UK 2012 Climate Change Risk Assessment

Method for undertaking the CCRA Part II – Detailed Method for Stage 3: Assess Risk

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Key Terms

Adaptation

- **Autonomous adaptation** Adaptation that does not constitute a conscious[1] response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.
- **Planned adaptation** Adaptation that is the result of a deliberate policy decision, based on awareness that conditions have changed / are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptive Capacity The ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Ballard, 2009).

Adaptation costs and benefits

- The costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs
- The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures

Consequence The end result or effect on society, the economy or environment caused by some event or action (e.g. economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected etc).

Impact An effect of climate change on the socio-bio-physical system (e.g. flooding, rails buckling).

Likelihood A general concept relating to the chance of an event occurring. Generally this is expressed as a probability or frequency.

Response function Defines how climate impacts or consequences vary with key climate variables; can be based on observations, sensitivity analysis, impacts modelling and/or expert elicitation.

Risk Defined as the probability multiplied by consequence. Ideally the probability and consequence would be quantified but a similar qualitative matrix can be used.

Sensitivity the degree to which a system is affected, either adversely or beneficially, by climate effects.

Uncertainty A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known.

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

[1] It is useful to clarify the term 'conscious' as used by the IPCC for the purposes of the CCRA. We treat autonomous adaptation as that part of the total 'anticipated adaptation' that is not a planned adaptation programme. It may include for example behavioural changes by people who are fully aware of climate change issues.

Executive Summary

The CCRA breaks new ground as an evidence base to inform UK adaptation policy in 2012 by assessing the current and future risks and opportunities posed by the impacts of climate to the year 2100. It will be complemented with an Adaptation Economic Assessment (AEA), which will appraise the costs and benefits of adaptation options. To achieve this the CCRA will:

- **Identify and characterise the impacts** of climate change
- **Assess vulnerability** of both the UK as a whole and of governments objectives
- **Identify the main risks** for closer analysis
- **Assess current and future risk** using climate and socio-economic projections
- **Report on risks** to inform action

Identify and characterise the impacts: a series of 11 sector reviews have been conducted by experts in the field. These reviews have identified a wide range of impacts and gathered initial evidence on the characteristics of those impacts such as the relative magnitude of consequences and uncertainties using IPCC approaches. The impacts have been consolidated and reviewed by experts. A subsequent ‘systematic mapping’ identifies additional cross-sector links.

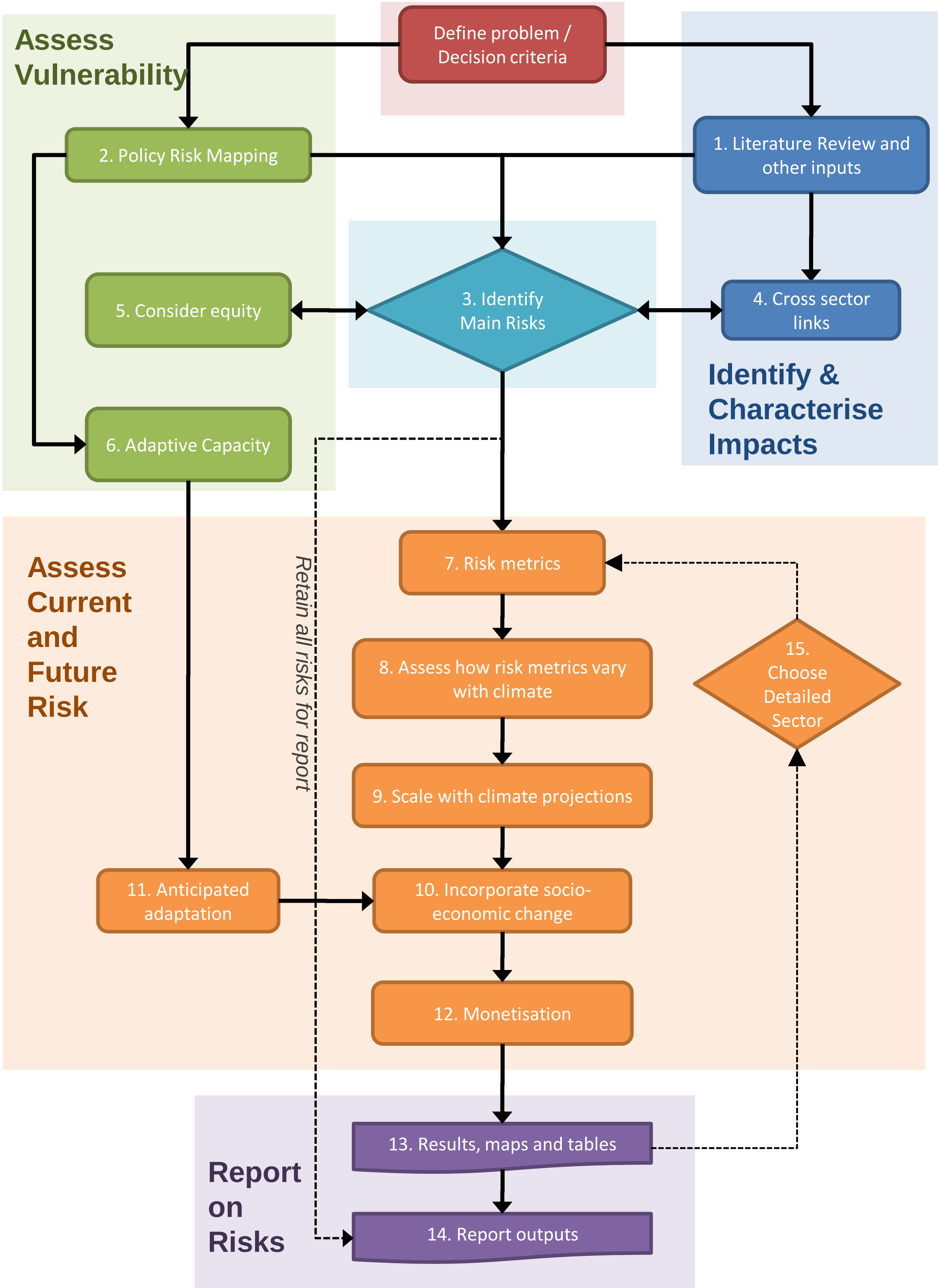
Assess vulnerability: The impacts of climate change will be assessed against the three ‘pillars’ of sustainable development: economy, society (including equity) and environment. These are equally weighted and calibrated using standard economic methods. An assessment of the adaptive capacity of major sectors will identify which are vulnerable. An analysis of government policy will map the risks on to the Government’s objectives. At a high level this is set out by the rationale for government intervention - the Departmental Adaptation Plans and other policy documents outline more detailed objectives and major policies.

Identify main risks: The more detailed assessment will then focus on larger risks - i.e. higher magnitude and likelihood where urgent decisions are needed. The selection process draws heavily on expert opinion and policy relevance, with a number of iterations.

Assess current and future risk: The CCRA will use risk metrics to create qualitative, or sometimes quantitative, “response functions” that relate consequences to climate variables. UKCP09 and transparent socio-economic assumptions will be used to assess the magnitude of consequences under possible future climates. Incorporating transparently both autonomous adaptation and existing policies will provide an estimate of the ‘residual’ consequences, expressed using monetary estimates where possible.

Report on risks: Risks will be categorised to identify as far as possible the relative severity of current risks and describe their characteristics to inform the broad management strategies that could be appropriate. A broad break down by parts of the UK and of England will be possible in some cases, alongside some case studies of local specific risks or sites using existing local evidence.

The figure below shows how these basic elements relate to each other. The more detailed numbered flow chart steps to the process are summarised in the text below.



Assess Vulnerability
Define problem / Decision criteria
1. Literature Review and other inputs
2. Policy Risk Mapping
3. Identify Main Risks
4. Cross sector links
5. Consider equity
6. Adaptive Capacity
Identify & Characterise Impacts
Assess Current and Future Risk
Retain all risks for report
7. Risk metrics
8. Assess how risk metrics vary with climate
9. Scale with climate projections
10. Incorporate socio-economic change
11. Anticipated adaptation
12. Monetisation
15. Choose Detailed Sector
Report on Risks
13. Results, maps and tables
14. Report outputs

1. Literature Review and other inputs

Purpose: Identify the full range of ways climate will impact on the UK and characterise what the evidence tells us about these.

Method: Based on literature review, stakeholder participation through workshops and correspondence with wider stakeholders and expert opinion.

Outputs: A list of impacts and their characteristics (such as magnitude, likelihood and pedigree of supporting evidence).

2. Policy risk mapping

Purpose: Identify 'policy-relevant' risks, map major policies already in place and incorporate policy targets in to later analysis.

Method: Summarise government policy, objectives and targets relevant to adaptation.

Outputs: Summary of current policy, which climate impacts are policy-relevant and inputs for assumptions when considering socio-economic futures.

3. Identify main risks

Purpose: Select some risks for a more detailed assessment.

Method: Initially a simple multi-criteria assessment based on magnitude, likelihood of consequences and the urgency with which adaptation decisions needs to be taken. Subsequently tailored and refined using expert opinion and considering policy relevance.

Outputs: Manageable lists of impacts that are considered in more detail.

4. Cross sector links

Purpose: a) Investigate sector interactions, b) identify cross sectoral themes and c) provide a basis for future analysis. (Modelling interactions quantitatively is not planned).

Method: Mapping processes and outputs step-by-step using a bespoke online tool.

Outputs: Systematic maps and cross sectoral impacts that may be selected for further analysis.

5. Consider equity

Purpose: To reflect issues of equity and social vulnerability in the assessment of risk.

Method: Review the impacts against a 'checklist' to describe distributional effects and aid identification of metrics to support this.

Outputs: A consideration of social vulnerability so that the selection of main risks reflects Government objectives around fairness. Also informs identification of social metrics (Step 7).

6. Assess adaptive capacity

Purpose: To understand how well major UK sectors may adapt autonomously. The CCRA focuses on institutional adaptive capacity but the capacity of other systems are considered where relevant evidence exists.

Method: Literature review followed by PACT[2] assessment of the some major sectors to identify organisations with a high, medium or low risk of poor decision making.

Outputs: Narrative assumptions about levels of autonomous adaptation (Step 13) and an understanding of which sectors are vulnerable. This will input to the Adaptation Economic Assessment (AEA) as well.

7. Risk metrics

Purpose: To identify practical metrics that represent the most important consequences of climate change so that these can be related to climate variables.

Method: Select metrics to provide a balance in practicality, usability and policy relevance.

Outputs: List of risk metrics used in Step 8.

8. Assess how risk metrics vary with climate

Purpose: To define response functions by graphing quantitatively or qualitatively the sensitivity of risk metrics to climate variables according evidence (where available) or expert opinion.

Method: Review of existing research to develop qualitative or quantitative response functions - how climate consequences vary with climate variables.

Outputs: Sets of qualitative matrices and quantitative sensitivity plots that estimate changes in risk metrics (consequences) in response to changes in climate variables (for Steps 9-14).

9. Scale with climate projections

Purpose: use the response functions to assess the magnitude of consequences the UK could face under the climate projections that UKCP09 suggests could happen.

Method: Selected climate projections will be used with the response functions. Existing evidence will be quantitatively scaled to UKCP09 where evidence allows. Expert opinion will be consulted where quantitative evidence is not available.

Outputs: Estimates of consequences under UKCP09 projections (for Steps 10-14).

10. Incorporate socio-economic change

Purpose: To incorporate socio-economics (e.g. economic growth) into the magnitude of the consequences the UK faces and assess the degree of uncertainty surrounding these.

Method: Basic socio-economic forecasts will be selected. Techniques to assess the influence of highly uncertain socio-economic changes will also be used.

Outputs: Estimates of changes in consequences under UKCP09 projections when coupled with socio-economic forecasts. These are used in Steps 11-14.

11. Account for anticipated adaptation

Purpose: To account for autonomous adaptation and the effect that existing government policy already has on reducing the level of risks.

*Method***:** An iterative step, using policy risk mapping (Step 2), and adaptive capacity (Step 6) to revisit assumptions in (i) developing the response functions and (ii)

[2] http://www.alexanderballard.co.uk/projects.php?id=13

the socio-economic forecast baseline. In many cases, the analysis will be qualitative or narrative.

Outputs: Assumptions and narratives about autonomous adaptation and adaptation under current policy to inform socio-economic forecasts. Reanalysis of some metrics to estimate 'net' risks after autonomous adaptation.

12. Monetise

Purpose: To undertake (where possible) a monetary estimate of the potential consequences of climate change and to enable for some risks a comparison using a common metric.

Method: Based on standard HM Treasury Green Book approaches and other approaches based on existing evidence. Many risks will not be monetised in this cycle of the risk assessment because of a lack of quantitative data.

Outputs: A selection of monetised and non-monetary estimates of the magnitude of key consequences.

13. Results, maps and tables

Purpose: To provide a basis on which to target adaptation policies by sector, geographically and by country.

Method: Present data at national levels and sub-national levels (major river basins for hydrology). In some cases this requires 'upscaling' or generalising detailed sub-national data to other scales. In other cases, national estimates will be 'downscaled' to provide data for geographical areas.

Outputs: Tables and maps to summarise risks and how they vary by area.

14. Report outputs

Purpose: To inform government about priorities for the Adaptation Economic Assessment and implications for a programme of adaptation policy.

Method: Standardised reports will be produced for sectors and for Devolved Administrations, with a break down to areas of England where possible. Key risks and sectors will be categorised in a way that informs formation of the statutory policy programme by Government. A detailed prioritisation 'ranking' of each risk will not be attempted.

