Department
for Environment
Food & Rural Affairs

Accounting for the effects of climate change

Supplementary Green Book guidance

May 2024

Contents

Executive summary

This supplementary guidance to HM Treasury's Green Book supports analysts and policymakers to ensure, where appropriate, that policies, programmes and projects are resilient to the effects of climate change, and that such effects are being taken into account when appraising options.

This guidance:

1. Builds on the conventional Green Book appraisal methodology to account for the effects of climate change.

2. Supports analysts and policymakers to identify if and how their proposals could be affected by climate risks and challenges.

3. Supports analysts and policymakers to design adaptation measures in response to climate risks and challenges.

It is important to develop policy and take decisions with an awareness that our climate is changing. The latest UK Climate Projections 2018 (UKCP18) show an increased chance of warmer, wetter winters, hotter, drier summers, more extreme weather events and rising sea levels. Many policies, programmes and projects will be directly or indirectly affected by a changing climate and appraisal should account for such impacts, where significant, and respond to them where cost-effective to do so. Otherwise decisions will not necessarily be being based on full understanding of how public value can best be delivered over time.

- Chapter 1 sets out why it is important to consider the effects of climate change (1.1), including examples of key issues to consider when accounting for the effects of climate change in appraisal (1.2).

- Chapter 2 sets out the principles of climate resilient appraisal and how it builds on the foundations of the Green Book (2.1). It provides an overview of the process for including climate change in appraisal (2.2) and of appraisal and decision methods under climate uncertainty (2.3).

- Chapter 3 supports identification of climate change risks to policies and proposals using a climate risk assessment (3.1). This includes accounting for direct and indirect effects, other important factors and examples.

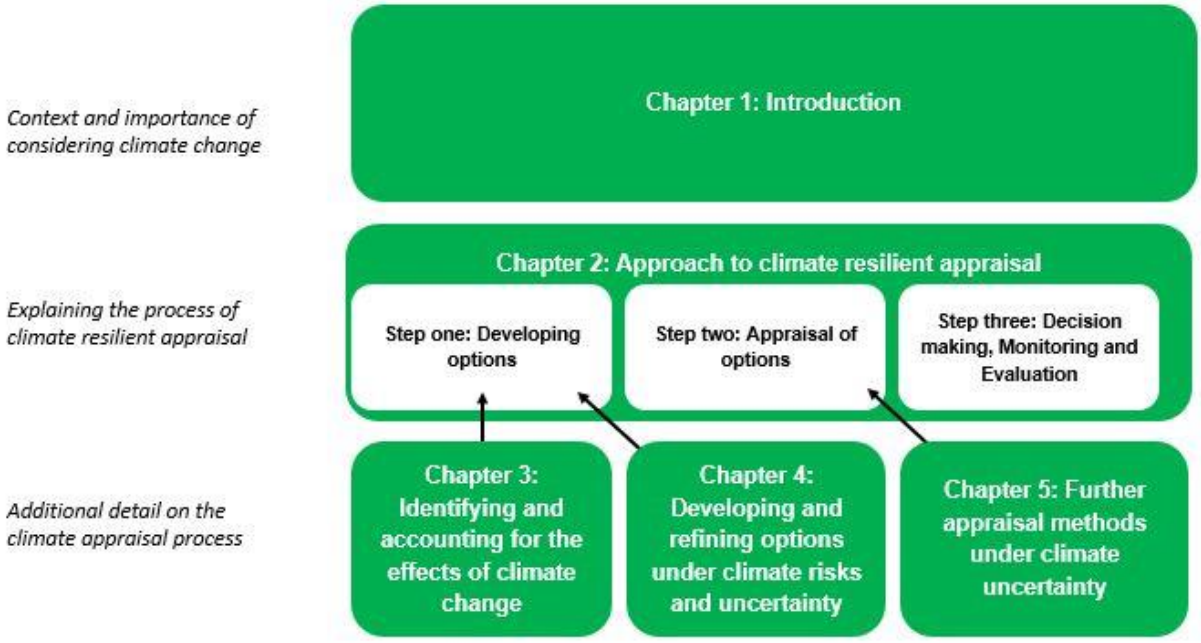
- Chapter 4 provides guidance on how to develop policy options in response to climate challenges, including the principles of good adaptation (4.1), approaches to good adaptation (4.2) and designing adaptation options (4.3).

- Chapter 5 provides practical guidance on how to perform economic appraisal under climate uncertainty. This includes guidance on appraisal under uncertainty (5.1),

incorporating climate change risks into the baseline and sensitivity analysis (5.2) as well as practical guidance on proportionate climate resilient appraisal (5.3).

A climate resilient appraisal example is provided in Annex A. The guidance also provides useful links for further information on climate change adaptation in Annex B.

Structure and purpose of each chapter



Note: this guidance intends to set out the process for climate resilient appraisal and provides some detail to support carrying out such appraisal. It may be necessary to seek further detailed guidance on the techniques described.

Chapter 1: Introduction

Our climate has already changed and will continue to do so as a result of anthropogenic (man-made) greenhouse gas emissions. Despite international efforts to mitigate further global warming, further change is locked-in and is unavoidable. Our policies, programmes, investments and plans need to recognise the potential impacts. Where possible and cost-effective, building resilience and adaptation can reduce the impacts of climate change.

The climate is changing as the Earth's average temperature rises. The Government has already committed to the goals of the Paris Agreement which aims to hold the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the increase to 1.5°C[1]. The Climate Change Act 2008 sets out a policy framework to deliver domestic emissions reductions and to ensure the UK adapts to inevitable climate

[1] The IPCC provides scientific and technical information about how this could be achieved and the impacts and benefits of doing so. See IPCC 'Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report' *2018, World Meteorological Organization, Geneva, Switzerland*

change. This involves commitments to produce a Climate Change Risk Assessment (CCRA) every 5 years, followed by a National Adaptation Programme (NAP) to address those risks. A focus on adaptation has been embedded in other key government commitments such as the 25 Year Environment Plan (25 YEP).

This document sets out how to account for the impact of climate change in the development, appraisal and evaluation of policies, programmes and projects. It should be read in conjunction with the Green, Orange, Magenta and Aqua Books.[2]

Snapshot of climate effects

The UK's national climate projections[3] show an increased chance of warmer, wetter winters and hotter, drier summers during the 21st century. Extreme weather events will also become more frequent and sea levels will continue to rise.

By the end of the 21st century all areas of the UK are projected to be warmer. By 2070, projections show that the range of average seasonal temperature changes are projected to increase. The temperatures could be between 0.9 °C and 5.4 °C warmer in summer, and 0.7 °C to 4.2 °C warmer in winter. Marine projections indicate that the sea level around the UK will continue to rise until at least 2100 under all future climate scenarios. The pattern of sea level rise is not uniform across the UK. E.g. for Belfast sea level projections suggest an 11-52cm rise in a lower concentration scenario (RCP2.6) and 33-94cm rise in a high concentration scenario (RCP8.5). In London these correspond to 29-70cm (RCP2.6) and 53-115cm (RCP8.5).

1.1 The importance of considering climate change

Many policies, programmes and projects will be directly or indirectly affected by a changing climate (reflected in, amongst other things, their effectiveness and costs). It will be particularly important to consider the risks and effects of climate change if a potential policy, programme or project:

- Has assets or elements affected by the weather and effects of climate change, including variability and extremes: for instance, capital assets such as housing developments, schools, health centres, or other important facilities as well as natural assets such as soils, woodland, peatlands, freshwater or marine and coastal habitats.
- Has long-term lifetimes, implications or implementation periods over which the change in climate could be significant.
- Involves significant investment, or has high value at stake (including human wellbeing and biodiversity), or involves significant operational or maintenance costs.

[2] The Green, Orange and Magenta Books are central government guidance on: the appraisal and evaluation of policies, programmes and projects (Green Book); the management of risk (Orange Book); and policy evaluation (Magenta Book), producing quality analysis (Aqua Book) respectively.
[3] Met Office 'UKCP18 Headline Findings' 2018, Met Office Hadley Centre

- Provides or supports (critical) national infrastructure.

- Involves decisions which will result in 'lock-in' to a particular future (e.g. development and housing policy), or where climate change may lead to irreversible damage (e.g. loss of life or communities, species' extinctions, permanent loss of natural capital).

- Has significant interdependencies with other government activities or the wider economy.

The risks and effects of climate change can substantially impact on the value for money of policies, projects and programmes in ways that can make a difference to decision-making. It may also be possible to build adaptation measures into policy options (see section 4.3.2, Delivering adaptation actions) and this can affect the value for money they offer.

1.2 Key issues to consider when incorporating the impacts of climate change into appraisal

- Uncertainty: there is uncertainty over the future impacts of climate change. This means it is important to both consider and potentially adapt to inevitable and known impacts and consider the risk of uncertain future climate risks, including being flexible in the face of potentially changing risks. Chapters 2 and 5 provide detail on how climate uncertainty can be incorporated into appraisals including considering a range of climate scenarios.

- Thresholds or Tipping points: The consideration of thresholds, or tipping points, is useful, especially given future uncertainty. Thresholds may be triggered by biophysical, engineering, performance or policy factors, resulting in a shift from one state to another. As a result of climate change, there is the potential for very large, abrupt and irreversible large-scale events that may 'tip' the climate or whole earth system beyond the scope of current adaptive capability. However, acting to improve the resilience of policies or projects before certain thresholds or tipping points are reached could lead to higher benefits, lower costs and avoidance of irreversible losses.

- Long-term time horizons: particular attention should be paid to policies, programmes or projects that have long lifespans (e.g. beyond 2035), long lead-in times or result in long-term implications. This is because, despite efforts to mitigate them, the impacts of climate change are likely to escalate and become more uncertain long-term.

- Interconnections: climate risks may ripple out, meaning climate impacts in one sector, place or area may impact others. Appraisal should consider interconnections between climate risks and between sectors, for example, changes to the natural environment, impacts on global supply chains, and risk to infrastructure.

- Early interventions: appraisals should consider whether early action to adapt to climate risks may result in lower costs and/or higher benefits over time. Early interventions may also have additional benefits in reducing the current, not just future, impacts of climate change.

- Lock-in: some actions or decisions today 'lock-in' the potential for future climate risk and are difficult or costly to reverse or change later. This includes decisions or investments that involve a long lifetime, the potential for large future climate risks and a degree of irreversibility. It is important to take an adaptive approach in the design and planning stages, to consider long-term scenarios and to build in flexibility.

Chapter 2: Approach to climate resilient appraisal

This section sets out the approach and step-by-step process to climate resilient appraisal. The guidance does not replace the Green Book approach but rather builds and elaborates on it to explicitly account for the effects of climate change to ensure decisions are resilient to future climate change risks.

2.1 Building on the Green Book

In the standard Green Book approach, the options for a project, policy or programme are developed based on a rationale for government intervention. The costs and benefits of these options are then taken into account in a Value for Money (VFM) assessment to inform a final decision on the preferred option. This may be by constructing a Net Present Value (NPV) or Benefit-Cost Ratio (BCR) to compare options. Finally, the chosen option is monitored and evaluated.[4]

Figure 1. Standard Green Book approach

In practice, economic appraisal which fully takes the effects of climate change into account, builds neatly on the already refined Green Book approach at three key stages:

1. **Developing options – Identifying climate risks and adapting options where necessary**

[4] For further detail on the general appraisal process see the Green Book.

As with the typical appraisal process, policy options are developed based on a rationale for intervention, but, with climate resilient appraisal, an assessment of the potential climate risks is also considered at this stage. Once any risks have been identified, options can be improved and revised to include adaptation measures at the design stage, where net benefits will be highest. These options may involve simple no or low-regret adaptation measures, or those which are more fundamental and address trade-offs to address issues identified in a climate risk assessment.

2. **Appraisal of options - Incorporating Climate Change risks and impacts into the appraisal process**

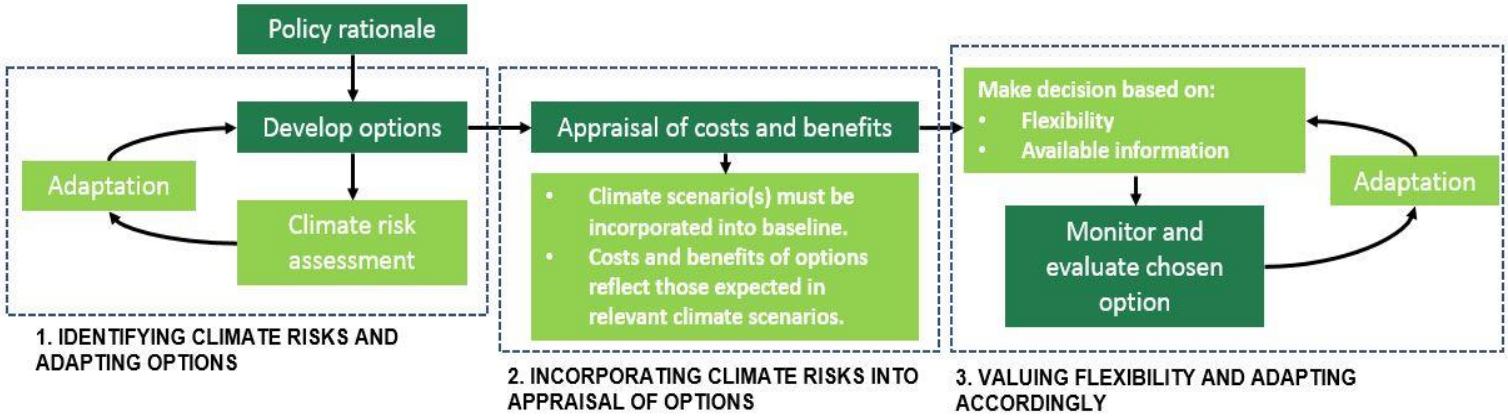
   This means including climate change effects and impacts in the costs and benefits of the shortlisted options for the project, policy, or programme being considered (including the counterfactual baseline). Given uncertainty, it may be necessary, based on climate risk, to consider multiple climate scenarios, where climate change effects and impacts differ. Comparing options with adaptation measures to those without adaptation allows us to recommend options which provide the best overall value given climate risks.

