real Options approach. Flexibility to upgrade in the future is reflected in the higher NPV, and switches the investment decision.

3.1.4 Practical issues to consider in a Real Options approach

Enforceability. An option will only have value if it can be enforced or undertaken. This may be constrained by the degree of managerial discipline, or other public commitments.

Time frames. The time frame available before exercising the option affects its value. With more time for useful information to become available, the greater the scope for the value of the option to vary.

Information. Gathering information on costs, benefits and probabilities associated with options can be resource intensive.

3.1.5 Further issues to consider when appraising options

Option analysis

The "do-minimum" option should reflect the state of the world in the absence of the proposal. This should incorporate unavoidable climate change, socio-economic changes and any adaptation that will occur autonomously. Some changes may be adequately certain to include; where there is less certainty sensitivity and scenario analysis should be applied.

Ancillary Effects

Benefit may arise from reduced vulnerability to current, as well as future, climate (and other economic and natural pressures) and should be included in the appraisal or evaluation.

Indirect Effects

The effects of climate change will be wide-ranging: interventions could have indirect effects on other sectors or areas. These should be included in the appraisal or evaluation, and quantified where possible.

Risk and Uncertainty

Costs and benefits should be adjusted to incorporate risk and uncertainty.

For risks that are quantifiable, adding a risk premium will be appropriate. Calculating a risk premium depends on being able to *quantify the impact* (first in physical terms, and then in monetary terms), and assign a *probability* to the impact being realised. The UK Climate Projections generate probabilistic outputs which will aid these calculations.

Sensitivity analysis can be used to explore uncertainty, to help determine key thresholds or switching points. This might be by

widening the bounds (higher or lower, or both depending on the expected direction of the change) around key variables in the analysis.

Discounting

Costs and benefits should be discounted at the standard Green Book discount rate. This incorporates a declining discount rate schedule giving weight to costs and benefits occurring in the future. If the proposal involves potentially substantial and irreversible inter-generational wealth transfers a lower discount rate may be appropriate; consult further supplementary Green Book guidance[6].

Consistent Use of Forecasts and Scenarios

Scenarios or projections should be consistent. Care should be taken to ensure that there are no inconsistencies when introducing other data, scenarios or forecasts.

Key areas to pay attention to include:

- *International effects* – such as migration
- *Other socio-economic trends* – such as aging
- *Valuation* – market prices should be consistent with any underlying socio-economic scenarios.

Specialised guidance

Specialised guidance is available (see section 4) on incorporating specific issues - such as flooding - into appraisal and evaluation.

3.2 MONITORING AND EVALUATION

Evaluation examines the processes and outcomes of a policy, programme or project against what was expected, and is designed to ensure lessons learned are fed back into the decision-making process[7]. The aim is to assess how successful, or otherwise, an activity has been and whether this is expected to continue to be the case:

- Has it been effective in terms of achieving specific outcomes?
- What factors determined why it was, or was not, effective?

Economic evaluation is conducted in the same way as appraisal - focusing on cost-benefit analysis – but in the knowledge of what has happened rather than what is forecast to happen.

[6] "Intergenerational Wealth Transfers and Social Discounting", available at www.hm-treasury.gov.uk/ d/4(5).pdf

[7] See the Magenta Book (www.nationalschool.gov.uk/policyhub/magenta_book) for more detailed guidance on policy evaluation.

3.2.1 Evaluation in the context of climate change

An evaluation may need to assess:

- an intervention designed to address a specific climate risk;
- an activity that has been amended to allow for climate risk; or
- an activity where climate change was not originally identified as a risk, but is a relevant factor in explaining outcomes.

Evaluating adaptation measures will often be complex, with a range of factors that need to be explained. It will be important to learn from experience in order to assess the performance of the measure, and ensure that future measures continue to be effective.

The long time frames over which the effects of climate change will occur means that it will often be difficult initially to assess the success of measures in terms of outcomes. Emphasis should be placed on monitoring and evaluating processes, to understand the contextual factors and mechanisms that underlie an activity's success, and develop the evidence base for evaluating outcomes.

3.2.2 Monitoring and evaluation in practice

The aim of an evaluation is to assess to what extent an activity has been, and is expected to continue to be, successful, in what circumstances, and why. A framework for monitoring and evaluation is to assess how a measure has performed against the principles of good adaptation described in section 2.2.1:

Effectiveness. Has the measure achieved the desired outcome? Have there been unintended consequences? Was there sufficient flexibility?