*Outputs***:** a) Standardised reports for sectors and for the Devolved Administrations, with consideration of areas of England and b) An overview to inform a statutory programme of adaptation policy.

15. Exemplar analysis at Tier 3 level

Purpose: to undertake an exploratory and exemplary detailed quantitative assessment of risk that will inform future cycles of the CCRA, other international or regional risk assessments and future research needs.

Method: Government will review the outputs of Tier 2 and may select a specific risk or geographical area for detailed Tier 3 assessment.

While the majority of the work will have been completed in Tier 2 assessment, some additional detailed analysis is likely to be completed based on a fully quantitative assessment in one sector or English area. Previous steps will be repeated but with a greater emphasis on metrics that can be quantified and developing quantitative modelling.

Full CCRA Method

1 Define problem and decision making criteria

Summary

Purpose: Defines the objectives of the CCRA and basis upon which later decisions (a statutory programme of adaptation policy) will be made

Outputs: A clearly defined objective against which risk assessment method can be judged.

1.1.1 Objectives

As a result of the Climate Change Act (2008) the UK is the first country in the world to have a legally binding, long-term framework to cut carbon emissions. The Climate Change Act also creates a framework for building the UK's ability to adapt to climate change. Part of the Act requires Government to implement a National Adaptation Programme – and to inform this, to lay before Parliament assessments of the risks posed to the UK by climate to the year 2100.

The risk assessment will be complemented with an Adaptation Economic Assessment (AEA) which will assess options for dealing with the largest risks, based on their costs and benefits. This will ensure that UK adaptation policy is informed by the best available evidence about the benefits of different adaptation options.

This project is being undertaken within the Adapting to Climate Change (ACC) cross government programme, based in Defra. The first assessment will be laid before Parliament in January 2012 and an updated assessment will be issued every 5 years.

The first cycle of the UK Climate Change Risk Assessment (CCRA) poses a complex analytical challenge and because of time and resource constraints it will need to build as much as possible on existing and ongoing evidence and approaches. This cycle will not assess every risk or sector in detail but will focus on assessing a subset of risks and opportunities where immediate or near term action, either by Government or others, is most valuable.

Some risks and adaptation options will be quantified in detail but most risks and options will be assessed qualitatively or semi-quantitatively.

1.1.2 Decision-making criteria

1.1.2.1 Overview

The decision-making criteria used in the CCRA flow from the objective of the study: informing the development of the National Adaptation Programme. The Programme's development will be guided by the standard framework for policy-making. This states that action should be taken either to achieve a more efficient outcome than would otherwise occur, or on distributional grounds (HM Treasury, 2003).

This means that the distributional implications of climate change consequences should be recorded where possible. It also means that the CCRA should enable a focus on risks that:

- Should be addressed by the Government
- Need to be addressed prior to the completion of the second cycle of the CCRA
- Are likely to lead to the greatest costs (social, environment and economic consequences) if they are not addressed

These three criteria are explained in more detail below.

1.1.2.2 Rationale for Government intervention

People will generally take action to adapt to climate change when it is in their interest and power to do so – that is, they will make decisions based on their understanding of the costs and benefits to them. In many cases, this will contribute to socially efficient outcomes, but there are a range of barriers that may prevent this from occurring[3]:

- **Market failures.**[4] Existing market distortions can affect people's incentives to adapt. These include imperfect information about climate impacts and misaligned incentives in the management of physical assets.

- **Policies and institutional arrangements.** The options and incentives available to individuals and businesses are shaped by a range of non-climate related policies and institutional arrangements. This is particularly the case for some of the most climate sensitive sectors, such as agriculture and the natural environment.

- **Behavioural barriers.** Adaptation decisions can be complex, and involve dealing with long time horizons and uncertainty. Evidence from behavioural economics suggests that it is challenging to make rational decisions in these circumstances.

- **Adaptive capacity.** Some communities and individuals lack the ability to respond to climate change because of financial or other constraints.

- **Natural capacity.** The ability of natural systems to adapt may be hampered by the rate of climate change exceeding the system's ability to respond, the existence of other stresses and the effects of human activity.

The Government may act to help overcome these barriers to adaptation by individuals and organisations. There may also be existing Government policies and commitments that could be vulnerable to the effects of climate change, and Government should ensure that its own actions are contributing to the UK's adaptation to climate change. Where Government action is justified in line with the criteria outlined above, action should only be taken where the social benefits of Government intervention are expected to be greater than the costs.

[3] These are explained in more detail in Cimato & Mullan (2010)

[4] Market failure refers to where the market has not and cannot of itself be expected to deliver an efficient outcome; the intervention that is contemplated will seek to redress this. Distributional objectives are self-explanatory and are based on equity considerations (HM Treasury, 2003).

1.1.2.3 *Urgency of decision-making*

The first CCRA will consider risks out to 2100, but it will be neither necessary nor desirable to address all of them directly after the first cycle of the Climate Change Risk Assessment, which will be repeated and built upon every 5 years. The choice about when to address risks is affected by four factors (OECD, 2008):

- Difference in adaptation costs over time – in some cases it may be more efficient to delay action because of technical progress, access to improved information or natural replacement cycles. Conversely, it may be more expensive to retrofit rather than build in adaptation at the outset.
- Short-term benefits of adaptation – for example, improved resilience to the current climate.
- Long-term consequences – risk of lock-in, or irreversible losses to the natural environment.
- Lead-time between policy adoption and implementation in practice

This cycle of the CCRA should focus on the decisions that need to be made between 2012 and 2017, according to these criteria.

1.1.2.4 *Prioritising action*

The Government should focus its resources on the areas where it is likely to lead to the greatest improvement in outcomes. The Green Book (HM Treasury, 2003) recommends that outcomes are measured in monetary terms where possible, to enable priorities to be compared across competing demands for Government funding. Where this is not possible, other metrics are a viable alternative.

In the CCRA, the described scale of the risks faced will guide where Government action is likely to have the greatest benefits. This will feed into the Adaptation Economic Assessment, which will identify the scope for additional adaptation actions that will lead to improved outcomes for the UK.

2 Risk Assessment

Assessments of climate change sometimes take a deliberately 'impacts driven' or 'vulnerability driven' approach to assess risks. In the CCRA both the impacts and the general vulnerability of the UK need to be understood in order to initially identify the main risks for which more detailed risk assessment can be carried out. Therefore 'impacts' and 'vulnerability' are given equal conceptual prominence. This chapter describes in detail the sequential steps that make up the broad conceptual categories of assessing impacts, understanding vulnerability and then using the understanding of these to select the main risks that will be analysed in further detail. The chart below demonstrates how these steps link together to produce outputs that can inform national adaptation policy.

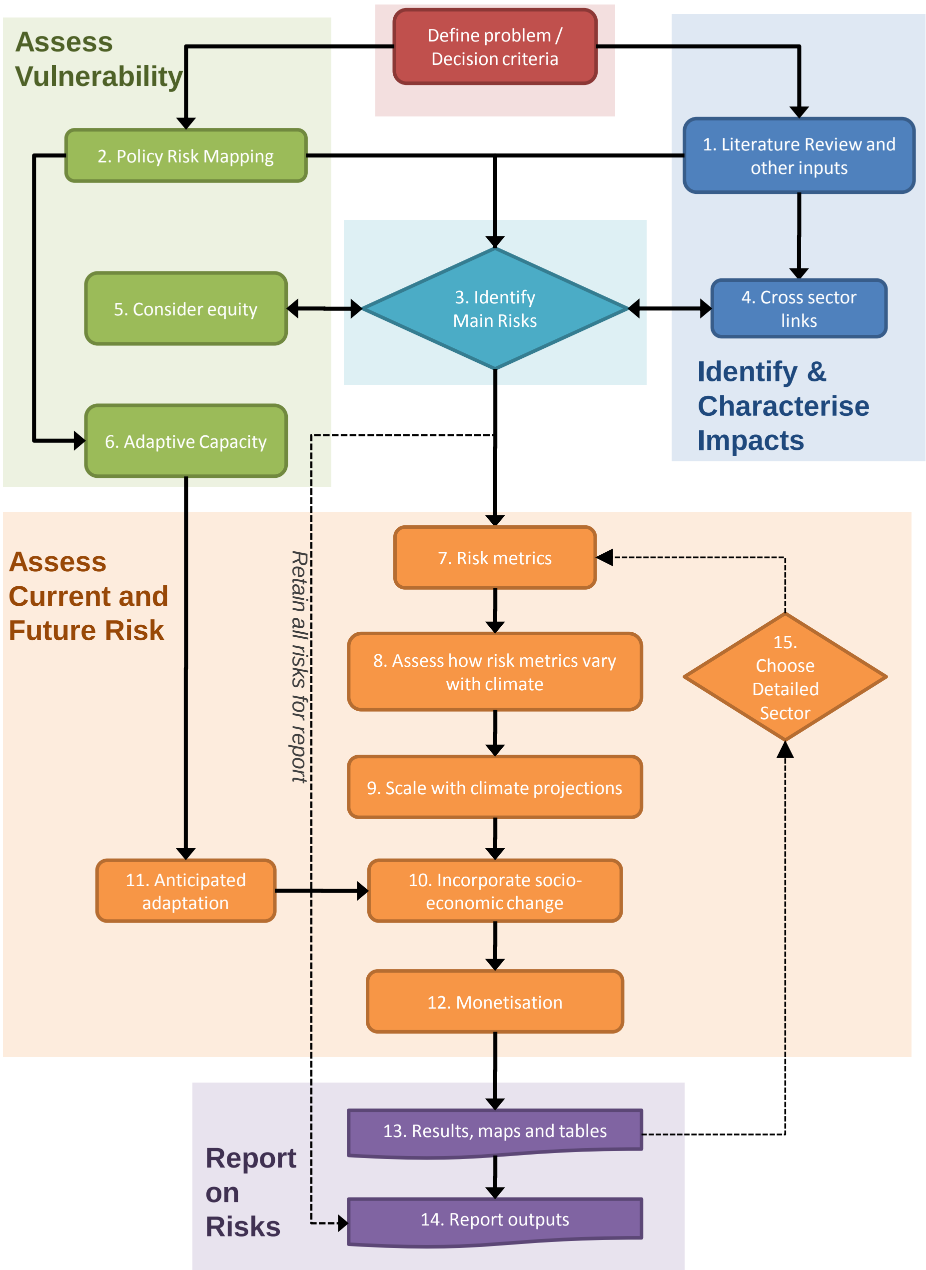


Figure 2-1 Flow chart of assessment steps

Devolved Administration and English Area analysis
The steps described above will first be applied at a UK level. The steps will also be followed when considering the Devolved Administration and geographical areas of England. Tailored workshops will:

- Provide an opportunity for stakeholders in each country to input in to defining what specific climate risks are important for them, which is important for the DA and to bring to the attention of the CCRA any further evidence they are aware of to support this;
- Review the outputs from the UK-wide sector-based assessment, in particular the identification of the main risks, to identify any priority omissions that should be addressed in the country-focussed assessment;
- Inform how any additional risks could be measured with new risk metrics and what data would be required to do this.

The workshops will be used to establish a tailored Tier 2 list of risks for each Devolved Administration and geographical English area. The same method process used for the UK level assessment will then be applied.

2.1 Literature Reviews and other inputs

Summary

Purpose: Identify the full known range of ways climate will impact on the UK and characterise what the evidence tells us about these.

Method: Based on literature review, stakeholder participation through workshops and correspondence with wider stakeholders and expert opinion.

Outputs: A list of impacts and their characteristics (such as magnitude, likelihood and 'pedigree' of supporting evidence) based on:

- Literature reviews conducted by experts across 11 major sectors
- Feedback from workshops
- Discussion with other major ongoing projects

This provides a very large list of impacts that informs subsequent steps, particularly steps 2 and 3.

A sector approach was adopted. The sectors were selected based around the major themes in which evidence tends to be organised – these were:

- Health
- Energy
- Transport
- Built environment (including cultural heritage)
- Business/Industry/Services (including tourism)
- Agriculture
- Forestry
- Water
- Floods and coastal erosion
- Marine (including fisheries)
- Biodiversity (including ecosystem services)

Each sector is led by a sector champion who prepared an initial report gathering evidence of the impacts of climate on their sector. The structure of each report is detailed in Appendix 1. In summary sector champions considered:

- Current risks (climate and non-climate) in their sector
- Future risks in the short, medium and long term
- Socio-economic drivers of risk
- Examples of adaptation decisions, measures and barriers
- A consideration of international impacts
- Research gaps and available data sets

The sector reports provided a discursive response to these questions and identified the impacts of climate change on the UK as reported in both peer reviewed and grey literature. Collectively, the reports provide a broad preliminary picture of the range and inter-connected nature of the spectrum of climate risks.

The climate impacts identified were extracted from each of the 11 sector reports to form a long list of over 600 possible climate impacts.

2.1.1.1 Other inputs

In addition, impacts were identified

- At workshops (a 'CCRA Forum' for a wide range of stakeholders and through Steering Group meetings)
- Through an assessment of impacts identified through existing local evidence.
- By a preliminary assessment of international issues (which informs a forthcoming more detailed assessment of international issues being undertaken by Foresight)[5].
- From other major recent literature.

At each stage, impacts were revised and / or consolidated. Information on 'cross-cutting sector issues' was also extracted from the literature and sector reports for:

- Security
- Telecommunications
- Critical infrastructure
- Spatial planning
- Emergency services

2.1.1.2 Characterising impacts

The climate impacts were logged and characterised with an assessment of:

- Climate effect that drove the risk
- Description of the impact
- Consequences (in the short, medium and long term)
- Whether the impact posed a threat, opportunity or was neutral
- Pedigree score of the weight of evidence (see below)
- The source of information about the impact
- The level of confidence (see below)

[5] Because international risks tend to be highly complex and uncertain they will be treated and reported differently from national risks in this assessment, drawing on the assessment of risks possible in the International Dimensions of Climate Change project being undertaken by Foresight in the Government Office for Science.