3. **Decision-making, monitoring and evaluation - valuing flexibility and adapting accordingly**

   When making a decision on which option to pursue, some value should be given to options that address uncertainty. This, for instance, may mean that policy options which can flex over time may become relatively more valuable. It may be possible to value such flexibility using quantitative measures as part of the benefits appraisal, but, at the least, the benefits of flexibility should be considered when choosing between final options. As monitoring and evaluation makes the effectiveness of options clearer over time, the more flexible options can be adapted according to changing information.

Figure 2 incorporates these additional elements into the overall appraisal process. This process is explained in detail in the following section.

Figure 2. Building on the Green Book approach to account for climate change

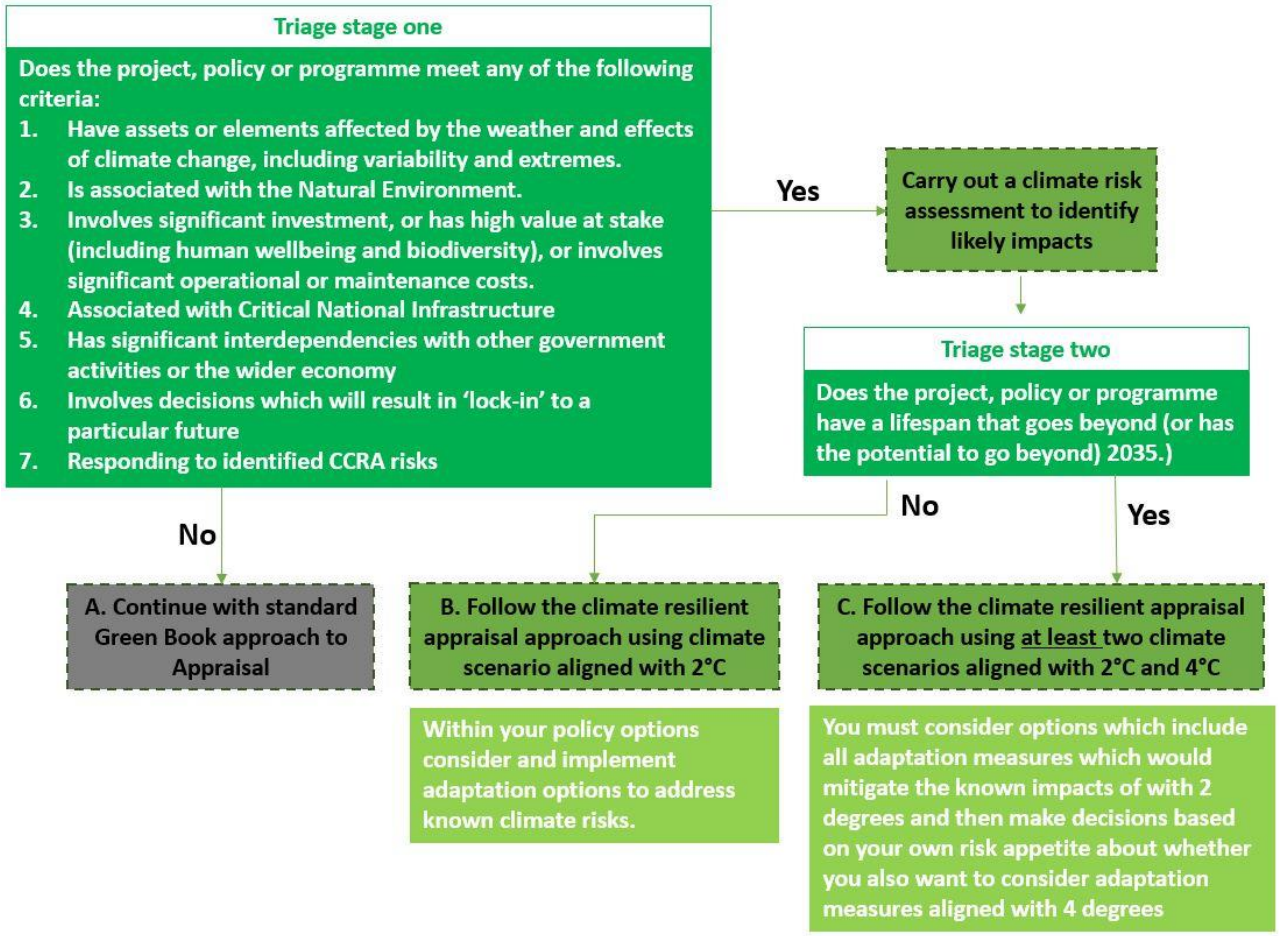


2.2 Step one: Developing options

2.2.1 Identifying climate risk

As with a standard Green Book approach the appraisal process starts with options being developed in response to a rationale for policy intervention. Accounting for the effects of climate change in appraisal should be done in proportionate way. Figure 3 provides a triage decision making tool to identify the minimum appropriate appraisal approach given potential climate risk to the policy/ program. The tool explains the steps for identifying if a Climate Risk Assessment (CRA) is needed and outlines a proportionate approach to incorporating climate scenarios and adaptation measures. More detail on how to conduct a Climate Risk Assessment is set out in Chapter 3. The EA's" "Climate change impacts tool" provides an overview of effects and impacts that should be considered. Information on all major climate change risks in the UK is provided in the UK Climate Change Risk Assessment[5].

Figure 3: Outlining a proportionate approach to accounting for the effects of climate in appraisal



To assist decision makers in making robust plans in the face of future climate uncertainty, the Government commissioned the Met Office to produce the UK Climate Projections

[5] The government's third Climate Change Risk Assessment was published in 2022, informed by the Climate Change Committee's independent assessment published June 2021 The fourth risk assessment will be published in 2027.

(UKCP18) - see also Annex C. Drawing on these projections and other supporting evidence, the Climate Change Risk Assessment (CCRA) sets out the risks and opportunities different sectors face from climate change. The findings and results of these assessments are published every five years and are an essential planning resource for those carrying out climate-related appraisals.

2.2.2 Developing Adapted policy options

Once climate risks and opportunities have been identified, options to adapt to climate risks can be considered. It is possible to refine or re-develop the initial appraisal options to improve resilience to future climate changes. These additional options can then be appraised alongside the initial options. These measures may be designed to alleviate the effects of known climate risks or allow for options to be more adaptable in the face of the resulting effects of a changing climate. It is important that the appraisal impacts of including adaptation measures on original options are made clear. The adaptation measures may, or may not, improve the costs and benefits of the original option. Further detail on how adaptation measures can be developed is provided in Chapter 4.

The proportionate approach set out here demonstrates a minimum requirement. It is important that organisations and individuals take ownership of their own climate risks, and that they demonstrate a clear, evidenced link with policy.

2.3 Step two: Appraisal of options

The potential effects and uncertainty surrounding climate change should be explicitly incorporated into the appraisal process. In practice, this means that the costs and benefits of alternative options should be appraised with one or more (as appropriate) climate scenarios providing a relevant baseline.

2.3.1 Include climate scenario(s) in the baseline

As with standard appraisal, a baseline is needed to measure the costs and benefits of each alternative policy option. Although there may be uncertainty over the types and extent of changes to the UK climate, what is certain is that the climate in the future will be different from the climate today. This means we cannot assume the benefits and costs of continuing along a current policy path will be the same in the future as they are in the present. Likewise, the magnitude of the challenge which a policy seeks to address may be different. We must therefore include changes to our climate within our baseline.

Take the example of considering how to deliver hospital services into the future and assume there are two alternative options, one to build new facilities, another to refurbish existing facilities. Choosing an alternative option is based upon assessment of the costs and benefits of each option compared with continued use of the current infrastructure (baseline). With current climatic conditions we may expect existing systems (roofs, ventilation and heating etc.) to continue to effectively deliver their function for 20 years.

However, evolving changes in climatic conditions, such as increased occurrences of high temperatures and heavy rain, may result in less resilient, ineffective or reduced lifetimes of assets, affecting the relative costs and benefits of policy options. Similarly, the hospital may also need to consider a potential shift in the needs of patients as a result of these changes in climate (the policy challenge). These changing goal posts against which policy impacts are measured must be factored into the appraisal process.

Climate scenarios offer simplified but plausible representations of how the future climate may unfold, based upon past observations and future projections of factors, such as emissions, population growth and energy demand. These can be used to provide the baseline assumptions within appraisal.

Climate uncertainty in the baseline

Whilst it is possible to ascertain a likely set of potential hazards, risks, impacts and even opportunities from each climate scenario, there remains a great deal of uncertainty. This is not least due to, yet unknown, consequences of globally ambitious long-term mitigation targets to reduce emissions and limit global temperature rise, in line with those set out in the Paris Agreement.

To account for future uncertainty in the appraisal of some policies or programs, multiple future climate scenarios should be incorporated to ascertain a robust baseline case.

As the projections suggest relatively small differences between trajectories of each climate scenario out to 2035, policies and programmes with lifetimes within this time horizon need only be appraised against a minimum of one scenario, consistent with a global temperature rise of 2°C, or '2°C' scenario (relating most closely to RCP2.6 in Table 1 below).

Where longer time horizons are needed (i.e. beyond 2035), significant potential differences in climate effects start to emerge between each of the climate scenarios, with no indication of which is more likely than another. It is therefore necessary to appraise using at least two climate scenarios. In practice this means considering a parallel approach in appraisal; one baseline should be consistent with a '2°C' scenario (RCP2.6) and the other appraisal baseline should be consistent with a global temperature rise of 4°C, or '4°C' scenario (RCP8.5). This approach is prudent to uphold the managing public money principles given our current understanding of risks.

Table 1: the projected increase in global average temperature (°C) averaged over 2081-2100 compared to the pre-industrial period (1850-1900) for the Representative Concentration Pathways (RCP) [6]

[6] UKCP18 Guidance: Representative Concentration Pathways. Further information on what the RCPs could mean for variables such as rainfall, seasonal mean temperature, sea level rise can be obtained through the summaries on the UKCP18 Headline Findings and Key Results webpages

RCP	Change in temperature (°C) by 2081-2100
RCP2.6	1.6 (0.9-2.3)
RCP4.5	2.4 (1.7-3.2)
RCP6.0	2.8 (2.0-3.7)
RCP8.5	4.3 (3.2-5.4)

The approach set out here demonstrates a minimum requirement. It is important that organisations and individuals take ownership of their own climate risks. Climate projections draw on a range of possible future scenarios which enable organisations to take decisions about their own resilience actions to suit their situation. Planning for more extreme change (e.g. aligned with H++ scenario[7]) is likely to be appropriate in situations where there are high vulnerabilities, low risk tolerance and long planning or investment cycles.

The use of climate scenarios aligned with global temperature rises of 2°C and 4°C is an approach widely adopted across UK and global government policy. It is also consistent with the advice provided by the CCC's latest progress report[8], the CCRA Evidence Report[9], and the EA's Climate Impacts Tool[10]. By aligning the appraisal method with the available climate science, data and tools, this helps to bridge the gap between the hazards data, which climate projections indicate, and the evidence on resulting risks and impacts needed for ascertaining potential costs.

2.3.2 Including the effects of climate change in appraisal

A climate risk assessment will identify potential elements of the costs and benefits of options which will be affected by changes in the climate under relevant scenarios (see chapter 3). These should be used in the appraisal.

Once the effects of climate change have been included in the baseline as outlined in 2.3.1, the appraisal of the costs and benefits of alternative policy options (including those with adaptation measures) should follow the standard guidance set out in the Green Book. However, the appraisal methods applied to compare options will be context-specific and may, amongst other factors, depend on the extent and type of climate uncertainty. Chapter 5 provides an overview of the potential appraisal methods and techniques that can be used in conditions of uncertainty.

[7] H++ climate scenarios https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/
[8] CCC (2023) Progress in reducing emissions: 2023 Report to Parliament.
[9] CCC (2021) Independent Assessment of UK Climate Risk.
[10] EA (2023) Climate impacts tool: Understanding the risks and impacts from a charging climate.

2.4 Step three: Decision making, Monitoring and Evaluation

2.4.1 Decision making

When final decisions on options are made in the climate resilient appraisal process, the decision rule may need to take a broad approach. In the presence of the significant uncertainty of climate change, a choice made solely on current NPV or BCR may not necessarily be the best one to make in the long run.

Uncertainty over future climate and therefore the requirement to consider appraisal for multiple scenarios may mean it is not clear which policy option is optimal. In this case it is important to consider the benefits of choosing policy options that may be more flexible over time (if the flexibility of benefits has not already been considered in the CBA quantitatively). It may also be appropriate to re-visit policy options and consider further adaptation measures which mitigate significant variability of outcomes under different scenarios.