Efficiency. Did the benefits outweigh the costs?

Equity. Did the measure impose significant disproportionate costs on individuals or groups?

Evaluation should be a continuous process. Monitoring should focus on developments in knowledge and information on changes in climate and adaptation processes, and the implications of this on the risk of exceeding thresholds.

Evaluating processes and outcomes will be a necessary component of a Real Options approach, and should be incorporated into the sequencing of the activity. This means the full range of information can be utilised and fed back into decision making. This will help ensure adaptation decisions are made at the right time.

Factors that may influence points at which to evaluate progress include:

- The provision of new climate information (such as new climate projections). This may occur at regular intervals.
- The availability of new research. For example, that resolves uncertainty about the effectiveness of an adaptation measure.

4. WHERE TO GO FOR FURTHER INFORMATION

Defra www.defra.gov.uk/adaptation

The Department for the Environment, Food and Rural Affairs is the UK Government department that leads on the cross-government adapting to climate change programme.

Guidelines for Environmental Risk Assessment and Management, DETR and Environment Agency - www.defra.gov.uk/environment/risk/index.htm

Flood and Coastal Erosion Risk Management guidance - www.defra.gov.uk/environ/fcd/guidance.htm

UKCIP www.ukcip.org.uk

The UK Climate Impacts Programme is a Government funded organisation, established to provide information on the impacts of climate change, primarily through climate scenarios for the UK, but also by developing tools to help users understand these in context.

Climate Projections

- UK Climate Projections 09 – Climate projections for the UK over the 21st century - www.ukcp09.net

Tools

- "Adaptation Wizard" – tool to help scope the effects of climate change - www.ukcip.org.uk/wizard
- "Climate adaptation: Risk, uncertainty and decision making" – report with detailed information on incorporating climate risk and uncertainty into decision-making
- "Business Areas Climate Impacts Assessment Tool" (BACLIAT) – a tool to help scope the effects of climate change at an organisational level
- "Identifying Adaptation Options" – for further information on types of adaptation options.

HM Treasury

Green Book www.hm-treasury.gov.uk/greenbook
Orange Book www.hm-treasury.gov.uk/orange_book.htm

Stern Review www.sternreview.org.uk

The Stern Review examined the nature of the economic challenges of climate change and how they can be met, both in the UK and globally.

The Committee on Climate Change www.theccc.org.uk

The Committee on Climate Change is an independent body established under the Climate Change Act to advise the UK Government on setting carbon budgets, and to report to Parliament on the progress made in reducing greenhouse gas emissions. The associated Adaptation Sub-Committee will provide external scrutiny of Government adaptation activities.

Environment Agency www.environment-agency.gov.uk

For further information on the Thames Estuary 2100 project.

Department of Health www.dh.gov.uk

For further information on the Heatwave Plan for England.

OECD www.oecd.org

Research on climate change adaptation, including "Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments" (2008) ed. Agrawala, S and Fankhauser, S.

Comments and questions on this guidance can be emailed to the Adapting to Climate Change Programme in Defra: adaptation@defra.gsi.gov.uk. The guidance will be reviewed annually; suggestions for improvements are welcome at the above address.

A. ANNEX A

CASE STUDY: THAMES ESTUARY 2100

The Environment Agency's Thames Estuary 2100 (TE2100) project is developing a strategy for tidal flood risk management to the year 2100. The implications for the Thames of future sea level rise and storm surge behaviour arising from climate change are critical considerations in developing the strategy. Because of uncertainty in future effects, TE2100 has developed an adaptive approach to future flood risk management.

The approach to building climate change impacts into the TE2100 strategy is set out as follows.

Stage 1: Assessing climate risks

The starting point for TE2100 was to understand the wider evidence and projections relating to future climate change, and build a picture of how future climate change could affect flood risk in the Thames Estuary. Focusing on mean sea level rise and storm surge behaviour, TE2100 developed a range of climate change scenarios, derived from work done by UKCIP and others. One of these was a "central" or "most likely" scenario derived from 2006 Defra guidance on sea-level rise[8], which implied total water level rise of around 1 metre by the year 2100. Other scenarios developed initially were:

- "Low" (half the rate of change assumed in the Defra scenario) – 0.5m rise;
- "Medium High" (derived from the UKCIP02 scenario of the same name) – 1.5m rise;
- "High Plus" – 2.7m rise;
- "High Plus Plus" (scenario if all the worst scientific predictions were combined) – 4.2m rise.