- Characteristics that determine if the impact should be selected for further analysis

An example of one impact and its characteristics is given below.

Climate effects	Impacts	2030s	2050s	2080s	Threat / opportunity / neutral	Consequences	Pedigree (weight of evidence)	Main sources (SS = Scoping study; SC = Sector report; RR = Sub-national report; CF = CCRA Forum; Other sources see below)	Level of confidence in being correct
Periods of extreme low rainfall	Meteorological and hydrological drought	x	x	x	T	Reduced water supply - **security of supply**; rivers unable to meet **WFD targets**	2	SC = Wade (2004);Goodess et al., 2002; Vidal and Wade, 2008; SS; CF	M

The impacts identified were consolidated where there was clear overlap and summarised in a Sector Summary Reports. Information given in the summary report for a typical impact is shown below.

Climate effects	Impacts	T/O/N	Consequences	Pedigree	Level of confidence
1. Ocean acidification	Reduced capacity of oceans to absorb CO_2	T	**Environment** : More pressure on mitigation	3	H

More than 600 impacts were identified at this stage.

2.1.1.3 Reviewing impacts

There are some impacts of climate change for which existing evidence is clear and there is in general a scientific consensus. However, for many impacts there is not yet consensus, and there may even be controversy.

For transparency therefore, we have recorded

- The level of confidence in being correct, using IPCC terminology, and
- The 'weight of evidence' using pedigree scores.

To achieve this, the following steps were then taken to review the initial list of impacts and consequences:

- Sector champions provided feedback and comments on the list for their sector.

- A technical sub-group of the CCRA Steering group, the 'In House Experts', provided comments on the sector reports and advice on how to best use the identified list of impacts and consequences.
- A preliminary sector workshop was held for each sector[6]. Specialists attending these workshops[7] reviewed the list for their sector and
  - Identified any important omissions and concerns or disagreement about the impacts;
  - Gave their views on pedigree scoring (and in some cases the levels of confidence).

Prior to the workshop, the group was sent

- a copy of the full sector report for their sector
- the sector summary report (so that they can see how their sector fits in)
- a table listing each of the impacts/consequences for their sector

Finally, the Project Steering Group was asked to identify the reviewers for the sector impacts and consequences tables to ensure that they provided a comprehensive list for this initial stage of the CCRA.

Pilot Learning

- By collating information from workshops as well as literature reviews, some impacts were identified several times but with subtly different consequences, leading to overlap and some duplication. With careful review the list of impacts can be rationalised to a shorter list that is more tractable to analyse.
- The original framing of impacts and consequences is important in terms of the level of abstraction and receptors considered; there needs to be consistency between sectors if impacts are to be compared. For example, if some impacts or consequences are divided up too narrowly they may seem small in comparison to other impacts or consequences that are considered at a higher level. Fixing a tightly defined level of detail at which impacts should be described was found to be impractical – considered judgement was found to be the most practical method.
- The water sector workshop also provided a number of lessons on how to run the workshop, which have informed the workshops for the other sectors

2.1.1.4 Pedigree score

A form of 'pedigree scoring' was developed based on Numerical Spread Assessment of Uncertainty Pedigree, NUSAP (Ellis et al., 2000; Risebey et al., 2001, HR Wallingford, 2009, http://www.nusap.net/). The purpose of scoring was to record and 'carry through' information on the 'weight of evidence' associated with climate risks.

The concept behind NUSAP is to provide a more comprehensive description of a numerical result in a way that captures aspects of error and uncertainty. NUSAP stands

[6] With the exception of Forestry and Business/industry/services, where feedback was obtained via telephone interviews.

[7] It was the intention of these workshops for the attendees to represent the sector as widely as possible, including public, private, academic and voluntary organisations and including representatives from the English regions, Scotland, Wales and Northern Ireland. To widen participation, an online mechanism for enabling input from those unable to attend was developed.

for **N**umber: **U**nit: **S**pread: **A**ssessment: **P**edigree and was the notation proposed by Funtowicz & Ravetz (1987). This string is composed as follows:

- 'Number' is the value being reported (highlighting the active significant figures):
- 'Unit' records the system being used:
- 'Spread' may be the standard deviation, the range, or minimum and maximum values:
- 'Assessment' provides an indication of the confidence limits, or may indicate any systematic error making use of previous results:
- 'Pedigree' is the most subjective element of the description. For this values are assigned against four attributes as detailed in Table 3.1.

Using this approach the results of an experiment to define a physical constant with a recorded value of 137.0360m would be reported as:

137+360 : E-4 m : ±1 : ±2.6 : (4,4,3,4)

Number : **U**nit : **S**pread : **A**ssessment : **P**edigree

The focus for the CCRA is on a range of information, some of which is quantitative but much of which is qualitative. However, for the assessment process, the primary interest is on a narrative description as provided by the pedigree component of the notation and guidance on this was presented in a previous project report.

	Score	Information or data *(Research Team, Sector Champions)*	Theory and Method *(Research Team, Sector Champions)*	Peer Acceptance *(Sector Champions)*	Consensus *(Sector Groups and Sub-national Stakeholders)*
“strength of evidence – scientific pedigree” →	**4**	**Comprehensive information** on impacts, valuation and adaptation based on observations and modelling	**Best available practice** and well established theory	**Absolute** – peer reviewed evidence from research literature. Panel agreement	**Accepted as ‘an ideal approach**.’ Sector Group agreement
	3	**Reliable analysis** of historical and observed data linking climate to impacts, including some monetisation	**Reliable method** commonly accepted	**High** – peer reviewed evidence suitable for the CCRA	**Accepted as ‘fit for purpose.**’ Sector Group agreement
	2	**Calculation or estimation** of potential impacts, without monetisation or adaptation analysis	**Accepted method**, partial theory but limited consensus	**Medium** – some agreement accepting that there are some contradictory views	**Some consensus** but different ‘schools of thought’
	1	Education opinion. **Expert view** based on limited information	**Preliminary method** unknown reliability	**Low** – no agreement	‘**New approach’** un-tested in sector
	0	Non-expert view/**guess**	**Crude speculation**/No discernable rigour	**None**	**None** – inappropriate use of data/information/modelling

Figure 2-2 Pedigree scoring guidance (HR Wallingford, 2009)

In Tier 1 of the assessment, a simplified system was applied to the collective evidence available to score each impact or consequence identified as follows:

0) Non-expert opinion, unsubstantiated workshop discussion with no supporting evidence
1) Expert view based on limited information, e.g. anecdotal evidence
2) Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector
3) Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'
4) Comprehensive evidence using the best practice and published in the peer reviewed literature; accepted as an ideal approach.

Initially, the actual scores ranged from 1 to 3, with the occasional 4. Pedigree scores can change as further evidence is gathered, or be modified through the peer review process. The procedure to establish the Pedigree score is as follows:

1) The preliminary list of impacts and consequences are scored by a research scientist, normally the sector champion

2) The scores are shared with the Sector Group and commented on at the workshops; scores are changed where appropriate.
3) The scores are updated following peer review of Tier 1 and/or Tier 2 reports reflecting the views of peer reviewers, outcomes of the assessment and any other new evidence that emerges during the study

The final reports reflect the pedigree scoring using appropriate language for the report audience

Pilot Learning

- Scoring can de difficult based on a high level review and requires a good understanding of the research within the sector;
- The simplification of the scoring to a simple narrative loses some of the detail on issues related to consensus and the theoretical basis of the cause and effect chain;
- The effort to record weight of evidence and retain and refine it through the study was welcomed by those attending the sector workshops.

Based on this feedback, it was decided that the scores be checked and refined and, as more evidence is gathered, issues of consensus and theoretical basis should be recorded. In addition whilst the simplified single value scoring defined above will be used as the basis of the pedigree score for the list of impacts and consequences (Tier 1), the approach may be expanded to reflect the full breadth of the original NUSAP definition of pedigree for the consequences that are explored in detail as part of the next levels of assessment (Tiers 2 and 3).

2.1.1.5 Assigning confidence level

For Tier 1 of the assessment a confidence level score was given to each of the identified impacts or consequences. The score is based on both climate effect and consequence and refers to the lowest confidence of the two. For example:

- If there is low confidence that there will be an increase in the frequency of intense storm events, but high confidence that there will be an increase in pluvial flooding, if there is an increase in the frequency of intense storm events. This therefore has a low degree of confidence.
- If there is high confidence that there will be an increase in seawater temperatures, but medium confidence that there will be shifts in populations of warm and colder water plankton, if there is an increase in seawater temperatures. This therefore has a medium degree of confidence.

The 'levels of confidence' terminology from IPCC[8] was used to provide some guidance for this, although initially only high, medium and low confidence classes were used. 'Very high' was used for a small number of impacts. The terminology used was as follows:

Confidence Terminology	Degree of confidence in being correct
Very high confidence (VH)	At least 9 out of 10 chance

[8] Details of the IPCC WG1 terminology can be found in: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/tssts-2.html . Background on the approach to assessing confidence levels is given in IPCC (2007) Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties. This can be accessed here: http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

High confidence (H)	About 8 out of 10 chance
Medium confidence (M)	About 5 out of 10 chance
Low confidence (L)	About 2 out of 10 chance
Very low confidence (VL)	Less than 1 out of 10 chance

Figure 2-3 Confidence terminology

The procedure to establish the Level of Confidence for each impact or consequence is as follows:

1) The preliminary list was scored by a research scientist and in most cases the sector champion
2) The scores were commented on at sector workshops; scores were subsequently changed where this was considered appropriate.
3) The scores are updated following peer review of Tier 1 and/or Tier 2 reports reflecting the views of peer reviewers, outcomes of the assessment and any other new evidence that emerges during the study
4) The final reports reflect the level of confidence scoring using appropriate language for the intended audiences.

The level of confidence attribute can be used to guide the scoring of likelihood as part of the selection of consequences for Tier 2 assessment. It is expected that confidence levels will become more refined as further information becomes available and more assessment is carried out.

Pilot Learning

The IPCC confidence terminology was generally accepted by experts as an appropriate approach for capturing uncertainty in the risk assessment. However, it was difficult to apply in cases where there was no substantial research literature. Despite these difficulties, the assessment of confidence will be maintained throughout the project and where there are wide ranging uncertainties in assessment these will be captured.

2.2 Policy Risk Mapping

Summary of Step 2: Policy risk mapping
Purpose: To a) enable identification of which risks are 'policy-relevant' according to current Government policies, b) acknowledge the effect of major policies that are already in place and c) inform analysis at a later stage of the potential benefits of successfully meeting policy targets.

Method: Departmental Adaptation Plans (DAPs) set out the objectives of central government departments and provide an assessment of how climate impacts may affect these. An assessment of all DAPs, as well as other relevant policy documents, can identify at an early stage those impacts which, having been identified in the previous step, are likely to be most relevant to government policy because the impact affects government objectives.

Each DAP seeks to identify existing policies already in place that affect the level of risk that climate impacts pose. Assuming that these policies are followed through, a qualitative assessment of these policies will enable the risk assessment to factor in the effect of these on modifying the level of risk faced both presently and in the future.

Many departments have long term plans for objectives where sustainability and resilience to climate change are important. Some of these plans set targets and aspirations. Given that the future socio-economic conditions of the UK are difficult to predict with accuracy, these targets provide a useful benchmark against which to base an analysis of risk.

Outputs: Mapping of current policies and adaptation targets to the broad range of impacts identified in Step 1. The outputs inform work on adaptive capacity (step 6) and the development of social and economic futures (step 10)

At a later stage in the assessment, reports from Reporting Authorities under the Adaptation Reporting Power of the Climate change Act (such as utilities and transport infrastructure providers) are expected to report on their own vulnerabilities and risks. These will provide additional evidence on organisations and sectors that provide important public services.

2.2.1.1 Identification of policy-relevant risks

This task is based on a review of Departmental Adaptation Plans (DAPs) and comparison with outputs from the scoping of impacts and consequences (Step 1).

This is a high level description of the policy landscape related to climate impacts for each sector of the CCRA.

- The primary source of information will be Departmental Adaptation Plans (DAPs) in England and Wales. These identify impacts relevant to each Government Department. They are often at a relatively high level and do not go to a level of detail comparable to the impacts being identified within the CCRA sector assessments (step 1). The DAPs do, however, allow current policy (as of March 2010) related to climate impacts to be aligned with Departmental strategy and objectives.

- The focus of this task is on policy and not regulation or guidance, as regulation can be seen as the enforcement of policy while guidance provides recommendation on the implementation of policy.
- A report will describe which organisations hold responsibility within each sector for setting policy or seeing it is enforced, for example one or more Government Department(s), government agencies or a regulator.
- The key policy documents relating to climate change in general or for specific impacts (i.e. heat, flood, sea level rise, drought, etc) will be described. This will help identify which policy areas are currently considered important by government.
- Of particular interest will be identifying gaps and overlaps in policy responsibilities.

2.2.1.2 Accounting for the effect of current policies

The aim of this task is to consider impacts within each sector and to identify where there is an existing policy response.

This task will use a structured approach to map existing policies on to impacts identified in Step 1. It will identify any areas where there is no existing policy response.