If it is possible to quantify and weight the relative importance of flexibility, the preferred option can be identified as through a Value for Money (VfM) approach. However, as this will not always be possible, it will be necessary to consider the potential benefits of options which are more flexible but may not (given existing information) deliver the highest VfM. For example, consider two projects to build flood water storage units, A and B, which are almost identical except that A has an option to increase capacity if needed over time and B does not. Even if B appears to represent better VfM now, project A, given its flexibility, may still deliver better VfM over time depending on the duration of the project costs and timings and given future uncertainties. Valuing flexibility will allow for the chosen options to be more robust to potential future climate change risks. However, arguments around future flexibility should not be used spuriously as a justification for ignoring VfM comparisons between options.

Choosing flexible options with adaptation measures allows for an iterative process to improve policy, programmes or projects over time following monitoring and evaluation of the chosen option.

2.4.2 Monitor and evaluate chosen option

Policy evaluation is the systematic assessment of the design, implementation and outcomes of an intervention. It involves understanding how government intervention is being, or has been, implemented and what effects it has, for whom and why. It identifies what can be improved and estimates overall impacts and cost-effectiveness. The Magenta Book contains detailed guidance on policy evaluation.

Evaluating adaptation measures and, more generally, how government policies or investments are affected by climate change will often be complex, with a range of interconnected social, economic and environmental factors that need to be considered. In

the context of uncertainty over future levels of emissions and, therefore, climate change, it is especially important to continually monitor and evaluate relevant policies or programmes to assess whether or not they are delivering target outcomes. It is important to learn from evidence on existing and pilot interventions to develop new policies and approaches, and ways of best assessing their performance. It is also important that sufficient monitoring data is being captured across climate interventions to assess policy performance using the most up to date climate trajectories.

2.4.3 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 used to assess how a measure has performed against:

- Economy. Has the measure reduced the cost of resources used or required?
- Effectiveness. Has the measure achieved the desired outcome? Have there been unintended consequences, or maladaptation? Was there sufficient flexibility?
- Efficiency. Did the benefits outweigh the costs? Would the decision have been different if today's information had been available when the decision was taken?
- Equity. Did the measure impose significant disproportionate costs on individuals or groups?

Evaluation to improve policies should be a continuous process at all stages of a project lifecycle (as demonstrated by ROAMEF).[11]

2.4.4 Setting milestones to review options

When appraisal decisions are made, it is also important to decide on future or long-term milestones to review the policy, project or programme. For example, once updated information on climate risks becomes available, check whether the chosen options are still appropriate or require adjustment. Factors that may influence points at which to evaluate progress include:

- The provision of new climate information or tools (such as new climate projections or EA's flood risk maps). This may occur at regular intervals.
- The availability of new research. For example, new research may resolve uncertainty about the effectiveness of an adaptation measure.

[11] HMT 'Magenta Book' 2020

2.4.5 Adjusting chosen options

Once new climate information becomes available, the project, policy or programme should be reviewed proportionally.

For example, the Thames Estuary 2100 Plan (Box 1) considers a set of 10 indicators of climate change. One such indicator is sea levels and this is monitored routinely across the plan's lifetime. Following review of sea levels, the strategy, if required, is modified in light of new information.

It is important to note the climate resilient process set out in the diagram in Figure 2 does not capture the process when more fundamental changes are required. For example, it may be the case that in light of new information simply adapting chosen policies, programmes or projects is not sufficient. New evidence on climate change risks may require either re-appraisal of selected options or even developing new options entirely.

Box 1: Case Study Example: Climate Resilient Appraisal – Thames Estuary 2100 Plan

The Environment Agency's Thames Estuary 2100 Plan for tidal flood risk management in the Thames Estuary to the year 2100 is a good example of how climate resilient appraisal has been applied. This is set out in detail in Annex A but a brief outline of the process is given below.

- The **policy rationale** for the Thames Estuary plan was identified around ensuring there is sufficient tidal floor risk management in the Thames Estuary to 2100.
- **Assess the climate risks**: focusing on mean sea level rise and storm surge behaviour, the project developed a range of climate scenarios, derived from work done by UKCIP and others.
- **Adaptation measures** were considered to mitigate the climate risks by ensuring options could deal with e.g. differing levels of extreme water level rises.
- **Appraisal of options** was conducted using Cost-Benefit Analysis (CBA) under a central sea level rise scenario but also considering other scenarios as part of sensitivity analysis to ensure options were robust to different states of the world. Multi-Criteria Analysis was also used to ensure a wide range of climate change impacts were accounted for in the CBA.
- **A decision was made** based on the highest Benefit-Cost Ratio given current knowledge of the most likely climate scenario.
- **To monitor and evaluate the option** a set of key climate change indicators are used for routine monitoring, milestones are set and a formal review of the indicator trends is carried out every 5 years.

Chapter 3: Identifying and accounting for climate change risks

3.1 Conducting a risk assessment

As outlined Figure 3 a full climate change risk assessment should be conducted if the criteria have been met. Risk assessments will help identify the likelihood and magnitude of a climate triggered event, including economic damage, social disruption, human illness or injury, and fatalities. Hazard, exposure, vulnerability and adaptive capacity should be considered when identifying climate change impacts on policies, programmes and projects.

- Hazard: the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.[12]

- Exposure: The presence (of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets) in places and settings that could be adversely affected.[13]

- Vulnerability: the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of elements including sensitivity or susceptibility to harm. For example, temperatures above a certain level may damage road surfaces. Therefore, a road surface in direct sunlight is more vulnerable to higher temperatures than a road surface in shade.

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

A climate risk assessment should take a structured approach, and can use tools such as the Environment Agency's Impacts tool[13] to start discussions or in early planning stages. It is important, however, to be aware of the limitations of each tool, and when each tool should be used within the planning process. For example, the Environment Agency's tool offers a starting point for understanding risk during initial considerations, but would need to be followed by a more in-depth risk assessment for subsequent detailed risk analysis and adaptation assessment. It describes the potential challenges that could be faced in England in the present, in the 2050s and the 2080s to the upper limit of a 4°C change.

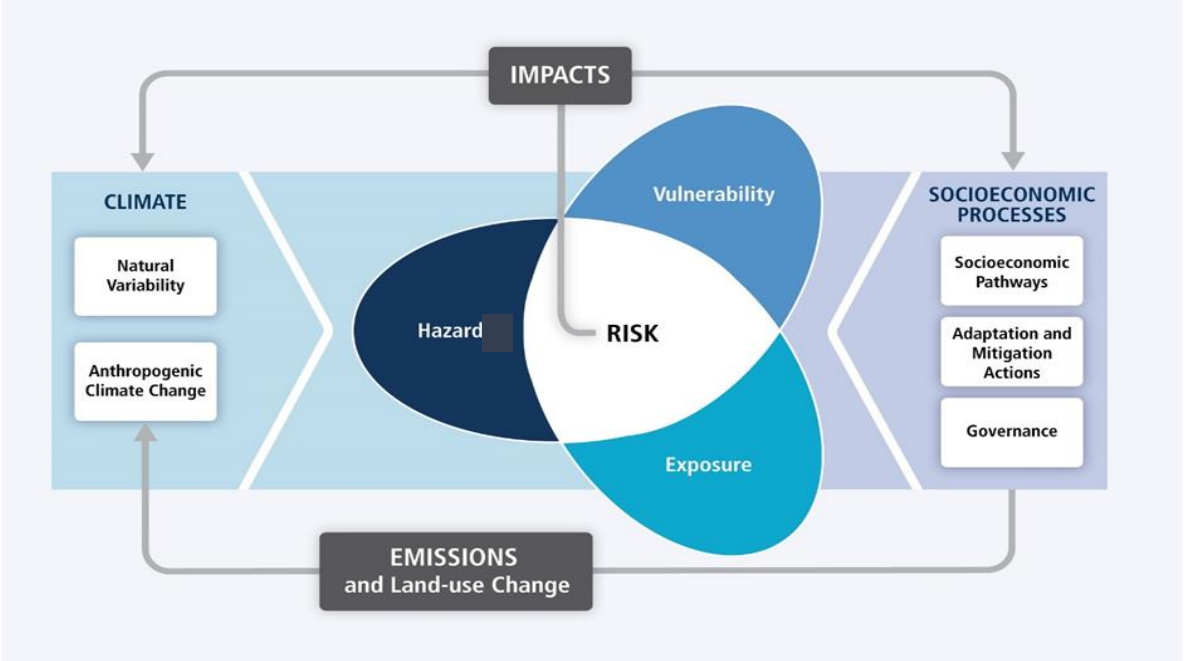
[12] Source: IPCC, AR6 https://www.ipcc.ch/assessment-report/ar6/

[13] Published 2023 this tool is based on UKCP18 data.

However, it does not replace the need for a more detailed risk assessment when undertaking more detailed options appraisal

Early stages should focus on identifying potential climate risk, if applicable, and how risks could affect activities, projects, design, implementation and/ or functions. Once these are identified, a more detailed risk analysis should explore how climate risks are transmitted to impact the policy, programme or project. Risks can be also be factored into project or activity design without a formal risk assessment.

Figure 3: Core concepts of climate change risk



Source: Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5) Climate Change 2014: Impacts, Adaptation and Vulnerability, Summary for Policymakers

3.1.1 Direct and indirect effects

Changes to our climate will affect people, the environment and different parts of the economy in different ways, so risk assessments should consider sensitivities, direct and indirect effects:

- Sensitivity: the degree to which a system is affected, either adversely or beneficially, by climate change or climate impacts. The effect may be direct or indirect.

- Direct effects: when an area of the economy, project design or operation, or activity is directly affected by climatic change. Where there are direct effects, failure to account for projected changes in climate is likely to lead to significant future costs such as damages or losses and/or retrofitting or early replacement.

- Indirect effects: when an area of the economy, a project or an activity is impacted – and potentially required adaptation – as a result of climate change and climate impacts in a different country, area or sector.

Box 2: Examples of potential direct and indirect effects of climate change within the UK

Flooding

- Direct effect: flood events can have a direct effect on health through physical injuries caused by falling into fast-flowing water, from hidden dangers under the water, such as missing manhole covers, or drowning.
- Indirect effect: indirect effects from flooding include electrocution, damage to health infrastructure, water and electrical supplies and the displacement of people and disruption to their lives.

Extreme weather (e.g. storms)

- Direct effect: coastal-based infrastructure, such as railway lines or roads might be subject to erosion, washed away, damaged signals or earthworks.
- Indirect effect: disruption to labour movement could result in economic losses for shops, businesses and the public sector, disrupted access and mobility of emergency services results in extended response times.

Source: National Adaptation Programme (2013)

3.1.2 Other important factors

When conducting a risk assessment, other important factors to be aware of include:

- Timing: attention should be paid to activities that have long-term time horizons, life-times, or implications. This may also include decision lead times. For example, when making decisions to build infrastructure, this lead-time needs to be considered, and there is often a need to start planning in advance, i.e. so the investment can be made in sufficient time before major impacts or a threshold is reached.
- Tipping points (and thresholds): a climate tipping point is a critical threshold where the climate changes from one stable state to another stable state. These can involve biophysical, engineering, performance or policy threshold (or tipping points), above which much larger impacts occur. Acting to improve the resilience of policies/project before certain thresholds or tipping points are reached could lead to higher benefits and lower costs.

- International effects: events elsewhere in the world triggered by climate change could have effects on activities that operate solely within the UK.
- Irreversibility: given uncertainty over the future climate, decisions that would be difficult or expensive to revise in future should receive additional scrutiny.

3.1.3 Examples of potential climate change risks

The most recent Climate Change Risk Assessment (CCRA), published in 2022, identified 61 key climate risks to the UK. The CCC's independent advice report further identified eight climate change risks for priority action in the UK (Figure 4) and assesses their urgency. These eight areas can be used in the first instance to give an indication of the potential climate change risks that are relevant to any options considered for a policy, programme or project and where possible the full list of risks should be consulted. It is important to note that these eight areas are not an exhaustive list of climate change risks and that other relevant risks should be considered on a case-by-case basis during the appraisal process.

Figure 4: Eight highest priority areas for adaptation in the UK.

Source: CCC
Notes: Figure shows the changing magnitude over time of the risk areas that require the most urgent action in the next two years. Change in magnitude is shown up to 2100 for the highest scenario assessed in the Technical Report for the relevant risks for that theme. Details are set out in an accompanying Annex to this report.