Further TE2100 modelling work done in collaboration with UKCIP has tended to confirm the extreme water levels suggested by the "central" scenario, but has shown that the "worst case" situation is more likely to be nearer "High Plus" (2.7m) than "High Plus Plus" (4.2m).

[8] *Flood and Coastal Defence Appraisal Guidance: FCDPAG3 Economic Appraisal; Supplementary Note to Operating Authorities – Climate Change Impacts*, Defra, October 2006.

Stage 2: Designing adaptation options

TE2100's options development process began by assessing the full range of available individual responses to increasing flood risk arising from water level rise. These were assembled through a comprehensive range of on-the ground studies across the Thames area, and included raising river walls, adapting or building flood barriers or flood storage areas, applying resistance and resilience measures to buildings, and so on. The next stage was to assemble these individual responses into portfolios of actions, which worked together coherently. Finally, portfolios were assembled into packages to create strategic High Level Options (HLOs), able to deal with differing levels of extreme water level rise (expressed in metres, without consideration of time at this stage).

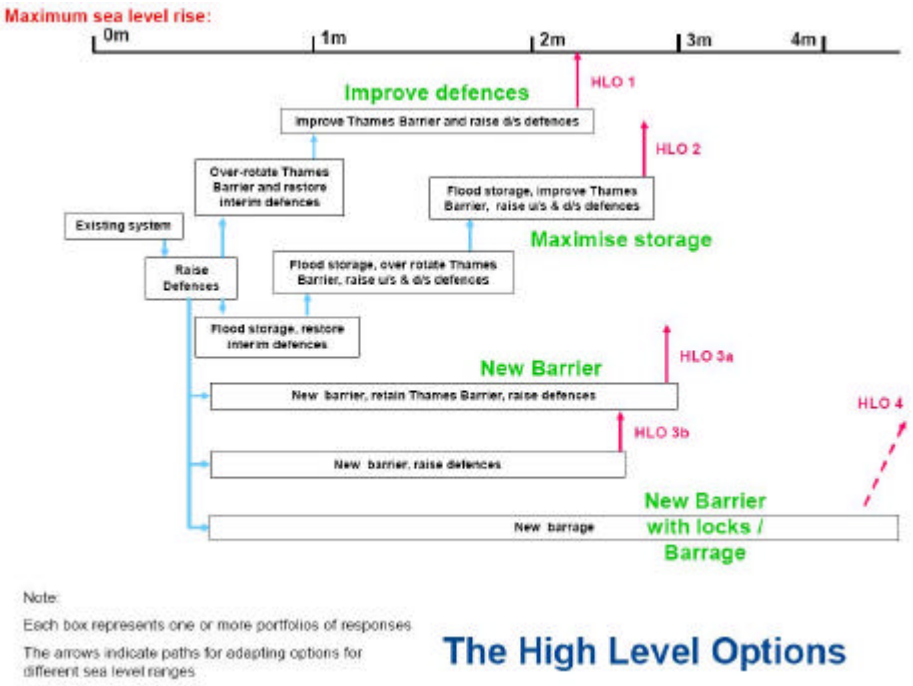


Figure 1 - Development of TE2100 High Level Options

In *Figure 1* above, each box represents a portfolio, and combinations of portfolios are assembled to produce the HLOs 1-4. It can be seen that HLO1 (improve defences) can cope with up to about 2.3m of water level rise, whereas HLO2 (maximise flood storage) and HLO3 (new flood barrier) allow adaptation to slightly higher levels. The ultimate solution would be HLO4 (tidal barrage), which can deal with in excess of 4.5m of water level rise.

The climate change scenarios can then be introduced to determine which Options are able to deal with which scenario. This is shown in *Figure 2* below, where the predicted water levels in 2100 under each scenario are shown with dotted lines. This shows that all Options can deal with expected water level rise under the "central" (Defra) and "Medium High" climate change scenarios, but only HLOs 2, 3 and 4

can deal with a “High Plus” scenario. Ultimately, only HLO4 (a tidal barrage) could deal with a “High Plus Plus” case.