- The task will identify relevant policy in development (whether in the planning, drafting or consultation stage) where there is sufficient information available to do so. This emerging policy is not included in mapping against risk, as the content of policy may change as a result of consultation. However it will be flagged for consideration in subsequent steps of the risk assessment.

2.2.1.3 Inform analysis of different future states at a later stage

The outputs of this report will inform both the development of socio-economic forecasts and scenarios (step 10) and adaptation options to be considered in the subsequent Adaptation Economic Assessment and National Adaptation Programme.

- Although the Policy Risk Mapping is an important early step, it will also be an element which continues throughout the CCRA, being updated for English areas and Devolved Administration policy later in the CCRA programme. The initial assessment takes the Departmental Adaptation Plans (DAPs) published in March 2010 as the primary source, and uses these documents to set the initial scope. It is important to note that this also means that at this stage the policy risk mapping will be limited geographically and this is recognised.
- The adaptation effect of current policy (for example through long term targets) alongside autonomous adaptation estimates provides an estimate of “anticipated adaptation”.

2.2.1.4 Other sources of evidence

In addition to the information provided by the DAPs, a high level search will be made for additional relevant policy, regulation or guidance. This search will not be detailed as the DAPs typically reference most, if not all, of the relevant central Government policy within a sector. This additional search is undertaken to confirm that this is the case but also to provide wider detail such as EU policy where this may be relevant, e.g. the Water Framework Directive. The search also allows any relevant cross-sectoral policy to be identified, should it exist.

Where they have been completed, the outcomes of relevant Government reviews (e.g. the Cave Review) will also be considered, as they may signpost additional policy, policy gaps or recommendations for policy development.

Tier 2: More detailed analysis of selected risks

2.3 Identify Main Risks

Summary of Step 3: Identify main risks
Purpose: To create a manageable assessment (in terms of the time and resources available) by purposefully selecting a subset from the full list of over 600 impacts for more detailed assessment in Tier 2.

Method: Conduct a simple multi-criteria assessment based on what the preliminary evidence tells us about the magnitude and likelihood of consequences and the urgency with which adaptation decisions need to be taken. For the purposes of the CCRA an 'urgent' decision is one that needs to be taken in the next five years (i.e. before the next cycle of the CCRA reports in 2017).
The initial selection derived using this method is reviewed by sector champions and additional sector specialists. Further refinement of this process occurs in subsequent steps and particularly to tailor the selection of risks for Devolved Administrations.

Outputs: Lists of impacts that should be considered, marginal impacts that may be considered and impacts that are not considered as part of the more detailed work in steps 7 to 12.

Tier 1 identified over 600 impacts of climate change across 11 sectors, and several cross-cutting themes. To be able to perform a meaningful risk assessment with the time and resources available it is necessary to select a sub set of the climate impacts to take forward to further analysis.

2.3.1.1 Selection method

This is an important stage of the assessment so a thorough process was constructed to identify a robust and transparent selection method. The process followed to develop the method was:

- General criteria for selection were drafted by Defra and the project team
- HR Wallingford tried out methods on the pilot water sector
- Method was reviewed and refined by the CCRA technical sub-group of In-House Experts.
- HR Wallingford applied the selection method with advice from sector experts.
- Selection for each sector was discussed at sector group workshops or where these were not possible through telephone interviews and smaller meetings
- Further lessons learned from later stages of the pilot were tested with In-House Experts for refinement

2.3.1.2 Selection method detail

Although some risks were selected for further analysis, no risks were discarded from the assessment altogether and all identified impacts remained logged for basic reporting in the final report.

The selection process is based on a simple multi-criteria assessment that uses the preliminary assessment of consequences, likelihood and the urgency with which adaptation decisions need to be taken. Criteria for each of these are set out below.
At this stage of the assessment, accurate scoring of these criteria was not possible. Therefore, criteria were developed defined by narrative and semi-quantitative descriptions of what constitutes ‘high’, ‘medium’ and ‘low’ scores (e.g. ‘high’ magnitude of consequence or ‘low’ urgency) to ensure consistency across sectors.

The criteria agreed by the technical advisory group to the CCRA (the In House Experts Group) to select the risks were:

- Magnitude of consequences, where total consequence is the sum of
  - Economic consequence
  - Social consequence
  - Environmental consequence
- Likelihood of the impact occurring
- Urgency with which a decision needs to be made

The criteria were equally weighted and the scores were derived by following the guidelines outlined in the appendices (selection scoring criteria).

Pilot Learning

Initially, the 'urgency' criteria was scored and included in the analysis in a multiplicative way. Further refinement lead the team to recommend that, theoretically, a binary (filter) approach would be more appropriate (i.e. if a decision is not urgent simply filter it out of the list of main risks).

However, in practice, sensitivity testing showed this made little difference to the overall selection outcome. As this stage of the analysis had been completed and there was a further round of refinement to come based on expert opinion it was decided not to go back and rescore all the impacts on a binary decision urgency criteria as this would make no practical difference in this case.

2.4 Cross sector links

Summary of Step 4: Cross sector links
Purpose: To a) investigate interactions between the sectors; b) identify cross sectoral themes and c) build an understanding of the complex cause and effect interactions of climate impacts, on which future analysis can build. (Modelling interactions quantitatively is not in scope).

Method: The systematic mapping approach provides a formal method of identifying direct, indirect and 'cross-sectoral' impacts and consequences. The general approach is:

- Identify and characterise impacts of climate change.
- Sector champions (i.e. experts) review these impacts and add any additional impacts that are relevant to their sector.
- Sector champions identify the outcomes that flow from the impacts (causes) and this process is repeated, whereby in each iteration the outcome from the previous iteration become the cause in the next .
- The resultant database is checked for rogue entries, duplicates etc and then reviewed by each sector champion.

A customised web based application has been developed specifically to enable the rapid systematic mapping as described. Newly defined cross-sectoral impacts that this mapping identifies are reviewed and those that have large consequences are added to the shortlist that will be taken forward for further analysis.

Outputs: a) Systematic maps that describe the interactions between climate, impacts and consequences both within and between sectors b) A searchable database that can be used to identify linkages related to climate variables, sectors or processes and c) cross sectoral impacts that may be selected for further Tier 2 Analysis.

The systematic mapping aims to identify key linkages between causes and consequences and the processes that lead to change. It is largely descriptive and does not seek to quantify the change in anything other than qualitative terms and without reference to specific future scenarios. The systematic mapping is also a process based method and will not cover risks that are a result of emergent system properties (i.e. which are not tied to a particular climate variable), such as collective societal response to the threat of climate change. Furthermore, it is inevitable that although every effort will be made to make the mapping comprehensive and to a consistent quality, it will be incomplete (there will always be unknown unknowns). A more detailed explanation of the systematic mapping method is provided in the Appendices.

2.4.1.1 Basic approach

The first step is to identify the impacts (or in rare cases consequences) that arise directly from changes in climate variables. It is expected that the direct impacts will be largely bio-physical. The climate variables to choose from are described in a database, and are based on UKCP09. Experts who undertake the systematic mapping consider those climate variables that are most relevant to their sector or area of interest.

The first round of mapping deals with just the direct impacts that arise from changes in the climate variables – in rare cases, these direct impacts will have immediate consequences (e.g. heat can have a direct impact on health, a social consequence). This will generate an extensive list of impacts which will be rationalised to remove duplications and merge terms, where appropriate, to establish a consolidated list of impacts. These impacts will then be used as the causes of change for the next round of mapping, where secondary bio-physical impacts will be captured. Some further social, environmental and economic consequences will start to be captured. This iterative process is illustrated in the Figure below.

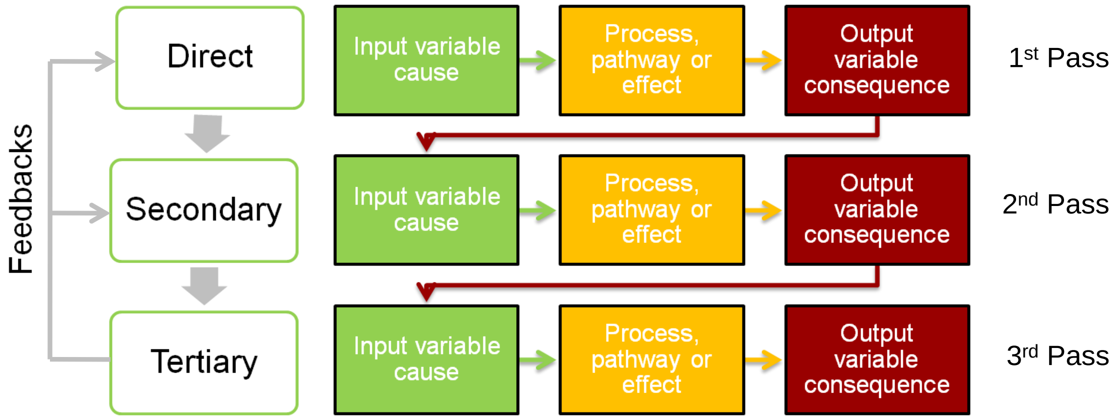


Figure 2-4 Illustration of forward chaining process

The mapping exercise will focus on identifying linkages between causes through to impacts and their consequences and a description of the linking process; in some cases other evidence may already define such linkages in detail using process models (e.g. flood risk) but systematic mapping in the CCRA focuses solely on understanding what the links are rather than the ability to represent or model the links.

To keep the process bounded, defined and manageable the cause, process and impacts / consequences are each defined in terms of a simple set of key words. However, for each process and consequence there is an opportunity for an author inputting data to add a short narrative to provide more detail and where possible include links or references to further more detailed information. Where the simplified key words do not capture the process or consequence identified, those entering data are requested to suggest alternative key words in the narrative.

For consistency, the consequence and associated process should be given in the positive form, which may then increase or decrease as a result of the change. For example, rather than stating that “crop failure is increased”, this can and should equally be written “crop production is reduced.”

There are a number of steps required to complete each iteration of the process:

- The data entry will be undertaken by the Sector Champions and core team sector analysts, starting with the climate variables as the cause of change for the initial (1st pass) data entry.
- Upon completion of the data entry for each iteration, the results will be consolidated to remove duplications and merge terms
- The consolidated list of consequences will be used for the next iteration
- After 3 or 4 iterations (to be determined based on feedback from Sector Champions) the completed mappings will be made available for review to other sector specialists.

2.4.1.2 Data Entry and Search Tools

To assist the process, a web based tool has been developed. Registered users enter data, search the data under a range of criteria, view, edit and delete records, and plot the results of the search as a simple diagram (digraph). Screen shots of the data entry and search results pages of the web tool are shown in the figures below. The fields used in the data entry form and the definition or type of values that can be entered are detailed in the table below.

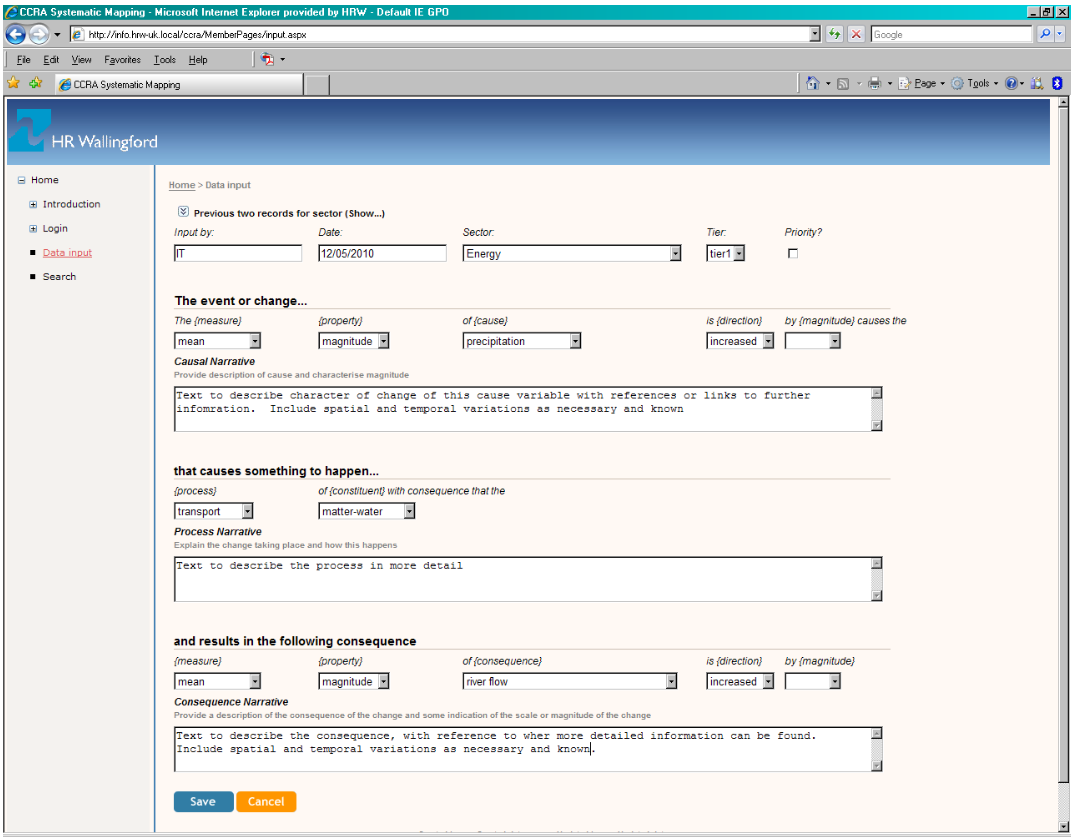


Figure 2-5 Screen shot of web tool for data acquisition

Data Field	Input required
Input by	Entered automatically based on login
Date	Entered automatically based on current date
Sector	1st Pass direct impacts classified as "Bio-physical" *Initial sectors:* Agriculture, Biodiversity and ecosystem services, Built Environment, Business/Industry/Services, Energy, Fisheries/marine, Flood & coastal erosion risk management, Forestry, Health, Transport, Water (supply/demand/quality) *Additional cross-cutting themes (to be added later):* Critical Infrastructure, Emergency Services, Finance and Insurance, Security, SMEs, Spatial Planning, Telecommunications, Vulnerable Groups
Pass	1st Pass, 2nd Pass, etc
Cause	
Measure	Duration of, Existence of, Extreme (high), Extreme (low), Frequency of, Mean, Sequence of
Property	Magnitude, Direction, Occurrence, State
Cause	Field lists available change with each pass. The 1st Pass uses the climate variables. Subsequent passes use a consolidated list of consequences from previous passes. *The initial climate variables are:* Aridity Carbon dioxide, Cloud cover, Drought plus intense rain, Growing season, Humidity, Intense rain plus high temperature, Lightning, Mist / fog, Ocean pH, Precipitation, Pressure, Sea level, Sea temperature, Snow, Storm surge, Storms[9], Summer precipitation, Summer temperature, Temperature, Waves, Wind speed, Winter precipitation, Winter temperature

[9] In this report we used the term storm to indicate sever atmospheric conditions marked by strong wind (wind-storm), thunder and lightning (a thunderstorm), and heavy precipitation. UKCP09 does not provide data on changing storm frequency or severity.