Source: The CCC's Independent Assessment of UK Climate Risk 2021

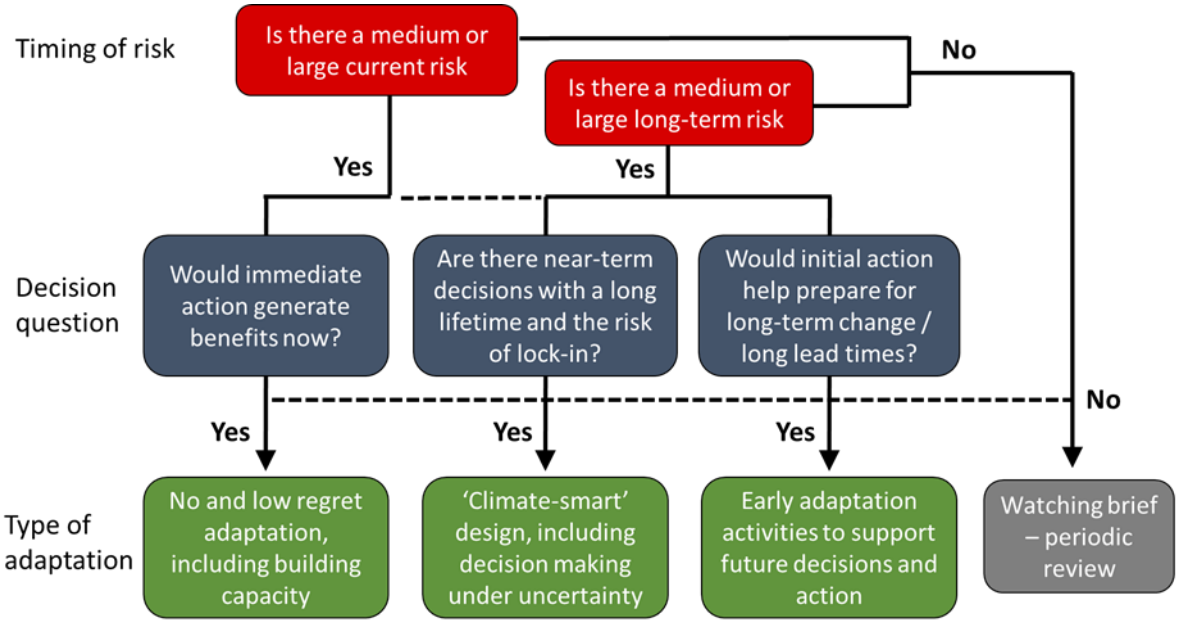
Chapter 4: Developing and refining options under climate risks and uncertainty

Action to reduce risks from climate change is called adaptation. Once climate risks have been identified, the next step is to design adaptation options to reduce risks from climate change. Adaptation measures should be aimed at adjusting an activity to account for the effects of climate change, or address market failures that provide barriers to individuals and organisations adapting in a socially optimal way to account for climate change effects.

4.1 Principles of adapting to climate change

Decisions relating to adaptation should take account of the magnitude of risk, but also the urgency of the risks. This means different adaption actions may be appropriate depending on the decision context. Figure 5 provides an illustrative decision-making process for considering different adaptation needs. In some cases adaptation measures should be combined together as part of an adaptive management pathway. Adaptation plans should consider longer term potential impacts or risks as appropriate (Box 3).[14]

Figure 5: Illustrative decision-making process for prioritising adaptation



Source: CCRA (2017), adapted from Fankhauser (2013) An Independent National Adaptation Programme for England

Source: Environment Agency's Draft National Flood (2019)

[14] Environment Agency 'Draft National Flood and Coastal Erosion Risk Management Strategy for England' 2019, Environment Agency, Rotherham

Well-designed adaptation measures should in most circumstances:

- not foreclose future options or unnecessarily constrain future choice;
- be efficient, effective and equitable under the widest set of all plausible futures;
- enable appropriate modification of polices, plans and projects as the reality of the future becomes known;
- Account for the potential impacts of adaptation across different groups and ensure that the reduction in social damage from adaptation justifies the costs of implementing the measure.

Box 3: The need for long term approaches to climate change – Humber flood risk management strategy

The Humber estuary is home to over half a million people and tens of thousands of businesses. It includes transport infrastructure, well-established chemicals and manufacturing industries, key ports such as Hull, Grimsby, Immingham and Goole.

The Environment Agency, Humber Local Enterprise Partnership (LEP) and 12 local authorities are working together to review the current Humber Flood Risk Management Strategy in order to help ensure the long term resilience of the estuary.

The estuary is exposed to river flooding risks and rising sea levels. By 2021, over £150 million will be invested in flood defence improvements to better protect over 70,000 properties.

The Humber strategy will draw out a number of trigger points at which difficult decisions need to be taken, allowing for implementation before they are needed.

4.2 Approaches to good adaptation

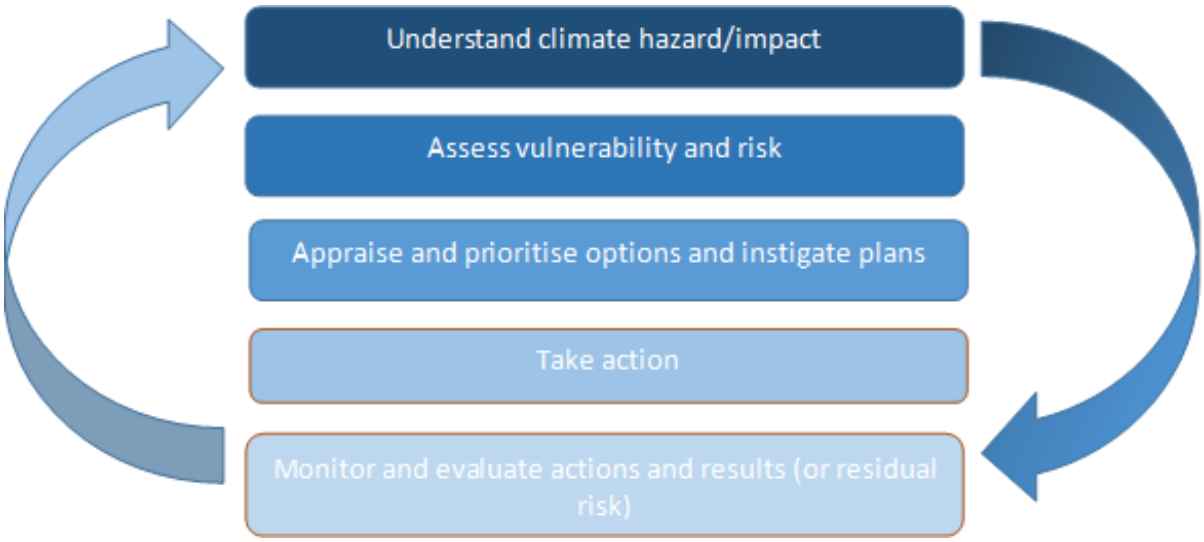
Approaches that promote an iterative approach or process promote good adaptation by addressing uncertainty over future climate change. An iterative approach benefits from being able to respond to changing information about risks. For example, information about flooding and coastal change is not static but constantly changing.

4.2.1 Identify no and low-regret and win-win measures.

An early priority is to identify possible ‘no-regret’ or ‘low-regret’ adaptation actions that reduce risks associated with current climate variability, as well as building future climate resilience. No-regret adaptation is defined as options that ‘generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs’. A variation of no-regret options are win-win options, which are options that have positive co-

benefits, which could include wider social, environmental or ancillary benefits. These are differentiated from low-regret options, which may have low costs or high benefits, or low levels of regret, or may be no-regret options that have opportunity or transaction costs in practice.

Figure 6: Iterative Process to Strengthen Resilience and Adapt



Source: Original, adapted from US Climate Resilience Toolkit

4.2.2 Adaptive management approaches

For many types of adaptation decisions, where there are long life-times associated with decisions, and especially the risk of lock-in or long lead times, then future climate change considerations and uncertainty become relevant. In these cases, adaptive management approaches, also known as iterative risk management or adaptive pathways, promote a process of good adaptation. This can allow a project, policy or programme to respond over time, incrementally, adjusting with new information and experience. Given the high uncertainty over the future impacts of climate change, this ability to adapt to changing risks is important. Pathways approaches have a number of benefits. They can sequence adaption over time, combining options as needed. They can also be used as decision support tools, particular when looking at long-term problems (such as TE2100) and the need to keep future options open in order to respond appropriately as the future develops. These pathways approaches often identify future thresholds. These are known as adaptation tipping points and relate to points beyond which a particular action is no longer adequate for meeting a plan's objectives and a different option or strategy is required.

The EA's National Flood and Coastal Erosion Risk Management Strategy lists the following potential benefits of adaptive pathways:

- Enable active collaboration with local communities and partners
- Unlock relationships with partners to fund FCERM investment
- Alignment of capital investment programmes with transport and utilities

- Influence long-term strategic and resilient place-making
- Better data, modelling and monitoring of climate change impacts
- Regular review to check the 'right pathway' is being followed

Many organisations are incorporating elements of adaptive approaches into their climate change adaptation measures. The Environment Agency's Thames Estuary 2100 plan uses an adaptive pathways approach to incorporate climate change into decision making. This plan identifies a series of approaches or options for different climate change, social and economic futures and is adaptable to a changing climate. See Annex A for a full case study on the Thames Estuary 2100 plan. Highways England also incorporated climate change into decision making using elements of an adaptive pathways approach when making the A1 more climate resilient (box 4). Network Rail's Weather Resilience and Climate Change Adaptation (WRCCA) decision making tool also incorporates elements of an adaptive pathways approach (box 5). They have also produced guidance for an adaptation pathways approach.

Box 4: Incorporating climate change into decision making – Highways England

Improving resilience to flooding and reducing flood risk is a key area for the Highways England Environment Designated Fund. In September 2012, a flood in Catterick, North Yorkshire affected 130 properties and caused the A1, one of England's main north-south routes, to be closed for 2 days.

The objective of the project, from a transport perspective, was to minimise the traffic disruption from flooding. In the appraisal, options for the scheme assumed appropriate design of drainage. Risks associated with weather events that could lead to flooding were given values during the appraisal and integrated into the scheme. Further assessment through a flood risk analysis (which included an allowance for climate change) clarified the vulnerability of both A1 and parts of Catterick to flooding.

A key element of the solution brought together funding from Highways England Environment Designated Fund, the Environment Agency, Local Levy and North Yorkshire County Council to provide better flood protection. This included the creation of an innovative new flood storage reservoir which was officially opened in April 2018. This reservoir helped to slow the flow of Brough Beck, which floods in severe weather, by adding meanders to the Beck and creating a control structure incorporating 'hydro-brakes' to control the flow of water. In all, the flood scheme can hold 91 million gallons of water, equivalent to more than 130 Olympic swimming pools, in times of flood.

As well as reducing the risk of flooding to the highway and 149 properties, more than 5 hectares of new habitat were created including wetland and grassland habitats, adding additional natural capital benefits.

Box 5: Network Rail's Weather Resilience and Climate Change Adaptation (WRCCA) Decision Making Tool

The WRCCA Decision Making Tool enables the analysis of mitigated and non-mitigated design options for schemes with weather and climate vulnerabilities. It ensures that options can be assessed and prioritised based on their financial and economic returns, accounting for the future costs avoided by adaptation.

The tool is constructed to be able to consider the whole life of the asset so it can also facilitate the consideration of schemes that do not have a financial return within the control period in which they are implemented, or which have a return in social welfare terms.

Network Rail suggest the tool should be used in conjunction with the related guidance notes – 'Weather Resilience and Climate Change Impact Assessment' and 'Climate Change Projections and Frequencies'.

4.3 Designing adaptation interventions

4.3.1 Setting out the justification and the case for adaptation

As with any policy intervention setting out the economic rationale for adaption measures is important as there are often barriers that make it difficult to plan for and implement them. These include economic, political economy and governance barriers, arising from market, information, policy and government failures[15]. Identifying such barriers and how to overcome them to build up the rationale for adaption is therefore useful.

4.3.2 Selecting adaptation interventions

Having identified the need for adaptation, the next step is to identify the most appropriate type of adaptation. Selecting adaptation interventions involves taking practical actions to either reduce vulnerability to climate risks, or to exploit positive opportunities. These may range from simple low-tech solutions to large scale infrastructure projects. Adaptation interventions or actions can include those listed below. These actions are not mutually exclusive as a mix of measures may be appropriate. For example, a strategy to reduce overheating in buildings may include installing external shading such as shutters to prevent overheating (preventing losses or reducing consequences) and insurance against damage from overheating (sharing risks). Adaptation measures should deliver adaptation actions by:

[15] Cimato and Mullan, 2010

- 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[16] or transfer them to others
    - Diversifying can help reduce dependency on any one outcome
    - Ensuring 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. Examples include the construction of a new sea wall to protect a stretch of railway from flooding and the potential for an increase in extreme weather events under the Dawlish Warren Railway Management Scheme in 2017. See box 7 for more detail on the appraisal approach for Dawlish.
    - Measures to enhance resilience to reduce consequences and impacts, and shorten recovery time
    - Avoiding impacts by changing the 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 Heatwave Plan for England (box 6).

[16]Environment Agency 'Dawlish Warren beach management scheme' 2017, Environment Agency, Rotherham

- Exploiting opportunities
    - Taking advantage of potential positive impacts of climate change, such as longer growing seasons and areas that are able to grow different crops.
    - Identifying win-win adaptation measures that provide additional climate and non-climate benefits.

Box 6: Responding to Climate Change – Heatwave Plan for England.

Climate change has increased the frequency and likelihood of heatwaves - periods of very high temperatures. Following the 2003 UK Heatwave which resulted in more than 2000 excess deaths, Public Health England 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:

    1. Summer Preparedness and Long-term Planning
    2. Alert and Readiness. Triggered when temperatures forecast to exceed thresholds.
    3. Heatwave Action. Triggered when temperature thresholds are exceeded.
    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.