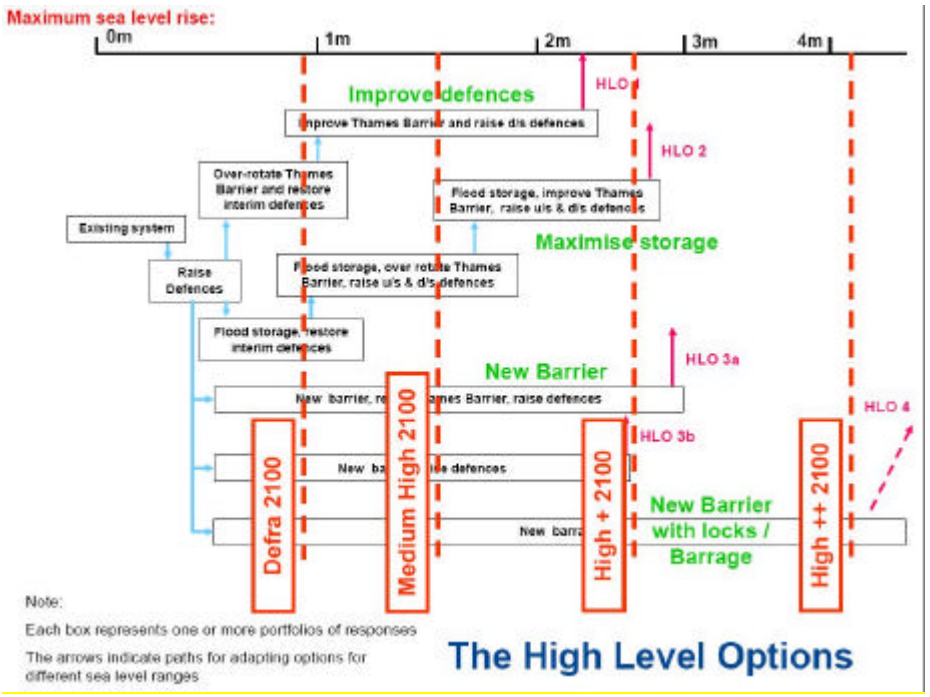


Figure 2 - High Level Options and climate change scenarios

The High Level Options were ultimately assembled as schedules of portfolios in particular time periods, as a response to water level rise reaching particular thresholds over time (based on best estimates). Key thresholds and portfolios are shown in *Figure 3* below, with the dotted red lines representing two examples of High Level Option. Under current best estimates, Threshold 1 (limit of the existing flood management system) occurs around 2030-40, Threshold 2 (limit of the Thames Barrier) around 2070, and Threshold 3 (limit of a modified Thames Barrier) beyond the end of the planning period in 2100. A sample of the detailed schedule for High Level Option 1 is shown in *Figure 5* at the end of this case study.

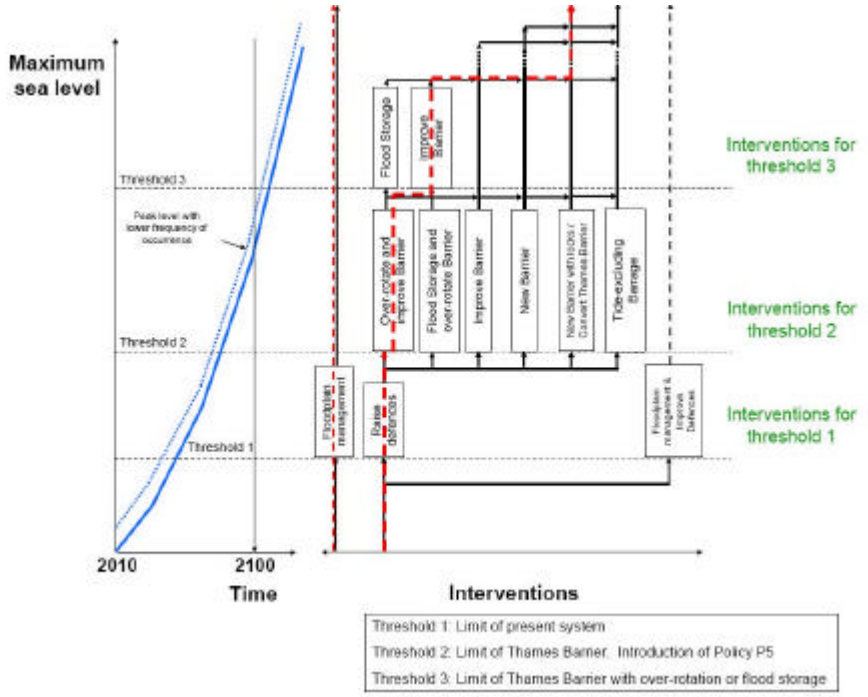


Figure 3 – Thresholds and interventions (based on best estimates)