Direction	Changed, Decreased, Gained, Increased, Lost, Unchanged
Magnitude	Free entry field for indicative order of change to be given as a value, percentage or text (which can be expanded upon in the narrative)
Causal narrative	Free text to capture a more detailed description of the cause, together with references to sources of further information.
Process, pathway or event	
Process	Consumption, Exchange, Migration, Reaction, Transfer, Transmission, Transport
Constituent	Chemical, Data/information, Energy, Fauna, Flora, Genetic material, Money/value, Pathogens, People, Sediment , Water
Process narrative	Free text to capture a more detailed description of the process, together with references to sources of further information.
Consequence	
Measure	Duration of, Existence of, Extreme (high), Extreme (low), Frequency of, Mean, Sequence of
Property	Magnitude, Direction, Occurrence, State
Consequence	Free text field to characterise the consequence in a few words (50 character field)
Direction	Changed, Decreased, Gained, Increased, Lost, Unchanged
Magnitude	Free entry field for indicative order of change to be given as a value, percentage or text (which can be expanded upon in the narrative)
Consequence narrative	Free text to capture a more detailed description of the consequence, together with references to sources of further information.

Figure 2-6 Summary of data fields for data entry

2.4.1.3 Application to Tier 2 Risk Assessment

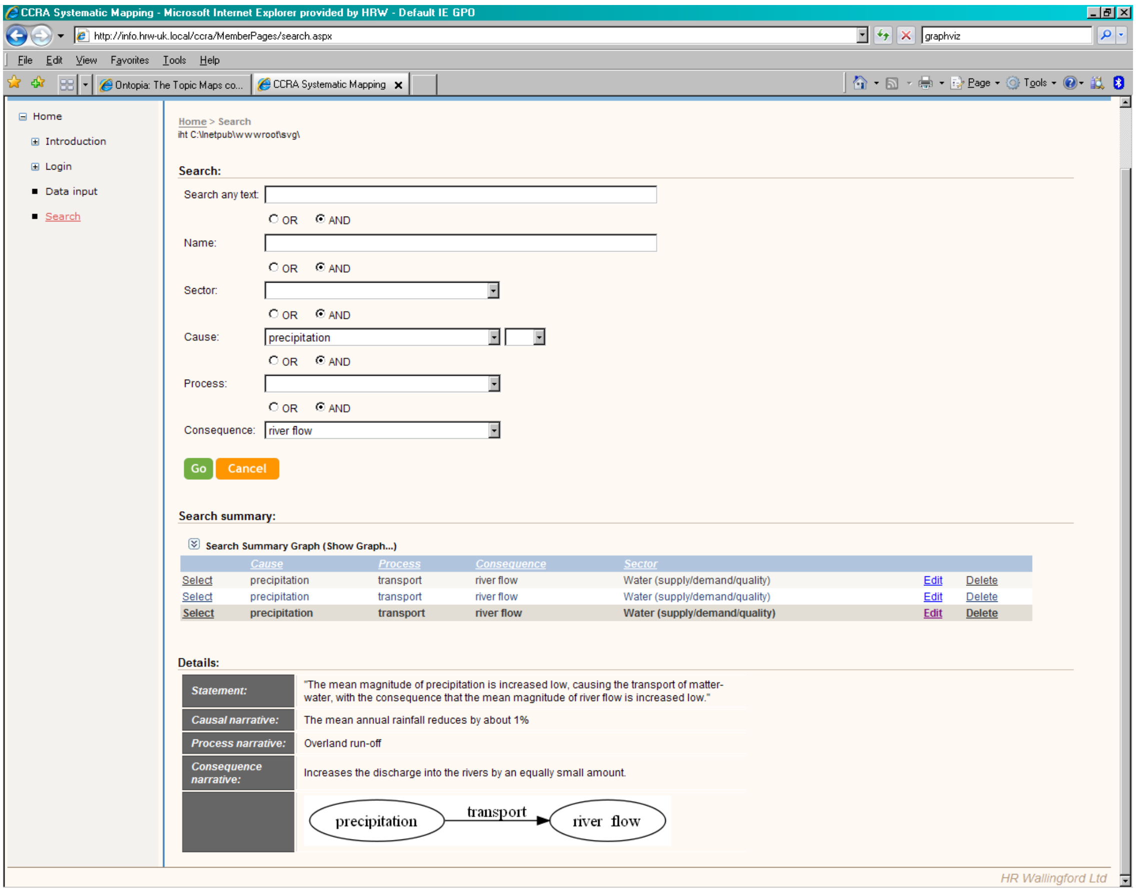


Figure 2-7 Screen shot of web tool for data interrogation

Once the data entry is complete, the results will be used to:

- summarise impacts and consequences by sector and identify any impacts/consequences that were not identified in the Tier 1 risk screening exercise.
- identify cross-sector consequences based on inter-connections introduced by sectors in response to changes in other sectors
- expose the completed results to specialists from the already identified cross-cutting sectors (security, telecommunications, etc) so a further set of consequences can be identified
- examine the results for potential feedback loops to climate change. The process adopted should establish links between consequences generated from the 1st, 2nd and 3rd passes (and potentially further passes) but not necessarily back to the starting cause (climate change). The consequences will therefore be examined for their potential to influence the climate change variables and any additional links added as feedback loops.

The consequences identified from each of the above will each be subject to the selection process used for the Tier 2 risk assessment and consideration will be given to adding any that score highly into the assessment process.

In addition, the options to simplify the data in ways that can be used to illustrate relevant aspects of the system and communicate key issues will be explored. This will examine the potential role of more sophisticated tools for analysis, synthesis and filtering of the data (e.g. topic mapping tools based on ISO 13250). The purpose is to explore what could be achieved in future risk assessment cycles and in other research.

2.5 Consider Equity

Summary of Step 5: Equity
Purpose: To reflect distributional considerations (social equity) in the assessment of risk.

Method: A social vulnerability 'checklist' has been developed against which to review the impacts of climate change.

Ways to incorporate equity to contribute to the balance of risk metrics will be identified at this point.

Outputs: A qualitative iteration to refine the short-listed climate impacts being taken to a Tier 2 level of assessment. A summary of equity issues, based on social vulnerability, for reference in the risk assessment reports and for further consideration in the appraisal of adaptation options at a later stage. Risk metrics that reflect vulnerability will be produced for Step 7.

2.5.1 Background

Equity considerations are an important part of the Government's rationale for intervention. The purpose of this step is to incorporate a brief description of the distributional effects of impacts identified in the Tier 1 assessment. This complements the assessment of the magnitude of social consequences that informs the selection of Tier 2 risks for further analysis.

Evidence on distributional effects of climate impacts within the UK is a relatively new field of evidence and recent discussion[10] has shown that incorporation of social vulnerability in to assessment is an emerging field. Although there are studies currently underway to fill this gap in knowledge (in particular the climate impacts programme of the Joseph Rowntree Foundation and studies funded by the Economic and Social Research Council) the CCRA incorporates this complementary step to provide a check on which to refine the selection of Tier 2 risks, identify risk metrics that reflect equity and help incorporate equity consideration in later stages.

This step is based on the application of a simple social vulnerability checklist, which supports the identification of risk metrics that reflect equity (see Step 7).

SNIFFER (2009a, 2009b) provide a recent and comprehensive review of social impacts and vulnerability to climate change. Their framework draws out some key social impacts of three climate impacts (heatwaves, flooding and storms) as well as three types of factors that increase social vulnerability to those impacts. This summarises social vulnerability in three categories:

1. Living in places at risk:
    a. Location
    b. type/frequency of event
2. Who are socially deprived in terms of:
    a. Poor health

[10] E.g. Joseph Rowntree Foundation discussion *Justice, Vulnerability and Climate Change* in Manchester in March 2010, UKCIP *Vulnerability Workshop* in London, April 2010.

    b. Financial resources
    c. Quality of home/workplace
    d. Mobility (in terms of transport)
3. Who are disempowered because of
    a. lack of awareness
    b. social networks
    c. systems and support

The first category “place” focuses on the exposure aspect of vulnerability, while the second category “social deprivation” focuses broadly on ‘sensitivity’.

2.5.2 Using the Social Vulnerability checklist

Each sector has generated a list of impacts of climate change for their sector and, as noted above, understanding distributional impacts will be necessary in order to assess the magnitude of the consequences.

It is impractical for this study to assess every Tier 1 risk against the social vulnerability checklist in detail. Instead, broad clusters of risks are used - which have already been developed, simply to facilitate communication and understanding between and within sectors. For example, in the water sector, although there are well over fifty Tier 1 impacts, they can be clustered into four broad areas:

- Pressures on water availability
- Pressures on water quality and ecology
- Deterioration of water company assets
- Water use and recreation

The checklist above is used against the broad risk clusters in each sector. A typical list of questions is provided below, using ‘Pressure on water availability’ the example risk, and below this an example of the type of evidence anticipated.

CAG social vulnerability factor	Questions to ask
Place	**Which locations are affected by *pressure on water availability*? Is it spread evenly across the area or not?**
Social deprivation	**How will people with poor health (physical or mental) be affected by *pressure on water availability*?**
	How will people with fewer financial resources be affected by *pressure on water availability*?
	How will people living or working in poor quality homes or workplaces be affected by *pressure on water availability*?
	How will people who have limited access to public and private transport likely be affected by *pressure on water availability*?
Disempowered	**How will people with lack of awareness of the risks associated with security of supply of water be affected by *pressure on water availability*?**
	How will people without social networks be affected by *pressure on water availability*?
	How will people with little access to systems and support services (e.g. health care) be affected by *pressure on water availability*?
Other factors	**Are there any other social vulnerability factors to consider with *pressure on water availability*?**

Figure 2-7 Social Vulnerability Assessment questions for the consequence: reduced supply of water

Category of social vulnerability factor	Questions to ask	Comment	Evidence	Extent
Place	Which locations are affected by reduced supply of water? Is it spread evenly across the area or not?	North-West and Midlands (reduced supplies) South and East (supply-demand deficit) Significant variation within areas with 'hot-spots' in 'growth areas'	Pilot Study Reynard, 2010	Numbers available from Tier 2 assessment – population affected

Figure 2-8 Illustrative Social Vulnerability Assessment checklist entry

The checklist, in the table above, seeks to capture a response to the questions based on information drawn from the Tier 1 sector papers (which included a question specifically on vulnerable groups), current research and the outputs of the Tier 2 risk assessment work. In the 'evidence' column the check list records a) if there is evidence and b) what sort it is i.e. expert, published research, modelled etc., and the same characteristics that are applied to the impact evidence (e.g. pedigree) will be assigned. In addition, information on the approximate scale of the distributional effects will be indicated in the extent column; these data will be available from the Tier 2 assessment based on baseline socio-economic data, and the use of Government projections.

2.5.3 Incorporating equity in risk metrics

Risks selected for Tier 2 which have been selected largely, or partly, because of their distributional consequences will be assessed to develop risk metrics, in line with the need to keep a good balance of risk metrics overall (see risk metrics section). An example of an existing measure that could be such a risk metric is the Outcome Measure 3 for flood risk management, discussed below.

Example of a distributional risk metric

The Outcome Measure system was initiated with measures and targets, set for achievement by Environment Agency, Local Authorities and Internal Drainage Boards, within the 2008-11 Spending Review Period. The expectation was that programmes of work that necessitated the expenditure of government capital would be prioritised according to their contribution to the targets, which now included more social than solely economic orientated factors.

Five outcome targets have been set for operating authorities to achieve over the 2007 Comprehensive Spending Review (CSR07) period. The CSR07 period is from April 2008 to March 2011. Of interest is Outcome Measure 3 (OM3). OM3 introduces deprivation reduction as a further measure of Flood Coast and Erosion Management success. Informed by research into the relationship between flood hazard exposure and multiple deprivation (Walker et al., 2006), OM3, in effect, necessitates the use of the Index of Multiple Deprivation (IMD) as a means to identify those neighbourhoods, where the allocation of FCERM benefits, could be most effective in reducing the risks faced by the exposed population's most deprived (ergo some of its most vulnerable) members. Outcome Measure 3 is linked to Outcome Measure 2 which focuses on the reduction of the number of households at risk from flooding. As per their description these are based on outcomes (adaptation in the context of this study) and would be framed differently to assess risks.