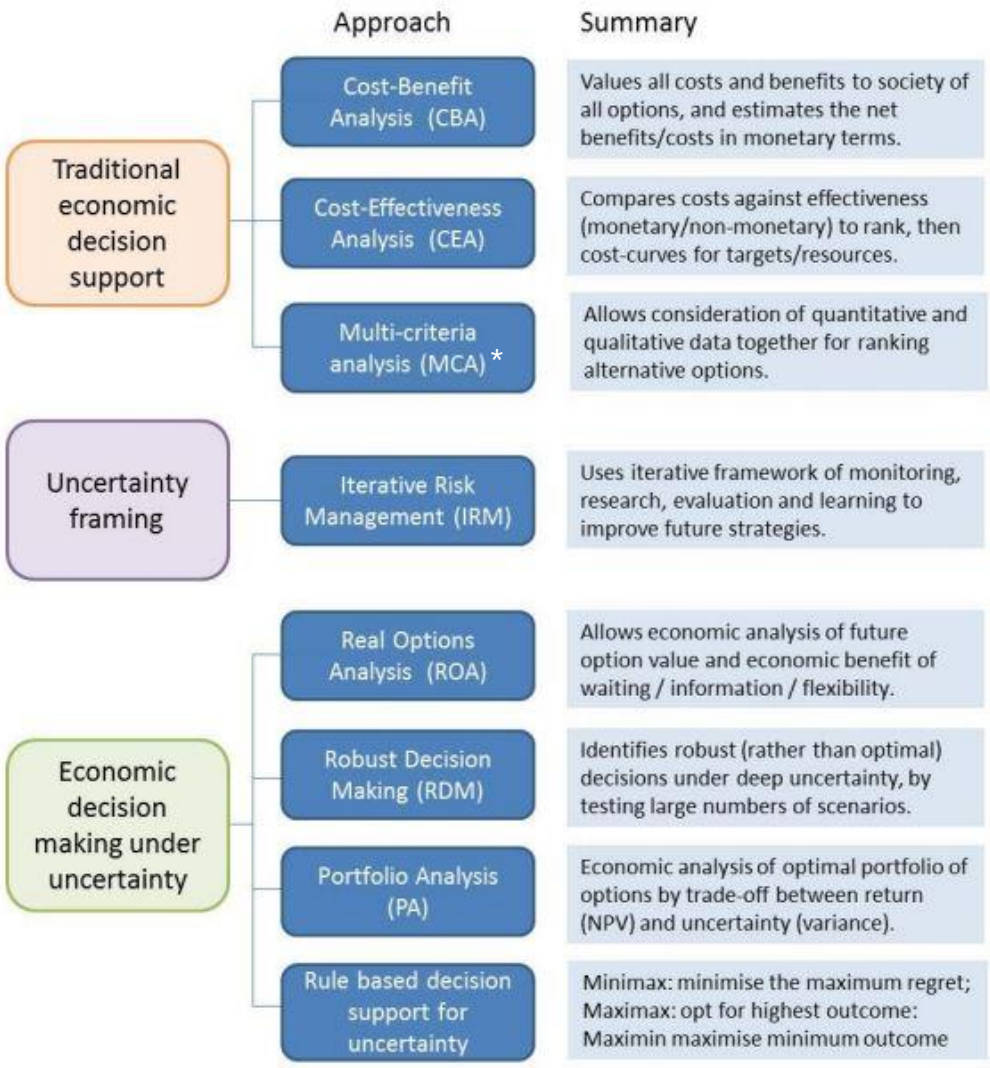
Chapter 5: Further Appraisal methods under climate uncertainty

5.1 Appraisal methods under climate uncertainty

Appraisal can be particularly challenging when there are elements of uncertainty. A number of techniques can be used to handle uncertainty. This chapter provides an overview of potential approaches that can be used to address uncertainty as well as further information on types of climate uncertainty.

Figure 7 sets out a list of decision-making tools that can be used to evaluate options as part of the climate resilient appraisal process. This includes traditional economic decision-making tools such as Cost-Benefit Analysis but also techniques which are suited to taking uncertainty into account such as Real Options Analysis. The appropriate tool will depend on policy, programme or project being appraised, although other options should be considered as additional or supplementary to standard cost-benefit techniques.

Figure 7: Potential Methods for Climate Resilient Appraisal



*MCA being phased out by HMT to be replaced by Multi-criteria Decision Analysis (MCDA)

Source: Watkiss and Cimato (2016)

Box 7: Scenario analysis: Dawlish station to coastguard's ramp resilience

Dawlish Station to Coastguard's Ramp is a section of railway between Exeter and Newton Abbot, in the South West of England. In the past, this section of the railway line has been susceptible to significant damage and disruption during extreme weather events, resulting in instances of the track being washed away and other localised damage, including landslides. The Department for Transport (DfT) and Network rail have jointly conducted an economic appraisal of the costs and benefits of an infrastructure scheme to mitigate these impacts and the growing threat they pose due to climate change.

Three climate scenarios were built into the capital appraisal to account for the potential effects of climate change; Low, Central and High. These three scenarios were comprised of four individual parameters:

1. Base level of disruption – the assumed 'base level of disruption' experienced to date, based on recent weather events.

2. Expected reinstatement costs – the expected cost of unanticipated major works following disruption events, resulting in closure of the railway.

3. Emissions scenarios – projections of future emissions from Met Office which are believed to drive climate change impacts such as sea level rises.

4. Impact of resilience assets on disruption – the proportion of costs avoided as a result of implementing the infrastructure scheme, predominantly reliant on Network Rail judgment.

The development of these scenarios facilitated the consideration of a wider range of potential future cost and benefit outcomes than would be achievable using a conventional appraisal process. In turn, this gave a greater degree of confidence that the results of the appraisal adequately reflected the uncertainty surrounding climate change and any potential impacts it could have on the rail network in Dawlish.

5.1.1 Types of uncertainty and climate change

Uncertainty is always a consideration for policy makers and supporting analysts. Broadly, there are three classifications of uncertainty: aleatory, epistemic and ontological.

Aleatory or random uncertainty is sometimes referred to as the 'known unknown'. Within the context of climate change, this might include the natural variability of the climate. Whilst aleatory uncertainty can be quantified, it can never be completely removed. Quantification might be carried out by deriving a probability function. If that is not possible, it is likely the uncertainty is epistemic.

Epistemic uncertainty is likely to be the largest source of uncertainty in any climate change risk assessment. It comes from a lack of knowledge or limited data. Epistemic uncertainty might result from a lack of knowledge about the input parameters or the structure of climate models. Sensitivity analysis is a good way of testing the effects of various assumptions on model outputs.

The third type of uncertainty is ontological. This type of uncertainty relates to unexpected or unforeseeable conditions, for example, future events that might render the analysis meaningless. Within the context of climate change assessments, this might include global economic shocks or large-scale natural disasters. Ontological uncertainty cannot be quantified but horizon-scanning exercises can help to identify potential sources.

Analysts should always try to explicitly state where uncertainty is prevalent, even if they cannot quantify it.

5.1.2 Overview of appraisal techniques under uncertainty

The appropriate appraisal method to apply as part of climate resilient appraisal should be decided on a case by case basis.

The ECONADAPT Toolbox provides a good starting point to decide on the appropriate methods to address climate uncertainty. The ECONADAPT research project aims to support adaptation planning by building the knowledge base on the economics of adaptation to climate change and converting this into practical information for decision makers.

This toolbox includes a list of some of the commonly used appraisal methods ranging from Cost-Benefit Analysis to Real Options analysis. These appraisal methods, examples of the types of appraisal options and common applications as well as whether they are able to address climate uncertainty are shown in Table 2 below.

It is important to note this is not an exhaustive list of methods but provides a comprehensive overview of potential techniques that can be applied and is good starting point to decide on how best to appraise a policy, programme or project.

Table 2: Potential appraisal techniques for climate resilient appraisal

Method	Well suited for	Common applications	Dealing with uncertainty
Cost-Benefit analysis	• Low and no regret options in the near future • Where clear market values can be used	• Agriculture • Forestry • Energy • Water and coastal management • Transport	• Does not explicitly deal with uncertainty • Can be combined with sensitivity testing and probabilistic modelling

Method	Well suited for	Common applications	Dealing with uncertainty
Cost-effectiveness Analysis	• Short-term options • Where benefits should be examined in non-monetary terms • Where pre-defined objectives must be achieved	• Health • Civil protection • Biodiversity protection	• Does not explicitly deal with uncertainty • Can be combined with sensitivity testing and probabilistic modelling
Real Options Analysis	• The appraisal of large capital investment over the medium term • Where information on climate risk probabilities is available • When future changes in operation are possible	Few applications exist, but include: • Construction • Regional planning • Energy • Forestry • Agriculture	• Deals explicitly with uncertainty by analysing the performance of options for different potential futures
Robust Decision Making	• The appraisal of investments over long time-scales • Where large uncertainties exist • Where a mix of quantitative and qualitative information needs to be considered	Few applications, but these include: • Water and coastal management • Agriculture • Energy • Health • Construction • Civil protection	• Deals explicitly with uncertainty by using a maximum-minimum approach to assess options under a wide range of possible climate scenarios (quantitatively or qualitatively) • Analyses the performance of options for different potential futures
Iterative Risk Management	• Policy appraisal over medium-long-term • When there are clear risk thresholds	• Water management • Coastal management • Agriculture • Health • Forestry	• Deals explicitly with uncertainty • Promotes iterative analysis, monitoring, evaluation and learning
Portfolio Analysis	• When a number of complementary adaptation actions are possible • When good economic and climate information exist	Few applications, but these include: • Water and coastal management • Forestry • Health • Fisheries • Agriculture • Biodiversity protection	• Deals explicitly with uncertainty • Examines the complementarity of adaptation options for dealing with future climates
Multi-Criteria Decision Analysis	• Scoping options • Where a mix of quantitative and qualitative data needs to be considered	• Water and coastal management • Agriculture • Biodiversity protection	• Can integrate uncertainty as an assessment criterion • Relies on subjective expert judgement or stakeholder opinion where empirical data are not available.

Source: ECONADAPT Toolbox

5.3 Appraisal in practice

In practice, it will not always be possible or appropriate to apply the principles of the climate resilient appraisal approach outlined in Chapter 2. This could be due to:

- **Proportionality.** When undertaking climate resilient appraisal, it is important to apply the principles proportionately.
- **Operating in a 'second-best' world.** In some cases it will not be possible to use the climate resilient approach due to significant information or data limitations.

The following sub-section covers the light-touch appraisal techniques which may be either more appropriate to apply or constitute a next-best alternative.

5.3.1 Light-touch appraisal techniques

A light-touch version of an appraisal technique maintains the concept of climate resilient appraisal but either simplifies its application or applies the key principle of the method.

Again, it is important to note that a form of Cost Benefit Analysis should be undertaken in appraisal and that other techniques should be considered to be supplementary.

Examples of light-touch appraisal methods are given in Table 3 below.

Table 3: Light-touch appraisal methods to address climate uncertainty

Appraisal under uncertainty method	Light-touch version
Real Options Analysis	• Apply decision-tree structures to think through a dynamic decision problem qualitatively • Trace out possible outcomes and decision points to help make dynamic choices
Robust Decision Making	• Apply concepts of robustness testing when assessing options • Limit uncertainty to particular aspects of climate uncertainty e.g. uncertainty from climate models • Consider options against uncertainty by using expert opinion e.g. through workshops with key stakeholders
Portfolio Analysis	• Consider a portfolio of options
Iterative Risk Management	• Focus on evaluation and learning when assessing longer term options

Source: Adapted from Watkiss and Cimato (2016)

Annex A: Climate resilient appraisal example

Case Study: Thames Estuary 2100 Plan

The Environment Agency's Thames Estuary 2100 Plan (The Plan) is developing a strategy for tidal flood risk management in the Thames Estuary 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. The Plan has developed an adaptive approach in order to manage the uncertainty in future effects. From initial assessment it was clear that climate would play a significant factor in the policy. EA therefore considered several different climate scenarios consistent with the level of risk exposure and impact of climate on the program.

The approach to building climate change impacts into the Thames Estuary 2100 Plan is set out as follows:

Stage 1: Assessing climate risks

The starting point 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, the project developed a range of climate 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[17], 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.

The Plan bases its recommendations on the "most likely" scenario, but also includes options for managing the worst case scenario "High Plus Plus". Changes to the scenarios are considered at routine intervals when the Plan is reviewed.