Stage 3: Appraise options to address the most likely view of risk

TE2100 has conducted Cost-Benefit Analysis (CBA) of all the High Level Options (later developed into "Phase 3" Options) under a "central" (Defra 2006 advice) climate change scenario. This has determined the best generic Option to promote under current knowledge of the most likely climate change outcome. Multi-Criteria Analysis has been used to articulate a comprehensive range of impacts for inclusion in the CBA. This has allowed the indirect and ancillary impacts (e.g. those to business and the environment) of adapting to climate change through flood risk management measures to be captured in the decision-making process, as well as the direct ones (e.g. prevention of damage to property, traditionally assessed through hydraulic flood risk modelling).

Stage 4: Appraise options under other scenarios

The next stage has been to repeat the CBA of Options under differing baselines and impact estimates suggested by the different climate change scenarios. This enables a view of how the Options perform under differing states of the world, again taking a broad view of costs and benefits. In turn, this shows up potential weaknesses in Options as interventions to deal with an uncertain future, and highlights critical points in key variables (such as sea level rise) at which a different Option may be preferred.

Stage 5: Monitoring and adaptation strategy

The scenario analysis in Stage 4 has been used to inform the development of an adaptation strategy, which is a key element of the wider TE2100 strategy. This works as follows:

a) The Option with the highest Cost-Benefit Ratio given current knowledge of the most likely climate change outcome is recommended. This includes a series of interventions through time, each of which have lead times which are estimated (based on when interventions are predicted to be needed in response to threshold values of climate change indicators – see *Figure 3* above). In turn, this implies *decision points* at which individual responses within the wider Option (such as raising walls or building a new flood barrier) need to be approved. This is illustrated in *Figure 4* below

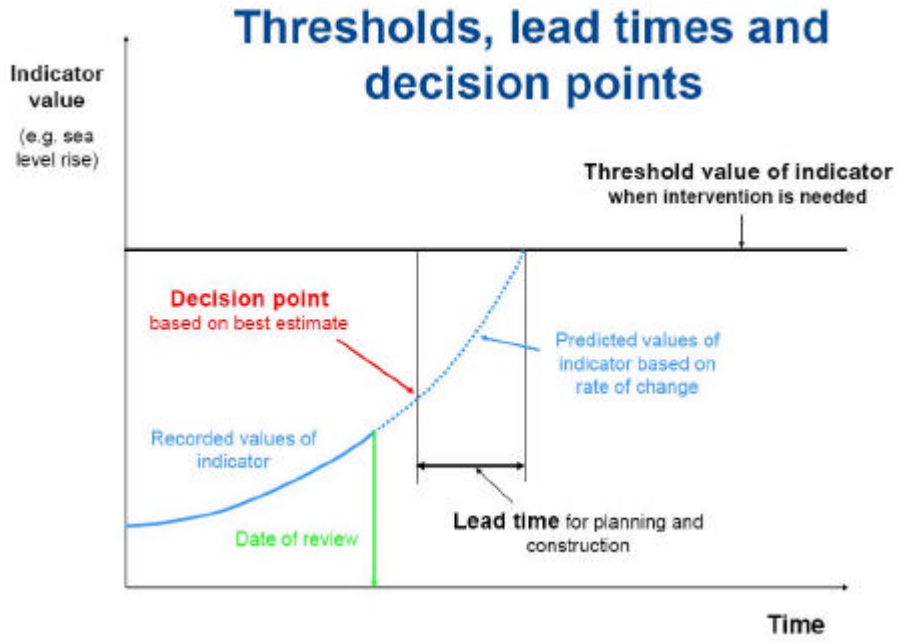


Figure 4 – Thresholds, lead times and decision points

b) A system of monitoring of key climate change indicators (such as sea level rise) is put in place.

c) Every 5-10 years the strategy is revisited. If monitoring in the intervening period has revealed that climate change is happening more quickly (or slowly) than predicted at the time the Option was developed, the implications for decision points are established. These may be brought forward (or put back) as appropriate. This ensures that adaptation decisions are made at the right time, to keep benefit-cost relationships close to those envisaged at initial appraisal.