OM2 Households protected	Number of households with improved standard of protection against flooding or coastal erosion risk.	e.g. There were 145,000 households at risk of flooding. The outcome is that 45,000 household are now at a reduced risk from flooding (move out of the 'significant' or 'greater' class).
OM3 Deprived households at risk	Number of households for which the probability of flooding is reduced from significant or greater through projects benefiting the most deprived 20% of areas.	e.g. 9,000 of the 45,000 households above, are classed as deprived households.

Figure 2-9 Potential risk metric incorporating equity for flood risk

Pilot Learning

- As part of the pilot work, evidence was collected on 'vulnerable customers' according to the water industry definition that identifies households that require a continued supply of water for health reasons. These customers are recorded as part of the company's drought contingency plans (for provision of emergency supplies) and can't be disconnected from the water supply network.
- The application of the checklist ensured that the issues of water affordability and poor health were recognised within the assessment. In addition as some background evidence (Walker Review) and data were available a metric could be developed that highlighted the number of vulnerable customers at risk in each English area of the UK.
- It is likely that other sectors will have much less data available on distributional consequences so some qualitative judgements will be required.

2.6 Incorporate adaptive capacity

Summary of Step 6: Assess adaptive capacity

Purpose: To a) inform the assumptions that the risk assessment needs to make about the degree to which autonomous adaptation of major UK sectors will be effective and b) inform an assessment of the degree to which current major UK sectors have institutional capacity to adapt. Most primary work in the CCRA relates to adaptive capacity of *institutions* and not other systems such as ecosystems.

Method: The primary work carried out for the CCRA focuses on *institutions and decision makers*. An initial literature review will summarise what is known about capacity in different sectors, so as to assist in selection of Tier 2 risks. Among selected sectors the PACT methodology will identify those with a high, medium or low risk of poor decision making. The adaptive capacity of other systems will be considered where existing evidence can aid this.

Outputs: Assessment for specific sectors and institutions, focused on decision making, which will inform assumptions made about levels of autonomous adaptation (Step 13). The detailed work on adaptive capacity will be a major input to the Adaptation Economic Assessment (AEA).

2.6.1 PACT Method

The purpose of this step is to identify the existing adaptive capacity of organisations, sector bodies and their capacity for decision making that takes proper account of the needs of adaptation. It uses the PACT (Performance Acceleration Climate Tool) methodology to identify those sectors with a high, medium or low risk of poor decision making, which will be used to guide the development of socio-economic scenarios and the assessment of autonomous adaptation (Steps 10 and 13).

Adaptive capacity is relevant to the risk assessment because the level of risk is likely to increase in the future, especially the medium and longer term. The future level of risk will be affected by the amount and quality of adaptation (i.e. of 'autonomous adaptation') that can be expected. Therefore work on adaptive capacity will inform sector assumptions on autonomous adaptation as part of the risk assessment. It will also contribute significantly to later work on the Adaptation Economic Assessment.

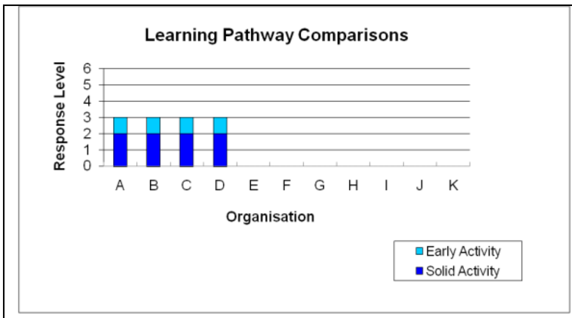
This is of particular importance where major, costly and hard to reverse actions (such as infrastructure renewal) are taken, which are likely to have a major impact on the level of risk. A key premise is that higher capacity organisations are likely to recognise and implement adaptation actions better, so that future risks are likely to be lower than where lower capacity organisations are involved[11].

For the assessment of risk, a very high level initial view of the quality of adaptive actions in the sectors will be taken, based on existing surveys – e.g. linked to the Carbon Disclosure project. This will provide simple metrics to assist in the prioritisation of sectors for more detailed analysis. To inform the National Adaptation Programme

[11] By 'organisations' we mean both formal organisations (such as water companies and local authorities) but also the temporary organisations that arise around specific adaptation actions (such as consortia that are being formed to address, say, sewage pipe replacement in a catchment area).

more directly, adaptive capacity will be assessed in detail in five sectors[12] (resources and time were insufficient to cover all eleven sectors). In each of these sectors we:

- Use the PACT self-assessment methodology to review a selection of organisations that take decisions in the field. This will take a ‘bottom up’ approach to the assessment of capacity, producing graphs such as those shown below (anonymous results taken from the water sector pilot study).
- In parallel, industry level organisations – trade organisations, civil servants (including in the DAs), regulators, etc will be examined. The purpose in doing so is to understand the help and assistance that can potentially be (or is already) given to individual organisations in taking crucial decisions. In parallel, some industry bodies have voluntarily undertaken a PACT assessment.
- Finally, a small number of actual adaptation actions that are being taken in the sector will be reviewed to see how any gaps are filled in practice.

<table>
<tr>
<td>
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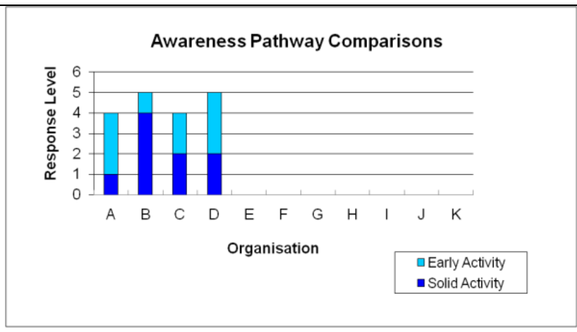
<td>
</td>
</tr>
<tr>
<td>Whilst PACT ‘response level 5’ is considered necessary for much work undertaken in the water sector, initial results suggest work needs to be done on improving basic learning processes for this to be reached.</td>
<td>The required levels of awareness of risks are, however, being approached in all organisations. Awareness-raising is less likely to be a priority for these organisations.</td>
</tr>
<tr>
<td colspan="2">The analysis will go further than the above, identifying specific ‘activities’ that are being implemented, or not, and by what proportion of organisations in each sector. Specific questions arising from the risk assessment have been framed to clarify (for instance in the water sector) how capacity differs between water resource planning and water quality, biodiversity, etc.</td>
</tr>
</table>

This provides a ‘bottom up’ and a ‘top down’ analysis of capacity, grounded in two or three case examples of on-the-ground actions.

More detailed work will be used to develop an assessment of the likely quality of any adaptation actions that may take place in each sector, i.e. in the absence of some adaptation intervention(s). The metrics for this opinion will be data-driven (along the lines above) but are also likely to be somewhat qualitative – e.g. high, medium or low risk of poor decision making. These will inform the assessment of autonomous adaptation (Step 13). The analysis will also point to suggested adaptation actions where an improvement would be most likely to assist outcomes, for further

[12] Working from this analysis of adaptation priorities, in agreement with funding organisations and other members of the project team, 5 sectors were selected for detailed analysis of adaptive capacity.

consideration in the adaptation and economic evaluation stages of the project (Stages 4 and 5).

2.7 Identify risk metrics

Summary of Step 7: risk metrics

Purpose: to a) identify practical metrics that together broadly encapsulate the most important consequences of climate change and b) identify data sets and data needs.

Method: A selection of metrics will be chosen to provide a balance across a number of criteria. A good balance of metrics:

- Is sensitive to climate but also allows the disaggregation of the effects on risk caused by climate change from effects on the level of risk caused by socio-economic change.
- Can be presented at all required geographical scales. Government datasets will be preferred sources to provide consistency between sectors and subsequent CCRA cycles.
- Reflects the three categories of economic, environmental and social consequences of climate change.
- Includes a consideration of equity though social vulnerability metrics.
- Is relevant/has legitimacy to the relevant Government policy.

Some metrics may be quantified, and some may be monetised but others will be qualitative (for example, the extent of valued habitats affected or any disproportionate consequences for disadvantaged groups in society). Sector group workshops contribute to the identification of suitable risk metrics and these are reviewed by the sector champions

Outputs: List of risk metrics for each sector along with data requirements that are used in Step 8.

2.7.1 About risk metrics

Risk metrics describe the consequences of climate impacts. For example, the proportion of the population affected by water supply shortages due to drought, or the financial cost of journey delays due to buckled rails.

In some data rich sectors metrics may exist that also incorporate more sophisticated aspects of the risk such as the changing frequency of events, or both changes in probability and consequences (such as changes in Expected Annual Damage (EAD) estimates used in flood risk management[13]).

Examples of risk metrics include:

- Average number of people flooded per year (no.)
- Number of 'vulnerable[14]' people living in the 1 in 100 year floodplain (no.)
- Crop water demand (mm)
- Optimum crop yield (kg/ha) (i.e. classic crop response curves)
- Water availability for public water supply (Ml/d)

[13] For most sectors there are insufficient data to understand the changes in probability of extreme events due to climate change and climate models have limited skill in describing relevant variables, such as wind speed and storm frequency. Therefore, simpler metrics describing consequences are the 'norm' and more appropriate.
[14] Typically defined in terms of age, social groups or multi-deprivation indicators

- Ecological status (no. of sites in a class)
- Habitat loss (hectares)
- Numbers of people suffering heat stress (no.)

2.7.2 Approach

The approach to developing risk metrics is as follows:

1. Once the list of consequences has been selected, a range of possible metrics is identified for each consequence. Draft lists of metrics are produced by the sector champion.
2. Potential risk metrics are discussed with expert groups and sector workshops, explaining how they relate to the impacts. This list is then reviewed by the sector champion, including adding any important metrics that they feel have been left out and narrowing down impacts identified as unsuitable to leave a set of metrics that reflect the main issues in that sector.
3. The examination of potential metrics takes a number of factors into consideration including explicitly examining the advantages and disadvantages and how the metrics can be defined (either qualitatively or quantitatively).
   Specifically, the following format is used to help this process and clearly recognise that no one metric is a 'magic bullet':

   "We propose [*what*] as the metric, for use [*with what impacts*]. The proposed metric will have the following [*advantages*] but we also recognise the following [*difficulties*], which should be overcome by [*how*]. The data needed will be [*what data*] and to collect it, we will need to [*do what*]. Possible counter arguments to this approach are [*list of counter arguments*] but even so we are making our proposal because [*why*]."
4. The results of the workshop discussion are analysed to derive a number of metrics for the UK-wide CCRA and potential alternative metrics for Devolved Administrations. The practicality of each metric in terms of data availability, any data licensing issues and the complexity of the metric are considered. Where the assessment required includes large amounts of analysis it is 'parked' for possible Tier 3 assessment or future risk assessments. If the metric would require original research it should noted and be recorded in the research gaps report.
5. Risk metrics are reviewed by policy makers to incorporate any policy relevance perspective.
6. Selected metrics are written up and include:

- the rationale for their selection
- sources of data including quality assessment
- the calculation method
- key assumptions and caveats and
- the metric's sensitivity to climate and socio-economic variables.

Pilot learning

The Water Pilot Experts workshop enabled detailed discussion of potential metrics, including the identification of existing data sets and analytical methods that could be applied within the CCRA. Both the Water Pilot Experts workshop and the Water Sector Workshop identified relatively simple metrics, such as changes in the regional water balance, but these were not immediately appropriate for quantifying risks (i.e. they did not always meet the criteria outlined above). Metrics that described indirect consequences, such as the number of people facing water shortages, were most relevant. Even if the metrics are based on statutory data in the public domain, it takes considerable time to develop comprehensive data sets for national risk assessment. For example more than 20 data sources and requests were needed to extract data for just one water supply metric.

The metrics used in the water resources Pilot Study fall into three groups and span metrics that could inform both Tier 2 and Tier 3 assessments. They were related to:

1. Supply demand deficit for public water supply (Ml/d).
    a. This encapsulates a range of supporting data in order to calculate a supply demand deficit, e.g. the average demand for water and decline in water availability and so on.
    b. A decline in water availability expressed as Deployable Output (Ml/d) is sensitive to any decline in water quality as well as changes in river flows and groundwater recharge. It is appropriate for Tier 2 assessment.
    c. The results of a full supply-demand balance is sensitive to a wide range of factors. It requires a number of analytical steps incorporating socio-economic and climate data and is appropriate as a Tier 3 metric. It can be presented in a number of ways, e.g. as an absolute deficit, percent deficit or as the number of people affected.
    d. These metrics require data from statutory Water Resources Plans, Business Plans and June Returns from water companies in England and Wales. Equivalent data do not exist in Scotland and Northern Ireland, although some assessment can be made by introducing assumptions in areas where data are limited.
    e. This metric can be monetised and/or presented in social terms indicating numbers affected (potential water shortage or increase in the cost of bills) or specifically the vulnerable people affected.
2. Low flow ecological status (no. of sites)
    a. This metric involves an assessment of data in the Environment Agency's 'CAMS Ledger' to estimate the no. of sites where ecological status and abstraction would be affected by lower river flows.
    b. This metric can be presented on a regional and sectoral basis and provides an indication of declining water quality and/or the likelihood of losing time-limited abstraction licenses.
    c. This metric can be monetised if assumptions are made about the environmental value of sites and/or the value of abstraction licenses.
3. Water quality change (km)
    a. This is a qualitative metric that estimates the length of river that may decline in status due to discharge consents. It is based on Environment Agency modelling and expert opinion.
    b. The metric can be monetised, at least in terms of order of magnitude, (as qualitative function data will be in classes rather than as values) if assumptions are made regarding the costs of declines in water quality per km of river.
    c. This metric can be quantified as part of Tier 3 assessment by working in collaboration with the Environment Agency.