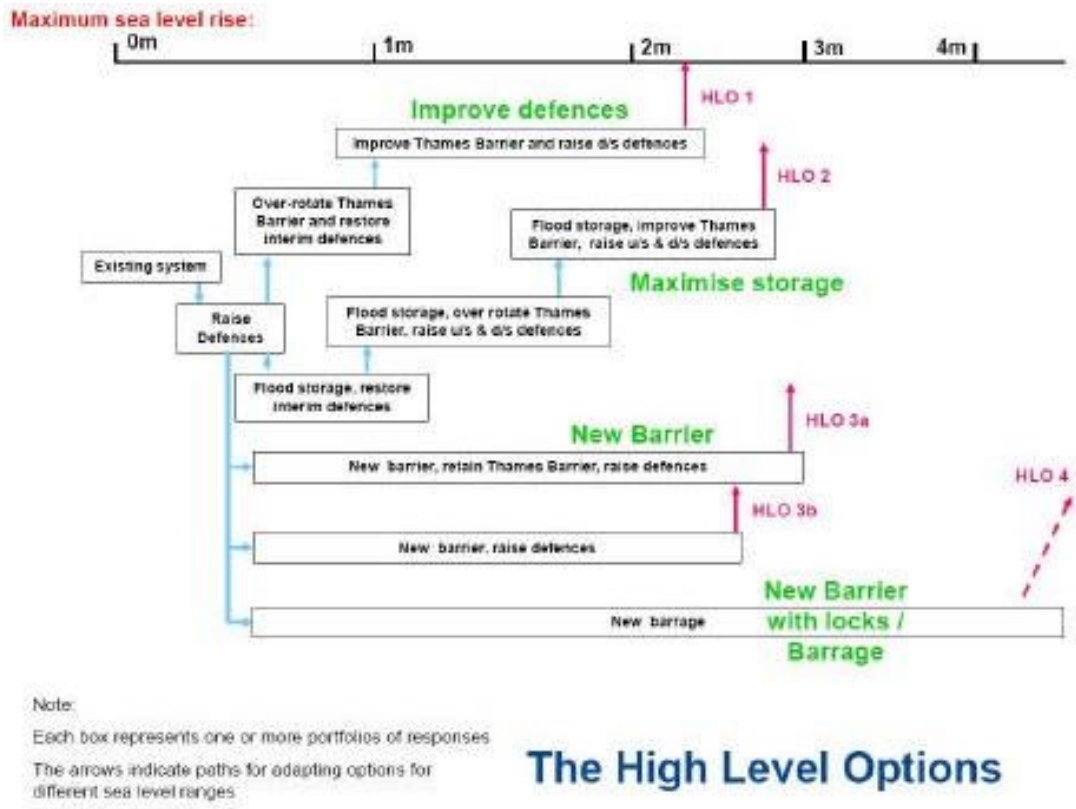
Stage 2: Designing adaptation options

The 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 Estuary, and

[17] Defra 'Flood and Coastal Defence Appraisal Guidance, FCDPAG3 Economic Appraisal; Supplementary Note to Operating Authorities – Climate Change Impacts' 2006, Department for Environment, Food and Rural Affairs, London

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 10: Development of TE2100 High Level Options



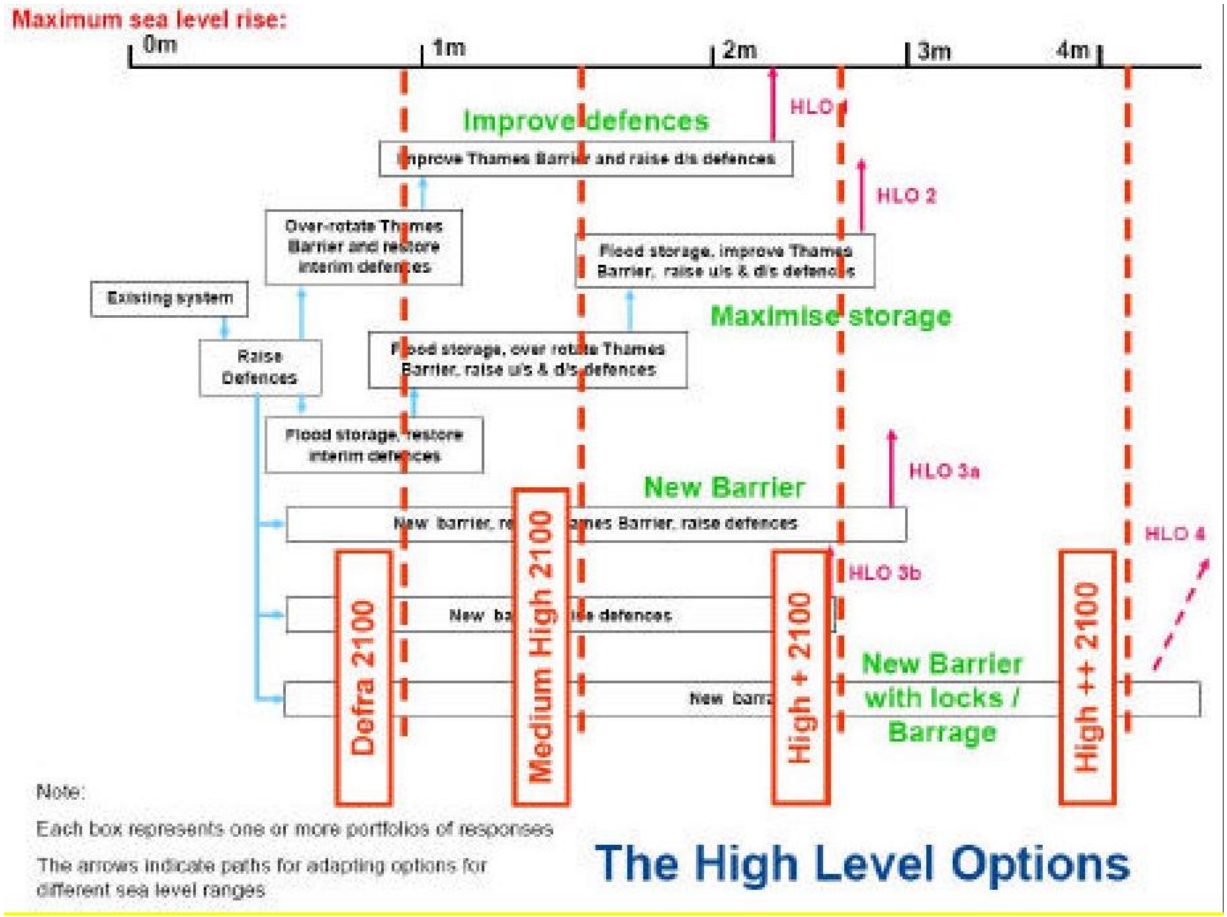
In Figure 10 above, each box represents a portfolio, and combinations of portfolios are assembled to produce the High Level Options 1-4. It can be seen that High Level Option 1 (improve defences) can cope with up to about 2.3m of water level rise, whereas High Level Option 2 (maximise flood storage) and High Level Option 3 (new flood barrier) allow adaptation to slightly higher levels. The ultimate solution would be High Level Option 4 (tidal barrage), which can deal with in excess of 4.5m of water level rise.

The climate scenarios can then be introduced to determine which Options are able to deal with which scenario. This is shown in figure 11 below, where the predicted water levels in the year 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 scenarios, but only High Level Options 2, 3 and 4 can deal with a “High Plus” scenario. Ultimately, only High Level Option 4 (a tidal barrage) could deal with a “High Plus Plus” case.

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 12 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 14 at the end of this case study.

Figure 11: High Level Options and climate scenarios



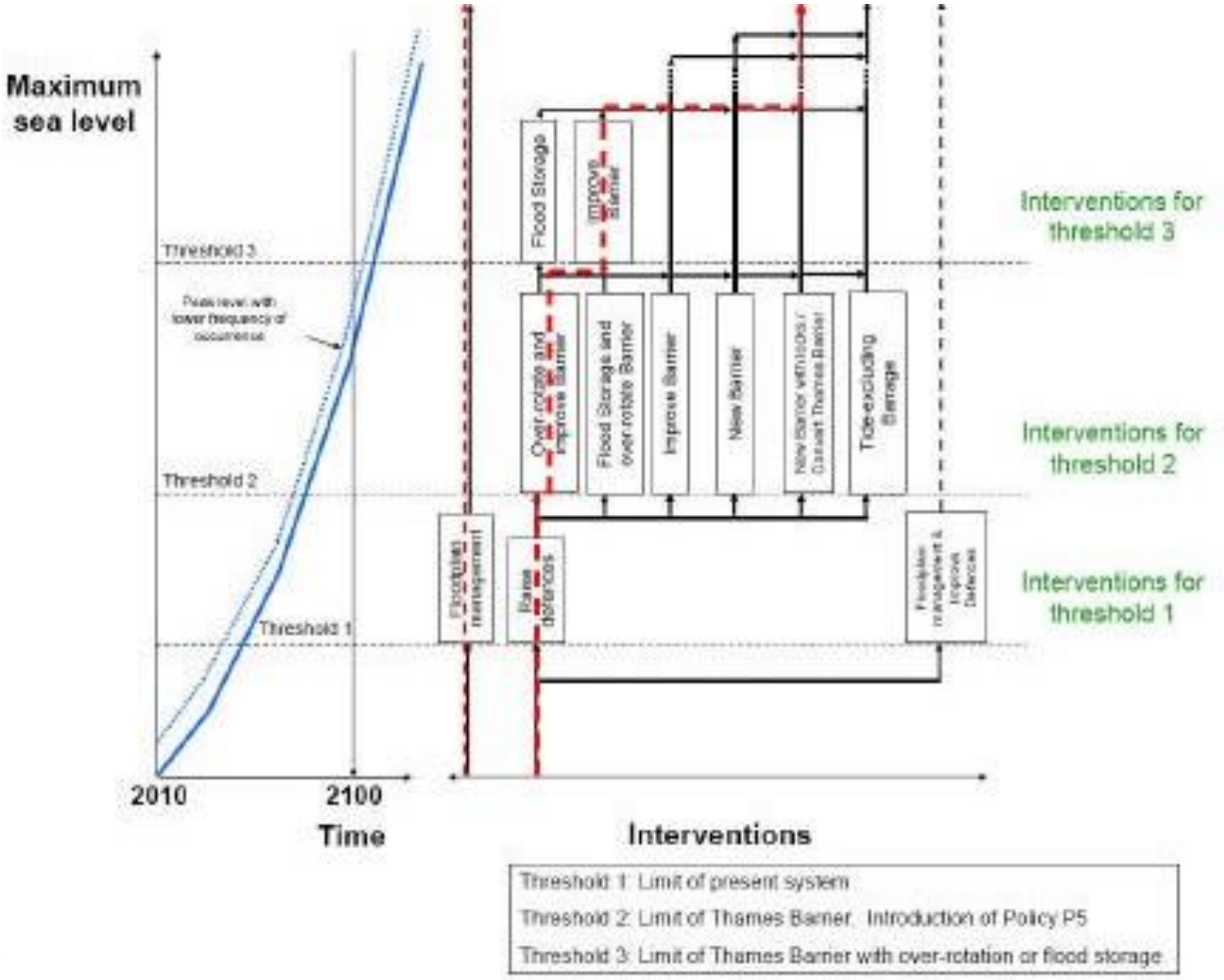
Stage 3: Appraise options to address the most likely view of risk

Developing the Thames Estuary 2100 Plan included a Cost-Benefit Analysis (CBA) of all the High Level Options under a “central” (Defra 2006 advice) climate scenario. This has determined the generic preferred 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 was to repeat the CBA of Options under differing baselines and impact estimates suggested by the different climate 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.

Figure 12: Thresholds and interventions (based on best estimates)



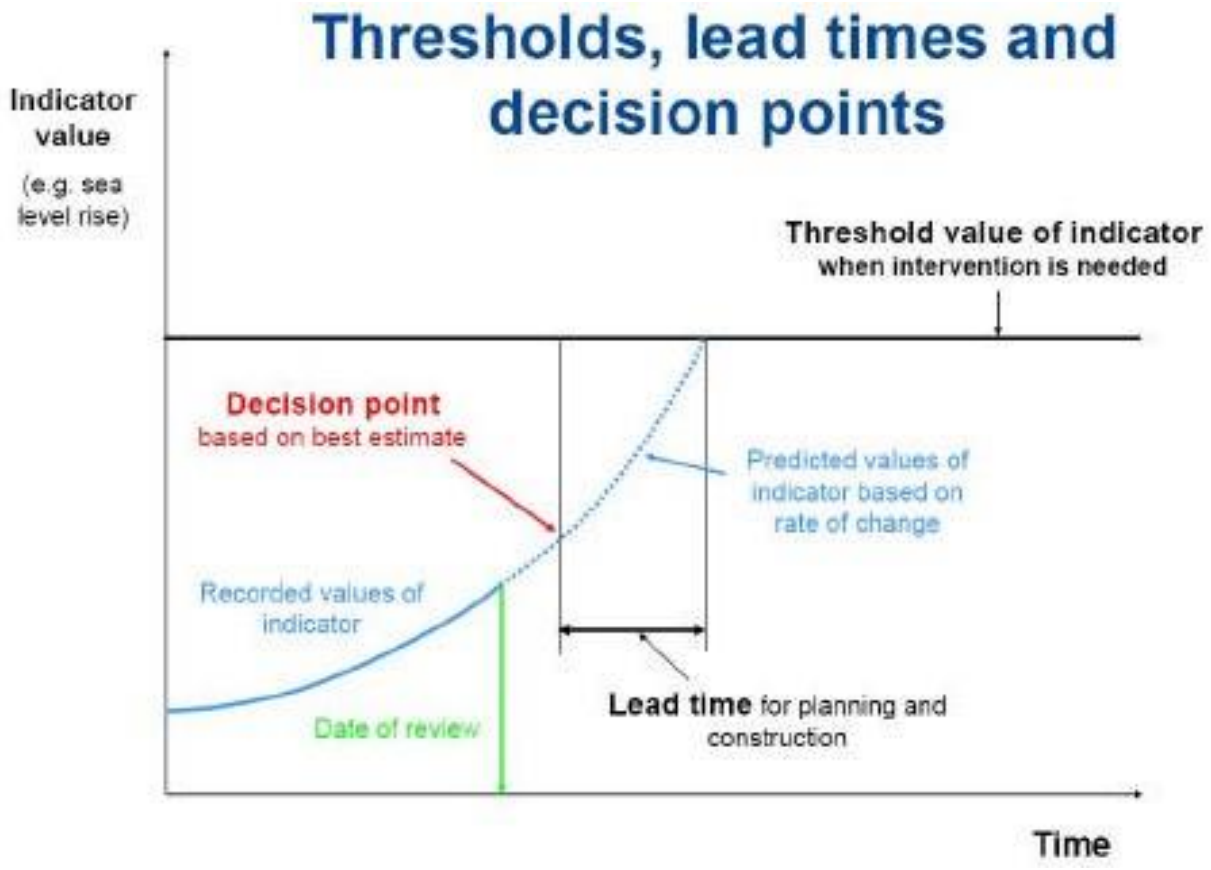
a. The Option with the highest Cost-Benefit Ratio given current knowledge of the most likely climate change outcome is recommended. This includes a series of interventions through time, each of which have lead times which are estimated (based on when interventions are predicted to be needed in response to threshold values of climate change indicators – see figure 12 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 13 below.

b. A set of 10 indicators of change was suggested including key climate change indicators (such as sea level rise) for routine monitoring across the life of the Plan and a formal review of the indicator trends carried out every 5 years.

c. At least every 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 then 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.