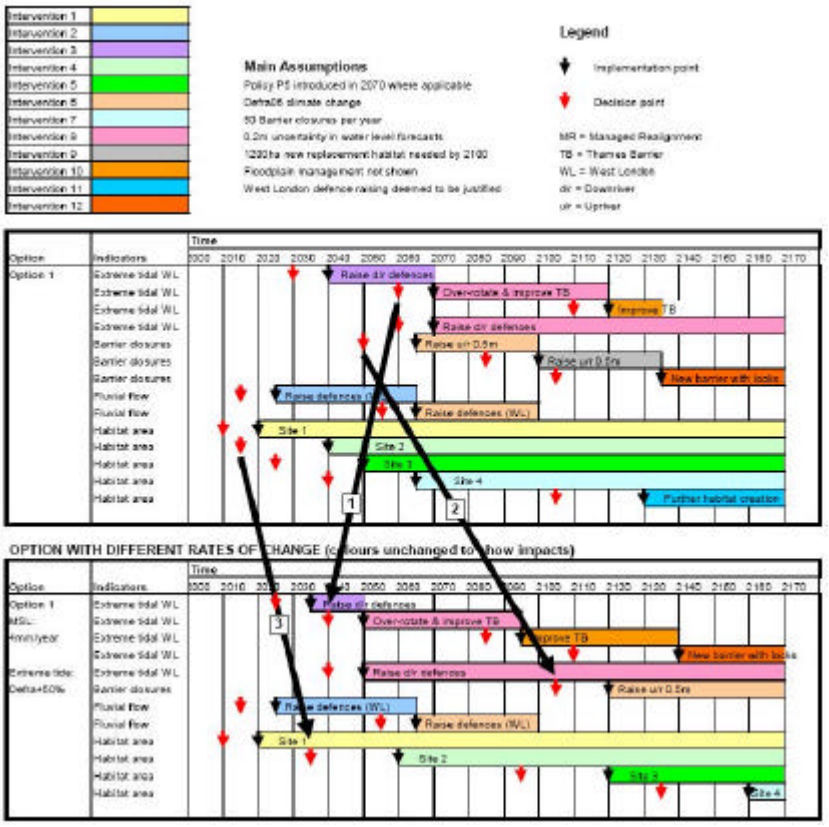


Figure 5 - The adaptation strategy in practice

Figure 5 shows how the individual elements of the strategy might be modified in practice, in the light of new indicator information. The top half of the diagram represents the progress of the strategy as initially predicted, based on then-best estimates. If, for example, monitoring reveals that the "Extreme tidal water level" indicator is changing more quickly than originally envisaged, the implementation point for over-rotating and improving the Thames Barrier (say) gets brought forward from 2070 (earlier best estimate) to 2050. This implies the decision point for going ahead with this intervention is brought forward from 2060 to 2040 (*Arrow 1*). Conversely, if the "Number of Barrier closures" indicator increases less quickly than envisaged (e.g. because of better forecasting techniques being developed which reduce the need for precautionary closures), then decisions to raise upriver defences (to keep barrier closure numbers within acceptable limits) can be put back, from 2050 to 2105 (*Arrow 2*). Finally *Arrow 3* illustrates how decisions to implement managed realignment for habitat compensation purposes could be put back in the light of new information that habitat area (another monitored indicator) was being lost at a slower rate than previously expected.

d) Also at each 5-10 year review, depending on the magnitude of indicator change observed through monitoring, the whole strategy could be reappraised in the light of new information, to

see if a switch to one of the other High Level Options is recommended by Cost-Benefit Analysis. For example, if climate change has accelerated significantly beyond expectations, there might be a case for switching to a more interventionist long-term strategy (ultimately, a tide-excluding barrage, HLO4). Such a switch would be possible (without significant wasted investment) in the early decades of the strategy, because the HLOs are designed to implement small, incremental changes which are common to all the options first, leaving the major irreversible investment decisions as far as possible in the future. The periodic reviews could also take on new information from wider climate change modelling (such as new UKCIP scenarios), as available.

e) The strategy is revised as necessary and the process goes back to step a).

One issue for successful adaptation is the possibility of some options (or parts of options) being prematurely closed off or ruled out, perhaps through the actions of third parties. For TE2100, one example of this is the possibility of land which may be needed for future flood risk management activities (new defences, flood storage areas, managed realignment etc.) being developed. As such, the TE2100 strategy is likely to recommend the safeguarding of land. This incurs opportunity costs but gives option value. If it is possible to minimise the opportunity cost of not developing relatively small parcels of land (for example through the land use planning system making other sites available), then the value of maintaining options for protecting London from increasing flood risk is arguably large.