2.8 Assess how risk metrics vary with climate

Summary of Step 8 - Assess how risk metrics vary with climate

Purpose: To graph quantitatively or qualitatively the sensitivity of risk metrics to climate according to available evidence.

Method: Review of existing research by sector experts, including recording key assumptions and uncertainties related to the assessment.

A response function shows how climate consequences vary with climate variables. The evidence required to develop a response function includes:

- Present day values of the consequence metric, e.g. rail disruptions due to extreme heat.
- Change in values as the climate variable changes e.g. additional number of disruptions due to extreme heat experienced in the past.

Most response functions will be imprecise / qualitative and based on expert elicitation involving the sector groups. Response functions will only be fully quantitative where there is existing evidence to enable this analysis. Some may directly link damage costs to climate variables.
Outputs: Sets of qualitative matrices and quantitative sensitivity plots, relative to a defined baseline, that estimate changes in risk metrics in response to changes in climate variables. These are used in Steps 9-14.

2.8.1 About Response Functions

The purpose of this step is to understand the sensitivity (according to the available evidence and expert opinion) of risk metrics to changing climate conditions. The development of response functions is based on qualitative/imprecise assessment by groups of experts and practitioners or quantitative analysis based on existing research studies. In both cases key assumptions and uncertainties are recorded and captured where possible by using expert elicitation techniques.

The conceptual disaggregation of climate and non-climate drivers of risk is an important part of the assessment. This will be achieved through identification and application of response functions that describe the sensitivity of a consequence to climate variables and separately the sensitivity to other basic socio-economic variables. Response functions may be based on observations, modelling or expert opinion or a combination of these. As such they are not 'best-fit' lines or empirical models that predict consequences based on climate variables. They are however a simple way of presenting the available evidence and enable some interpolation and scaling of consequences so that they can be presented with respect to UKCP09 projections and socio-economic forecasts or scenarios.

Particular care is required if any scaling of consequences involves extrapolation beyond the available evidence because there may be thresholds in natural and social systems that may either dampen or exacerbate (via feedbacks) consequences of climate change. Many of these thresholds are unknown unless detailed research has already been completed to identify critical thresholds in systems. Some validation of these functions is possible in cases where there has been significant research involving modelling of the future impacts of climate change or by examining spatial or temporal analogues of change for the UK climate, e.g. rainfall-runoff relationships in Southern France may provide an analogue for the UK in the 2030s (though spatial analogues must also be treated with caution).

In practice, for this first cycle of the risk assessment, many thresholds will be unknown. However for metrics where thresholds are known the assessment can identify thresholds and possibly illustrate the likelihood of exceeding thresholds as part of steps 8, 9 and 10.

2.8.2 Approach

The steps to develop response functions are:

1. Review available research studies and industry reports on the sensitivity of metrics to climate. Consult with academics and other experts on the appropriateness of linking particular metrics to changes in climate variables.

2. Collect the available data from research literature and organisations.

3. Identify which climate effect(s) the metrics are sensitive to: for risks where there is a clear dominant variable it will be possible to map climate variables directly to risk or consequence metrics. For example, coastal 'squeeze' of ecosystems will clearly be affected most by sea-level rise. For many risks, derived climate variables (combining two or more primary climate variables) will be most appropriate. Examples include relative aridity (which is a function of precipitation and temperature – see below) and potential evapotranspiration. The systematic mapping exercise will be consulted to check if it has already identified the key climate variables linked to the relevant consequences.

4. Socio-economic sensitivity: in most cases risk or consequence metrics respond to both climate and socio-economic variables. Response functions can also be developed for socio-economic variables. However the climate and socio-economic drivers will be applied as a two-step process to disaggregate climate and non-climate factors so that assumptions are clearly stated and an audit trail established. For each risk and individual metric the key socio-economic sensitivities will be defined. For example the total demand for water for public use is sensitive to population growth, household numbers, technological change and attitudes to water use.

5. Synthesise and scale risks: Each response function is constructed to two dimensions: the metric (y-axis) versus climate variable (x-axis).

    a. For imprecise/qualitative metrics a simple matrix with classes indicating ranges of change in a consequence versus changes in climate variable should be used. The ordinates of the function may be derived, in the first instance, from existing studies or developed through expert elicitation in small groups. Then the views of a wide group of experts should be sought in order to explore different views and capture the uncertainties related to estimating consequences. This expert elicitation should record individual's expertise and any reasoning behind scoring of consequences, citing the research literature where information exists (Cooke, 1991; Aspinall, 2010).

b. For quantitative metrics, simple sensitivity plots can be developed to link consequences with rising temperatures or other climate variables. In some cases it may be possible to include confidence intervals for these relationships but in others this will not be possible and a choice will need to be made as to whether to retain the function in quantitative form or reduce to a more qualitative assessment to avoid a misleading level of precision.

The information gathered in step 2 above should be sufficient to present current risks from a baseline of (ideally) 2010. Of course risk metrics can be framed in absolute terms (e.g. the number of people affected) or relative terms (e.g. an increase in the number of people affected). If the latter, there will need to be a record of the current baseline exposure, burden, expected annual damage or similar, to make any sense of the relative change due to climate. Monetised risks are the easiest to compare but otherwise recording number of people, properties, etc. affected is useful and the magnitude tables (Figure 2-5) can be used to guide definition of high, medium, low consequences for expert elicitation matrices.

In the subsequent step 9, these functions can be used to scale consequences for a range of climate projections: the analysis will be presented for near term thirty-year time periods (2010-2039- "2020s") and medium and longer term (2040-2069- "2050s" and 2070-2099- "2080s"). This also facilitates a direct link to the Adaptation Economic Assessment, capturing the different adaptation categories and policy horizons. Risks will be summarised for each sector using tables, simple graphics and maps including a representation of uncertainty. In some cases, consequences will be monetised and in others alternative social and environmental metrics will be used.

Pilot learning
The Pilot Study developed qualitative and quantitative examples of response functions. For example, decline in water quality due to low flows - an example of a qualitative response function.

- The general form of the response function is shown in the figures below. If flows are reduced in summer months, as characterised by the Q95 flow, there is less dilution for polluting discharges and any diffuse pollution reaching rivers during storm events.
- The modelling work completed by the Environment Agency indicates relatively minor consequences, although other scoping study work indicates that the consequences for water quality may be greater due to a combination of effects.
- Therefore a simple matrix was developed to be used as the basis for expert elicitation. The matrix cells are filled in for specific ranges of decline in flow with values up to 100. The most likely answers will be scored highly and the unlikely answers scored as 5 or 10.
- The planned approach was for the matrix to be filled in by a number of experts, each of whom should 'self-certify' their level of expertise and back up their scores with a brief description and references to the peer reviewed literature. However, this was seen as a complex task and different approaches were considered, e.g. by framing a question and then asking for a best estimate and confidence intervals or just asking for a single answer.
- There will be many cases where experts (and certainly many practitioners) are unable to characterise the spread of results and only plump for a single answer. In these cases an idea of the spread of results could be determined by asking a large number of experts.

2.8.3 Extended pilot learning

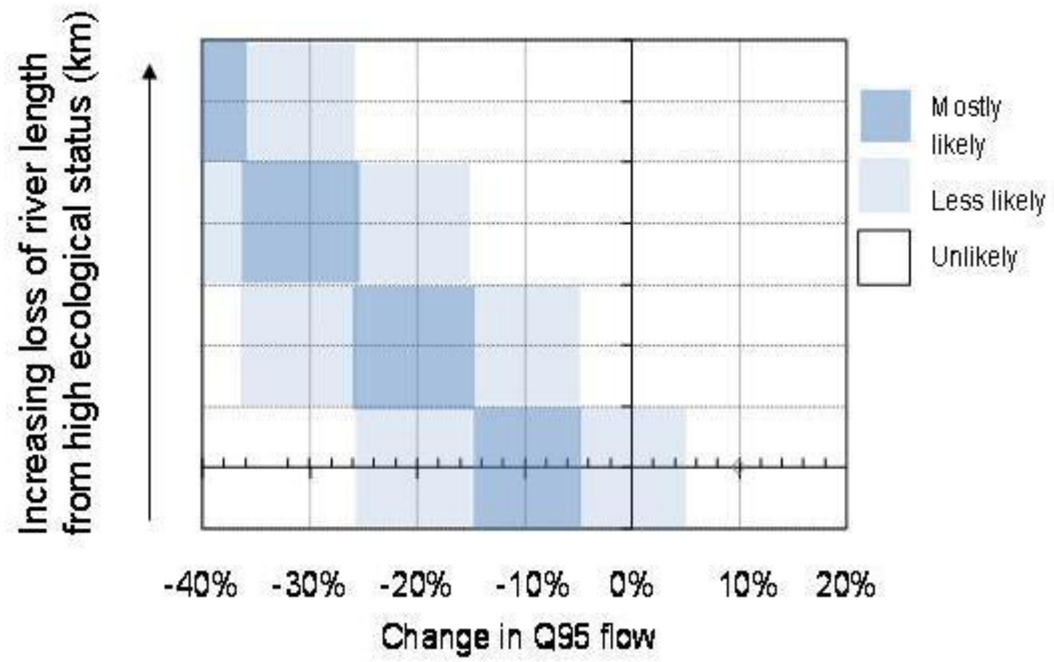


Figure 2-10 Illustrative changes in ecological status due to lower levels of dilution in summer months - general form of response (values of y axis left deliberately blank)

Magnitude class	Estimated probability of magnitude class change in metric (response can span classes)						
Very High	30	**10**	**5**	**0**	0	0	0
High	50	**30**	**15**	**0**	0	0	0
Medium	20	**50**	**50**	**25**	0	0	0
Low	0	**10**	**30**	**50**	10	0	0
Very Low	0	**0**	**0**	**25**	90	100	100
	-80%	**-60%**	**-40%**	**-20%**	No change	+20%	+40%
	Change in Q95						

Figure 2-11 Illustrative changes in a metric which might be predicted by expert elicitation

Area in bold indicates possible changes in flows for a selected emissions scenario – see step 9).

Decline in Deployable Outputs is an example of a quantitative response function.

- The sensitivity of UK water supplies to climate change can be estimated quantitatively based on modelling completed by water companies.
- The plot below shows how areas of the UK are sensitive to changes in relative aridity. As the water industry is required to assess the impacts of climate

change for the 2020s (and then scaled to 2035) there is substantial evidence available for this future period.

- There are relatively few studies looking at the 2050s and beyond so the functions require extrapolation based on expert opinion and the few studies available. As such, the results for the 2020s can be regarded as having a stronger pedigree, whereas the results for later period a lower pedigree.

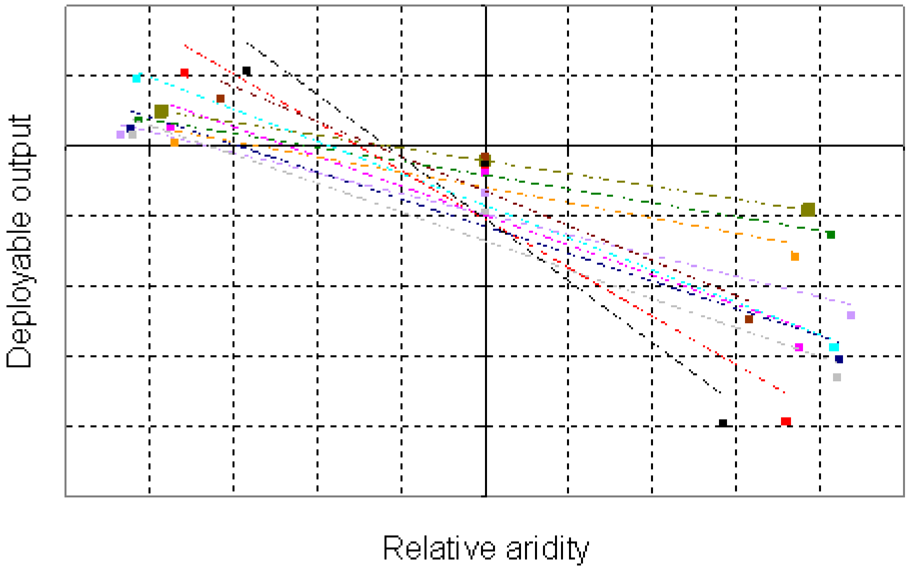


Figure 2-12 Illustrative change in water environment due to climatic variation based on modelling studies completed by water companies (normalised to 2020s aridity rather than 1961-90 in this case) (each line represents the sensitivity of a UKCP09 river basin area- values on axes have been left deliberately blank).

2.9 Scale with climate projections

Summary of Step 9: scale with climate projections
Purpose: To use the response functions to assess the level of risk the UK faces under UKCP09 climate projections in the absence of socio-economic change.

Method: Selected climate projections will be used with the response functions. Existing evidence will be quantitatively scaled to UKCP09 where evidence allows. Expert opinion will be consulted where quantitative evidence is not available.

A two-stage approach to accounting for climate and socio-economic change has deliberately been chosen to disaggregate climate and non-climate factors and transparently state our assumptions.

Outputs: Estimates of changes in risk metrics for selected UKCP09 projections. These are used in Steps 10-14.