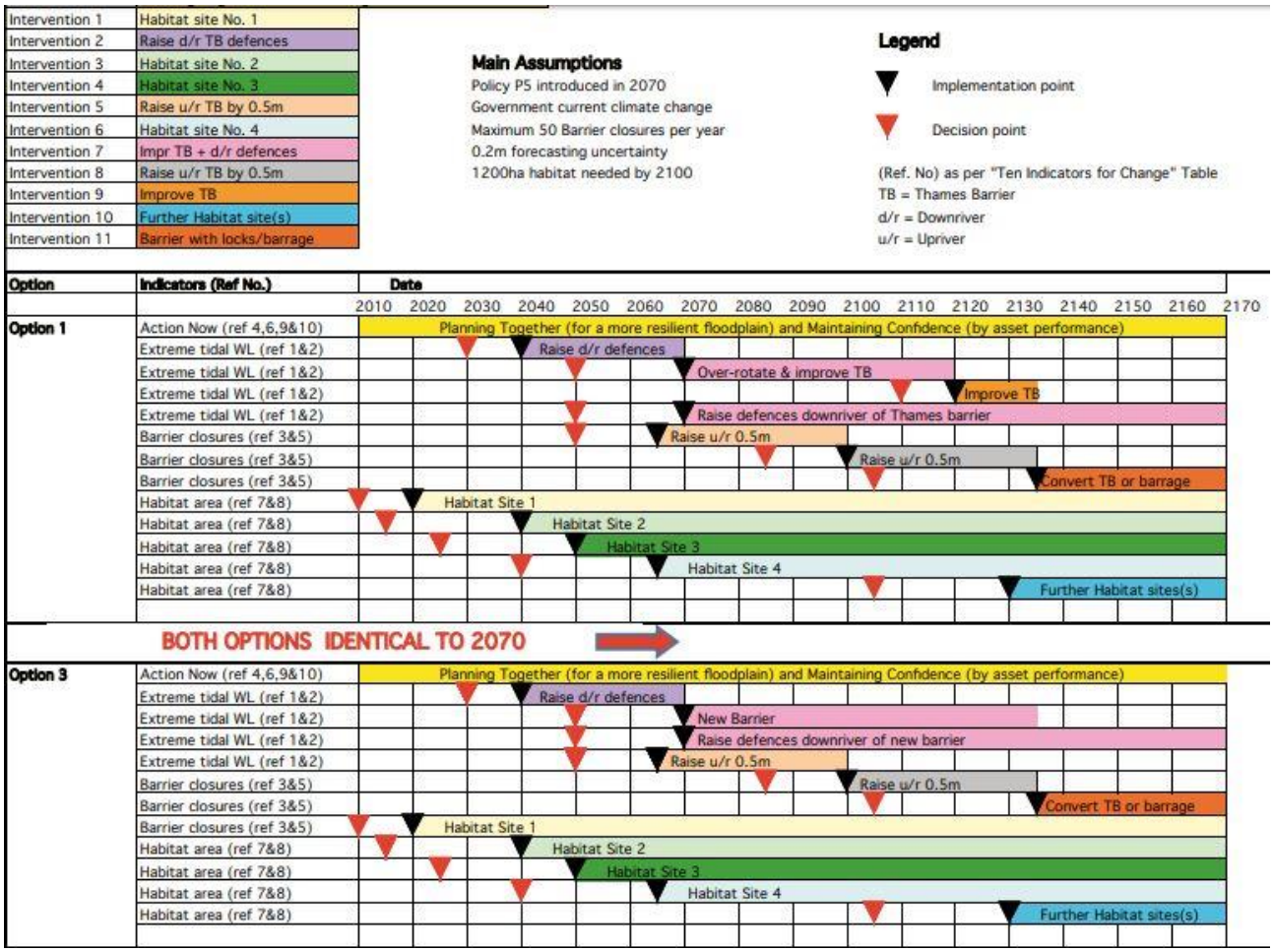
   Figure 14 shows how the individual elements of the strategy might be modified in practice, in the light of new indicator information. The top half of the diagram represents the progress of the strategy as initially predicted, based on then-best estimates. If, for example, monitoring reveals that the “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.

Figure 13: Thresholds, lead times and decision points



d. Each time the Plan is reviewed, the whole strategy could be reappraised, depending on the magnitude of indicator change observed through monitoring or 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 (such as High Level Option 4, a tide-excluding barrage). Such a switch would be possible (without significant wasted investment) in the early decades of the strategy, because the High Level Options 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.

Figure 14: The adaptation strategy in practice



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 the Thames Estuary 2100 Plan, 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 Plan recommends the safeguarding of land through adopting a riverside strategy approach. The riverside strategy approach safeguards land required for flood defence maintenance and raising activities, improves flood risk management in the vicinity of the river, creates better access to and along the riverside, and improves the riverside environment.

By adopting this longer term approach to planning the riverside the intention is to enable planning authorities to make better long term decisions that incorporate future flood risk management needs.

Annex B: Where to go for further information

Defra

The Department for the Environment, Food and Rural Affairs is the lead government department for domestic adaptation to climate change, responsible for delivering statutory adaptation requirements set out in the UK Climate Change Act 2008 (CCA).

Through Defra, HMG is responsible for adaptation policy in England and reserved matters for the UK. National governments in Northern Ireland, Wales and Scotland are responsible for adaptation in all devolved policy areas.

Adaptation policy is mainstreamed across government – policies, programmes and investments must take climate change into account.

Comments and questions on this guidance can be emailed to climate@defra.gov.uk. The guidance will be reviewed; suggestions for improvements are welcome at the above address.

Useful references

Policy landscape

Title	Website
Climate Change Act (2008)	http://www.legislation.gov.uk/ukpga/2008/27/contents
England (and UK reserved matters Climate Change: Third National Adaptation Programme 2023-2028)	https://www.gov.uk/government/publications/third-national-adaptation-programme-nap3
Scotland: Climate Change Adaptation Programme 2019-2024	https://www.gov.scot/publications/climate-ready-scotland-second-scottish-climate-change-adaptation-programme-2019-2024/
Wales: Prosperity for all a climate conscious Wales (2019)	https://www.gov.wales/prosperity-all-climate-conscious-wales

Northern Ireland: Climate Change Adaptation Programme 2019-2024	https://www.daera-ni.gov.uk/publications/northern-ireland-climate-change-adaptation-programme-2019-2024

Impacts, vulnerability and adaptation assessments and tools

Title	Website
UK Climate Change Risk Assessment (CCRA3) 2022	https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-2022
UK Climate Projections 2018 (UKCP18)	http://ukclimateprojections.metoffice.gov.uk/ The UK Climate Projections provides the most up-to-date assessment of how the climate of the UK may change over the 21st century. Find information to help with your climate change risk assessments and adaptation plans
Environment Agency: Climate impacts tool 2023	https://www.gov.uk/government/publications/climate-impacts-tool
Environment Agency. National Flood and Coastal Erosion Risk Management Strategy for England (2020)	https://www.gov.uk/government/publications/national-flood-and-coastal-erosion-risk-management-strategy-for-england--2
Business Areas Climate Impacts Assessment Tool (BACLIAT)	https://www.ukcip.org.uk/wizard/future-climate-vulnerability/bacliat/
UKCIP Adaptation Wizard	https://www.ukcip.org.uk/wizard/ 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

Meteorological Observations

Title	Website
Met Office State of the Climate Reports	https://www.metoffice.gov.uk/climate/uk/about/state-of-climate

Monitoring, evaluating and measuring

Title	Website
The Committee on Climate Change (CCC)	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 Adaptation Sub-Committee (ASC) provides external scrutiny of Government adaptation activities, particularly overheating.
2023 Report to Parliament – Progress in preparing for climate change	The Adaptation Sub-Committee's UK Climate Change Risk Assessment Evidence Report sets out the priority climate change risks and opportunities for the UK. The ASC also reviews and scrutinises adaptation progress on a two yearly basis: https://www.theccc.org.uk/publicationtype/0-report/02-progress-reports/
HMG also monitors progress on adaptation. See for example Government response CCC Report to Parliament –'Progress in preparing for Climate Change'.	https://www.gov.uk/government/publications/government-response-to-the-climate-change-committee-2023-adaptation-progress-report/government-response-to-the-climate-change-committee-2023-report-to-parliament-progress-in-adapting-to-climate-change

25 Year Environment Plan: progress reports	https://www.gov.uk/government/publications/25-year-environment-plan-progress-reports

Government advice and wider resilience references

Title	Website
HM Treasury Green Book	https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent
HM Treasury Orange Book	https://www.gov.uk/government/publications/orange-book
UK Health Security Agency's Adverse Weather and Health Plan	https://www.gov.uk/government/publications/adverse-weather-and-health-plan
MHCLG National Planning Policy Framework	https://www.gov.uk/guidance/national-planning-policy-framework
Government Actuary Department (GAD) comment - Climate change	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760907/Climate_change_GAD_comment__Nov_2018.pdf
25 Year Environment Plan	https://www.gov.uk/government/publications/25-year-environment-plan/25-year-environment-plan-our-targets-at-a-glance

Links to useful ongoing work

Title	Website	Description
NIC	https://www.nic.org.uk/	The National Infrastructure Commission (NIC) provides the government with impartial, expert advice on major long-term infrastructure needs take into account, in a consistent way, not only the technological future but also the future climate.
Network Rail Weather and Climate Change Adaptation	https://safety.networkrail.co.uk/home-2/environment-	

	and-sustainable-development/wrcca/	
Network Rail's Weather Resilience and Climate Change Adaptation (WRCCA) Strategy	https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/wrcca/wrcca-strategy-2/	The WRCCA strategy was published in 2017. The strategy is intended to provide a framework within which all work relating to weather resilience and climate change adaptation is undertaken within Network Rail and to enable renewed energy, focus and investment in prioritized activities through engagement with the business in consultation with external stakeholders. Guidance: https://safety.networkrail.co.uk/wp-content/uploads/2023/12/NR-GN-ESD41-Adaptation-Pathways-Approach-Guidance-Note-issue-1.pdf
'Preparing for a changing climate: Good practice guidance for local government' ADEPT, Defra and Local Adaptation Advisory Panel:	https://www.adeptnet.org.uk/groups/environment	Published in June 2019, this report focuses upon good practice guidance for local government for adapting to climate change.
Environment Agency: Thames Estuary TE2100: detailed information	https://www.gov.uk/government/publications/thames-estuary-2100-te2100/thames-estuary-2100-te2100.	2019. Thames Estuary TE2100: detailed information (plan and programme)

Research programmes, reviews and reports

Title	Website
Strategic Priorities Fund (SPF) UK Climate Resilience Programme	https://www.ukclimateresilience.org/.
RIDE Forum	https://www.ukri.org/what-we-do/supporting-collaboration/partnerships-nerc/ride-forum/ RIDE forum provides details on a wider range of climate and environmental impacts through impact report cards for

	the water, biodiversity and infrastructure sectors. Report cards are also available for agriculture and forestry.

Other useful references

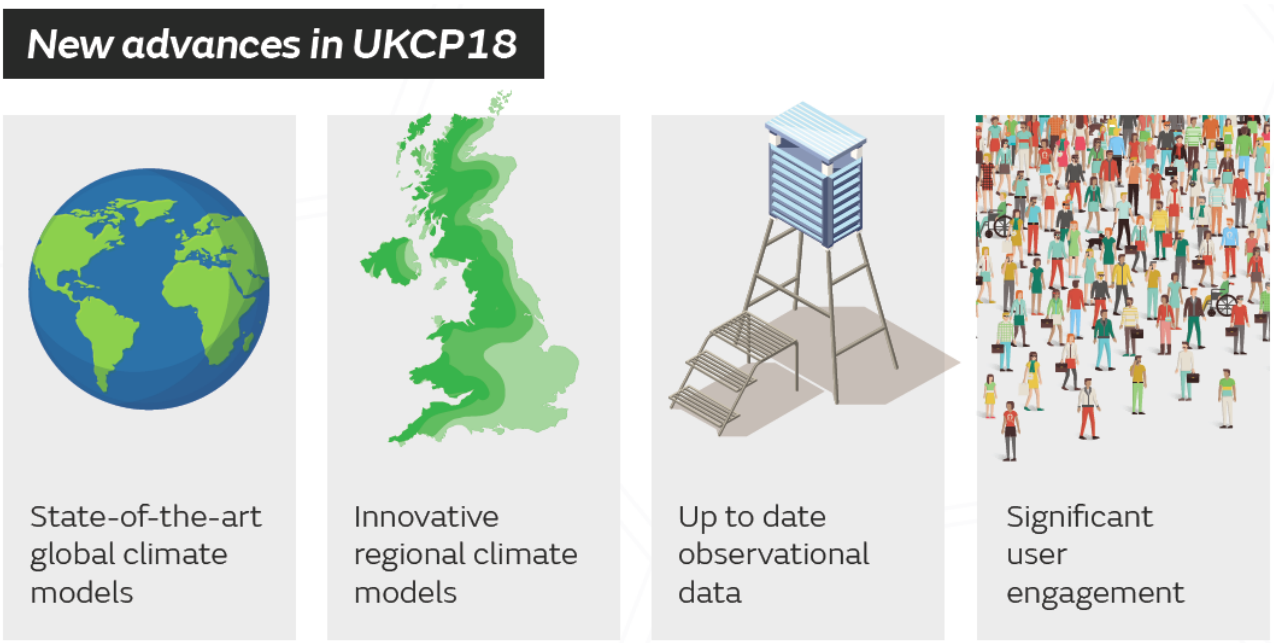
Title	Website
Intergovernmental Panel on Climate Change (IPCC) Reports	https://www.ipcc.ch/reports/
Met Office Climate Adaptation Webpage	https://www.metoffice.gov.uk/research/climate/climate-impacts/mitigation-adaptation
Met Office Climate Impacts Webpage	https://www.metoffice.gov.uk/weather/climate-change/effects-of-climate-change Including more on causes and impacts of climate change on: - Urban environment - Food security - Food and forestry - Water resources - Wind power
Stern Review	https://webarchive.nationalarchives.gov.uk/ukgwa/20100407172811/https:/www.hm-treasury.gov.uk/stern_review_report.htm 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.
OECD	https://www.oecd.org/climate-change/theme/resilience/ Research on climate change adaptation, including the 2008 “Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments” report.
Climate Adaptation: Risk,	https://www.ukcip.org.uk/wp-content/PDFs/UKCIP-Risk-framework.pdf

uncertainty and decision making report	Report with detailed information on incorporating climate risk and uncertainty into decision-making

Annex C: UK Climate Projections 2018 (UKCP18)

Building on the success of the UK Climate Projections released in 2009 (UKCP09), UKCP18 uses cutting-edge science to deliver a major upgrade to the range of UK climate projection tools designed to help decision-makers assess their risk exposure to climate change. UKCP18 provides updated probabilistic projections of key climate variables (such as temperature, rainfall) over the UK. Figure 1 shows the new advances in UKCP18.

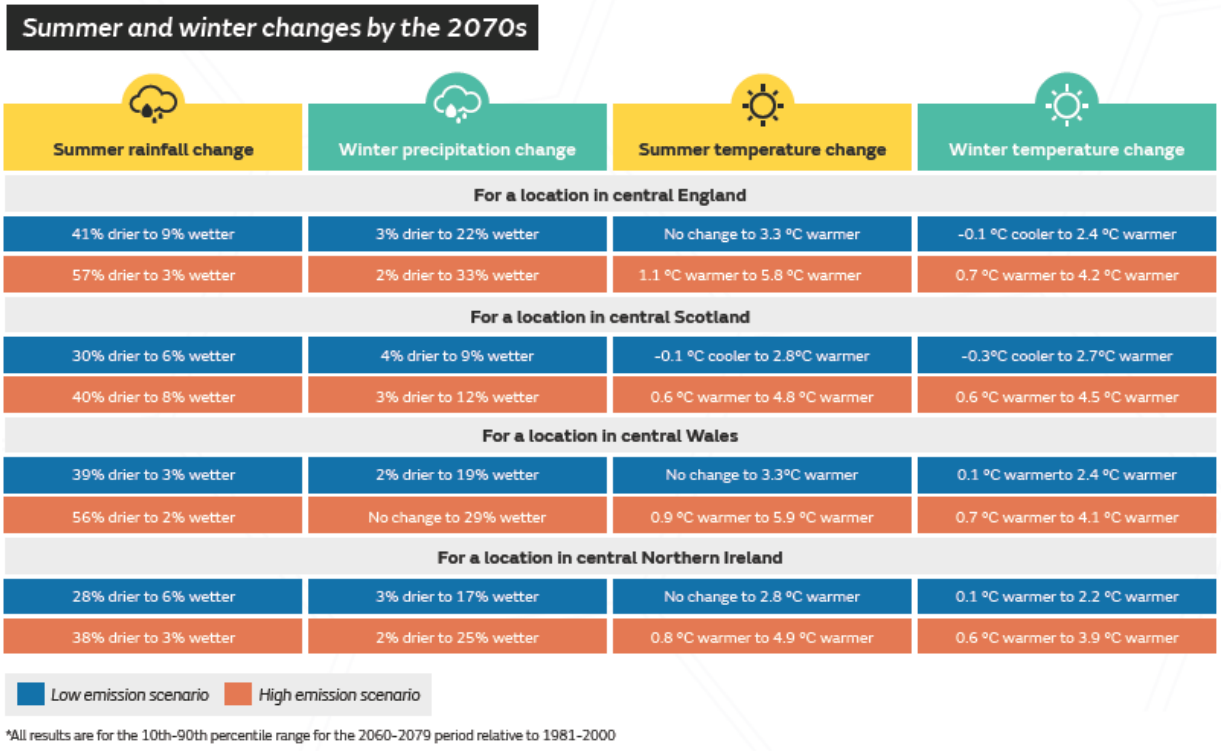
Figure 1: new advances in UKCP18



Source: [UKCP18 climate change over land, Met Office Hadley Centre (2018)]

By the end of the 21st century all areas of the UK are projected to be warmer. By 2070, under a high emission scenario, the range of average warming amounts to 0.9 °C to 5.4 °C in summer, and 0.7 °C to 4.2 °C in winter. Figure 2 shows the projected range of regional changes in summer and winter temperature and precipitation by the 2070s.

Figure 2: summer and winter changes by the 2070s



Summer and winter changes by the 2070s

Summer rainfall change	Winter precipitation change	Summer temperature change	Winter temperature change
For a location in central England			
41% drier to 9% wetter	3% drier to 22% wetter	No change to 3.3 °C warmer	-0.1 °C cooler to 2.4 °C warmer
57% drier to 3% wetter	2% drier to 33% wetter	1.1 °C warmer to 5.8 °C warmer	0.7 °C warmer to 4.2 °C warmer
For a location in central Scotland			
30% drier to 6% wetter	4% drier to 9% wetter	-0.1 °C cooler to 2.8°C warmer	-0.3°C cooler to 2.7°C warmer
40% drier to 8% wetter	3% drier to 12% wetter	0.6 °C warmer to 4.8 °C warmer	0.6 °C warmer to 4.5 °C warmer
For a location in central Wales			
39% drier to 3% wetter	2% drier to 19% wetter	No change to 3.3°C warmer	0.1 °C warmerto 2.4 °C warmer
56% drier to 2% wetter	No change to 29% wetter	0.9 °C warmer to 5.9 °C warmer	0.7 °C warmer to 4.1 °C warmer
For a location in central Northern Ireland			
28% drier to 6% wetter	3% drier to 17% wetter	No change to 2.8 °C warmer	0.1 °C warmer to 2.2 °C warmer
38% drier to 3% wetter	2% drier to 25% wetter	0.8 °C warmer to 4.9 °C warmer	0.6 °C warmer to 3.9 °C warmer

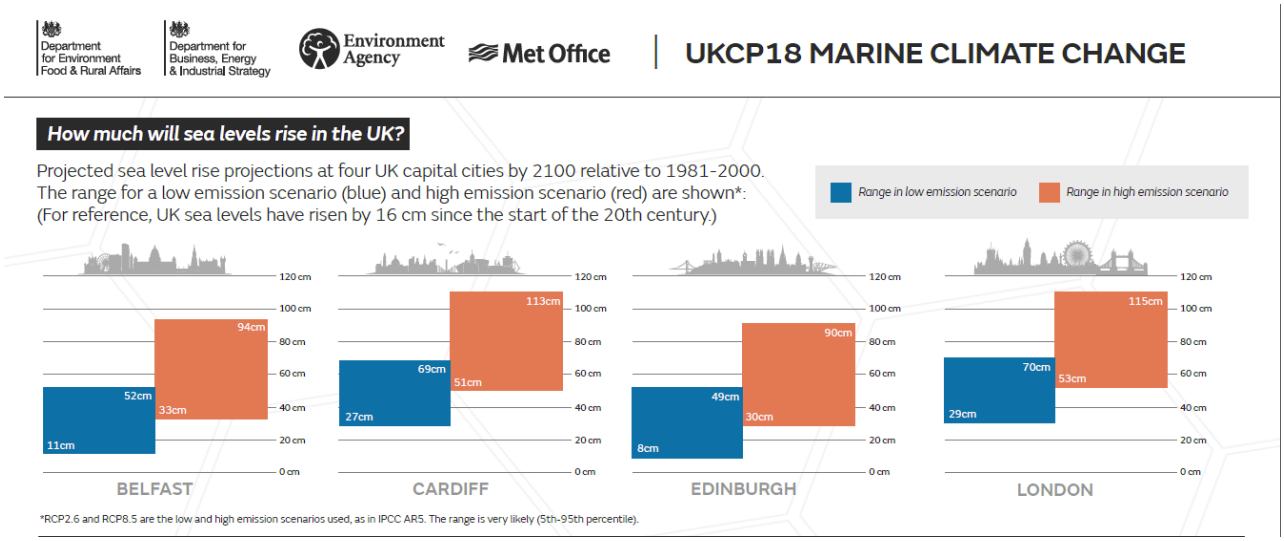
Low emission scenario | High emission scenario

*All results are for the 10th-90th percentile range for the 2060-2079 period relative to 1981-2000

Source: [UKCP18 climate change over land, Met Office Hadley Centre (2018)]

UKCP18 also provides a new set of marine projections which project that the sea level around the UK will continue to rise to at least 2100 under all concentration pathways. The pattern of sea level rise is not uniform across the UK. Sea level rise is lower in the north and higher in the south. This is mainly due to differential movement of land as the earth's crust responds to deglaciation following the last ice-age (by 'bouncing back' from the weight of glaciers).

Figure 3: UKCP18 marine climate change



Source: [UKCP18 marine climate change, Met Office Hadley Centre (2018)]

UKCP18 uses the new IPCC Representative Concentration Pathways (RCPs) to drive future climate scenario projections. These scenarios are based on plausible future trajectories of atmospheric greenhouse gas concentration (not emissions), relative to pre-industrial levels. There are four RCPs, all of which are used in UKCP18; RCP 2.6 (strong mitigation-low concentration- scenario), RCP 4.5 (stabilisation scenario), RCP 6.0 (stabilisation scenario) and RCP 8.5 (high concentration scenario). Each pathway results in a different range of global mean temperature trajectories over the 21st century. UKCP18 can be used to inform scenario analysis (Para. 5.62, Green Book 2018) to appraise policies, programmes and projects and ensure they account for the effects of climate change.

Annex D: Summary table of UK Climate Change Economic Impacts

The process of climate risk assessment seeks to identify and quantify the economic impact of climate risks to support climate resilient policy appraisal. Table 4 provides indicative values for the economic costs incurred during past extreme weather events, such as the 2003 heatwave and 2015/16 winter floods. Table 4 also outlines the future probability of climate hazards over time and across two climate change scenarios. For further valuations of potential impacts of climate change on your policy, please use the Monetary Valuation of Risks and Opportunities in CCRA3 report.

Impact	Description	Low	Central	High	Unit	Source
Probability of heatwave in 2020s	Annual likelihood of 2018 level heatwave in 2020s	0%		20%	Annual probability	WSP 2020
Probability of heatwave in 2°C warming scenario	Annual likelihood of 2018 level heatwave in 2°C warming scenario by 2050-2080s	40%		60%	Annual probability	WSP 2020
Probability of heatwave in 4°C warming scenario	Annual likelihood of 2018 level heatwave in 4°C warming scenario by 2080s	60%		80%	Annual probability	WSP 2020
Probability of winter flooding in 2°C warming scenario	Annual likelihood of 2015/16 level floods in 2°C warming scenarios by 2050-2080s	5%		20%	Annual probability	WSP 2020
Probability of winter flooding in 4°C warming scenario	Annual likelihood of 2015/16 level flood in 4°C warming scenario by 2080s	20%		50%	Annual probability	WSP 2020
Flood transport costs	The cost of the 2015/16 floods on vehicles, rail, & roads	£363	£457	£552	£m 2023 prices	Environment agency 2018
Flood health costs	The cost of the 2015/16 floods on health	£39	£52	£66	£m 2023 prices	Environment agency 2018
Flood education costs	The cost of the 2015/16 flood on education	£4	£5	£6	£m 2023 prices	Environment agency 2018

Flood utilities costs	The cost of the 2015/16 flood on utilities	£110	£126	£142	£m 2023 prices	Environment agency 2018
Flood local authority and emergency services cost	The cost of the 2015/16 flood on local authorities & emergency services	£70	£92	£115	£m 2023 prices	Environment agency 2018
Total flood costs	The total cost of 2015/16 floods	£1,577	£1,941	£2,305	£m 2023 prices	Environment agency 2018
Heatwave health costs	The average annual cost of heat mortality for 2000-2009	£144		£4,411	£m 2023 prices	CCC 2019
Heatwave transport costs	The cost of 2003 heatwave on transport sector		£69		£m 2023 prices	Metroeconomica 2006
Heatwave energy costs	The cost of 2003 heatwave on energy		£125		£m 2023 prices	Metroeconomica 2006
Heatwave built environment costs	The cost of 2003 heatwave on built environment		£193		£m 2023 prices	Metroeconomica 2006
Heatwave productivity costs	The cost of 2010 heatwave on productivity		£1,010		£m 2023 prices	Baglee et al 2012