The purpose of this step is to apply the UKCP09 projections to the response function to estimate consequences under different projections; this will help to investigate how different degrees of climate change may affect the timing of consequences of a particular magnitude (for example, passing of a climate threshold) under different emissions scenarios. It is based on scaling using the relevant climate variable(s) and/or expert opinion and provides consistent assessment for all sectors for steps 11 to 14. The scaling approach makes use of response functions as outlined above.

The CCRA will consider near term (2020s) and the longer term (2050s and 2080s) climate projections noting that there is a statutory requirement to consider risks up to 2100.

The choice of emissions scenario (low, medium or high) does not start to produce significantly different projected climate variables until after the 2050s. This dependence also varies according to the climate variable(s) in question due to different ratios of signal to noise for, say, temperature versus precipitation.

For the near-term time horizon when climate scenario is independent of emissions, any scaling required will be based on the UKCP09 projections from the medium emission scenario (SRES A1B).

For longer-term time horizons when emissions scenarios become important, any scaling of impacts will make use of 3 emissions scenarios:

- **High emissions A1FI**. This is the highest emissions scenario released by IPCC and is included in UKCP09, so probabilistic projections are available for this scenario. In addition, for specific purposes, this scenario may be coupled with the High ++ sea level/storm surge scenario that was used in the Thames Estuary 2100 project and which is also available from UKCP09.
- **Medium emissions A1B**. Again, probabilistic projections are available from UKCP09. This was not in UKCIP02 but nevertheless A1B is already a widely-used scenario (e.g. in IPCC) so pre-existing impacts assessments may be useable in the CCRA. Indeed the water industry climate assessments make use of downscaled climate model outputs for the A1B scenario.
- **Low Emissions B1**. Again probabilistic projections are available from UKCP09. A comparison with an aggressive mitigation scenario E1 suggests that although

the E1 projection may depart from B1 projections by the middle of the century, the lower end of UKCP09 Low Emissions is an adequate surrogate for the first CCRA. A qualitative narrative of the differences between the UKCP09 Low and the E1 scenario will provide supporting information.

No judgements will be made on the relative likelihood of any given emissions scenario. Currently it is too early to judge whether contemporary emissions are following any particular scenario, and this is unlikely to change within the timeframe of this CCRA.

2.9.1 Approach

Use of UKCP09 provides an opportunity to capture climate change uncertainties for individual emissions scenarios but also presents a number of challenges to the project. These include presentation of wide ranging uncertainties, dealing with joint probability of changes in climate variables and the difficulty of dealing with changes in extremes clusters of events and climate variables that are not fully captured in UKCP09[15].

[15] Some extremes data, for example on heavy precipitation, are provided by UKCP09 but other extremes are not captured and in most cases climate models have limited skill is describing such events. Clustering of events is also a well known phenomena in flood risk research where it appears that are 'flood rich' and 'flood poor' eras in the historical record.

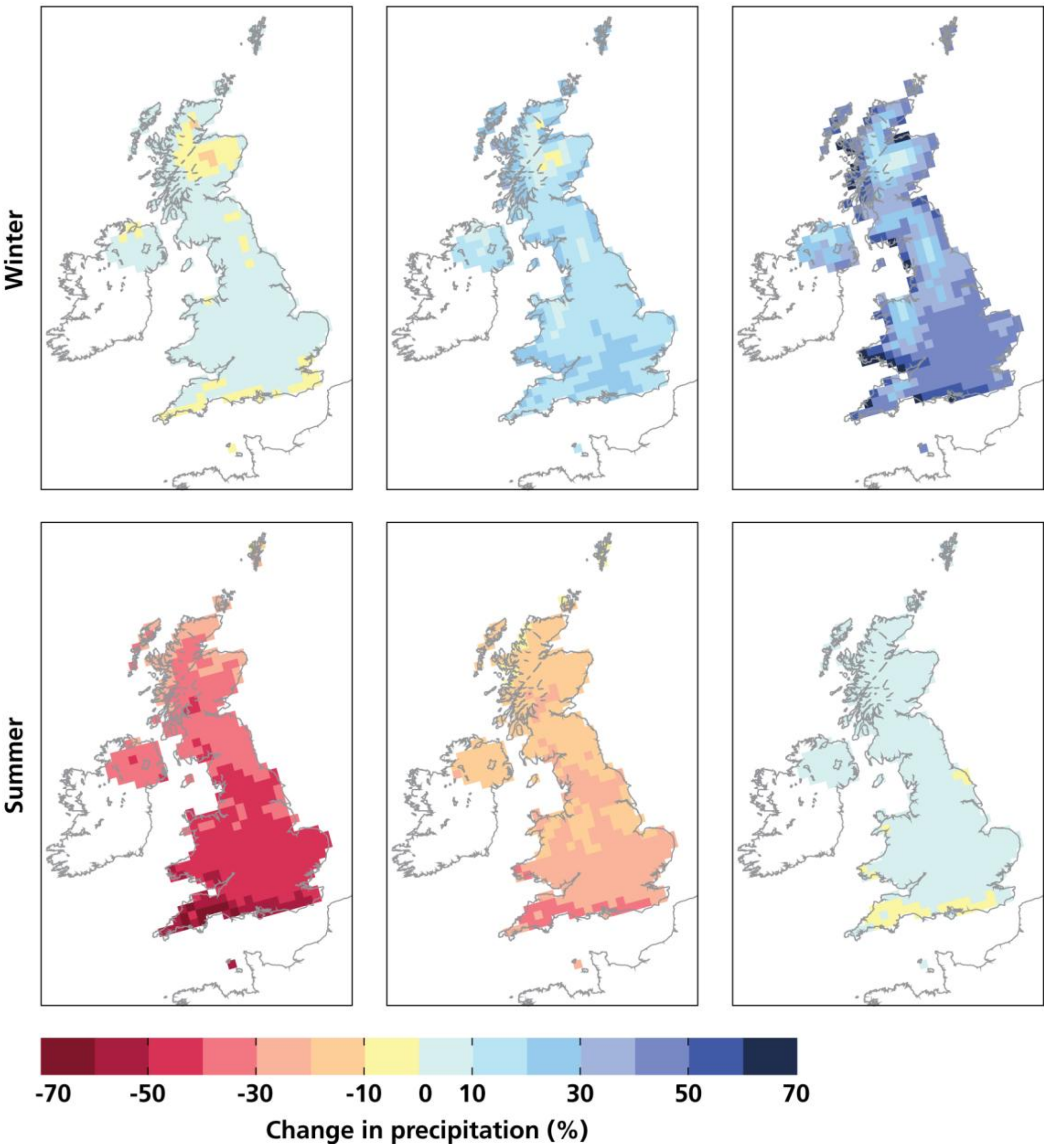


Fig 2-13. Example UKCP09 output for summer and winter mean precipitation, for the 2080s (2070-2099), medium emissions scenario at the 25km grid scale. Cumulative probability levels from left to right are 10% (very unlikely to be lower than), 50% (equally likely to be higher or lower than) and 90% (very unlikely to be higher than)

The CCRA will use UKCP09 as follows:

- The response functions will present changes in consequence versus key climate variables. In the cases where this variable is a single variable, like annual temperature or seasonal precipitation, the UKCP09 outputs can be used directly, making use of the 10, 50 and 90 percent probability levels, which provide the two extremes and an “average” projection from UKCP09.
- For cases where derived variables or combined climate variables from UKCP09 are used, for example relative aridity or potential evapotranspiration, the UKCP09 sampled data will be used (10,000 values for each emissions scenario). The derived variable is calculated based on these data to produce 10, 50 and 90 percent probability levels for that variable. In this way issues related to combined probability are represented.
- For sea level rise, fully probabilistic data are not available and the CCRA project will simply make use of the UKCP09 Marine Scenarios and additional work on the High ++ scenario.
- For climate variables and phenomena that are not covered by UKCP09, the CCRA project will develop approaches on a case by case basis. For example, there are parallel research studies on UKCP09 and changing flood extremes and these results can be incorporated into the project. For possible changes that are not captured by UKCP09 or any other robust sets of projections (for example future changes in wind), the project can only flag these issues up and include a qualitative narrative and expert opinion to inform the assessment.

Pilot Learning

The pilot work in the water sector found that the selected metrics were sensitive to annual average temperature, relative aridity (a combination of annual precipitation and temperature change) or changes in low river flows, expressed in terms of Q95 – the flow that is exceeded 95 percent of the time. Therefore metrics could be scaled to produce UKCP09 estimates of consequences based on these variables.

The table below illustrates variations in future aridity for England and Wales using colour coding from light blue to orange for increasing aridity (warmer and drier).

	UKCP09 aridity - Average England and Wales								
	Low Emission			Medium Emission			High Emission		
	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)
2020	0.49	1.00	1.55	0.49	1.03	1.61	0.51	1.02	1.58
2050	0.87	1.59	2.41	1.05	1.82	2.71	1.20	2.03	2.98
2080	1.11	1.96	2.97	1.53	2.54	3.75	1.94	3.14	4.58

Figure 2-13 Illustrative variations in future aridity for England and Wales

This work demonstrated that variables from UKCP09 can be combined to develop derived variables that maintain the statistical characteristics of climate as presented by the Met Office emulator. These variables can be used for scaling impacts from studies using UKCIP02 and other projections. However, any extrapolation of evidence will be subject to high levels of uncertainty and require expert elicitation.

2.10 Incorporate socio-economic change

Summary of Step 10 - Incorporate socio-economic change
Purpose: To a) incorporate the effects of socio-economic change (such as economic growth) on the magnitude of the risks the UK faces and b) assess the degree of uncertainty surrounding these.
Method: A central estimate of basic socio-economic forecasts will be selected. A qualitative futures scenarios approach will also be used, with the most appropriate technique depending on the degree to which important risks are altered by a small or large number of socio-economic dimensions.
Outputs: Estimates of changes in risk metrics for UKCP09 projections coupled with socio-economic forecasts and sensitivity analysis and futures techniques narratives for other uncertain dimensions of change. These are used in Steps 11-14.

2.10.1 Background

The Climate Change Risk Assessment has a statutory obligation to consider risks to the year 2100. The UK will be very different in 2100, and this will have implications for the types and level of risks climate change could bring, and how we might best respond to these now. For example, the expected costs from flooding depend upon the climate directly - but also the value of assets at risk and the degree of investment in flood risk management, each of which are greatly affected by non-climate uncertainties such as the number of people living by the coast and the economy of the UK.

In addition, socio-economic factors (population, technological change and economic growth) determine future greenhouse gas emissions, and so affect the level of climate change. Equally, the same socio-economic factors influence the vulnerability of social and economic systems to projected climate change, and may also determine the nature of adaptation response. These relationships are explored further in Appendix 4 as a basis for establishing a suitable approach for this CCRA.

The standard approach for accounting for non-climate uncertainty in economic risk analysis is to use forecasts of the key variables for the relevant period of time. Uncertainty is then dealt with through the use of sensitivity testing – e.g. to explore the consequences of higher, or lower than expected growth rates. The challenge with this approach is that the degree of uncertainty increases the further forward in time one looks. By 2100, the levels of uncertainty around central forecasts are likely to be very wide. The approach to this long term forecasting will be outlined in the forthcoming third and final methodology report on the Adaptation Economic Analysis, and may be a refinement of the approach described below.

2.10.2 Socio-economic forecasts

For the development of the baseline socio-economic forecast the project will adopt the following approach:

- Sector teams will make use of existing Government data sets and assumptions for the short-term assessment (2020s), which has broad consistency with the use of a single climate projection being used in the CCRA for this period.
- Consistency between sectors will be achieved by using common data sets for underlying socio-economic variables (such as population and GDP).
- The data set will be extended for the 2050s, but with sensitivity analysis to test future socio-economic assumptions, such as upper and lower estimates of population growth.

Common data sets are being identified and are likely to include:

- Population projections, including age distribution.
- Household assumptions.
- Economic forecasts, GDP growth, per capita income, income distribution, etc
- Land use.

These will be used to provide a consistent central set of assumptions.

2.10.3 Futures Scenarios

The CCRA will use futures methodologies similar to those used by Foresight and Shell. Instead of trying to predict the future, these methodologies examine how the characteristics of the risks could be affected by alternative plausible futures – 'Futures Scenarios'. Futures Scenarios are constructed to test risks against the variables (drivers of change) *most* likely to affect those risks in ways whose direction is uncertain (important uncertainties). These 'drivers of change' (e.g. oil price, trade, growth, financial stability) can be condensed into higher level 'dimensions' (e.g. state of the economy). In these dimensions, the extremes of uncertainty are represented as polar scenarios (e.g. economic stability vs fluctuation).

The diverse risks captured by the CCRA may not be adequately tested against a few specific scenarios. For this reason, the risks will be stress tested against a matrix of important dimensions.

The following process will be used to develop and apply the Future Scenarios:

1. Identify the range of possible risks.
2. Identify the variables (drivers of change) that would have the most significant effects on risks (for example the state of the economy, patterns of demography, geopolitics). Cluster and prioritise individual drivers of change to create a broader set of Dimensions of Change (around 10).
3. Create a matrix of risks vs. dimensions of change to identify whether
    a. a small number of dimensions stress test a large proportion of risks - or, if
    b. risks are diffuse and a small number of dimensions would not stress test most risks
4. If risks are concentrated, create a set of qualitative narrative future scenarios against which to assess risks and policy considerations.
5. If risks are diffuse, use a matrix approach (dimensions vs. risks) to test risks against dimensions most likely to influence those risks.

Stage 1 – Identify the risks

The process of identifying, clustering and prioritising risks is covered in section 2.3.

Stage 2 – Identify drivers of change

Socio-economic variables can be identified using a standard futures framework of Societal, Technological, Environmental, Economic, and Political (STEEP) drivers. Data sources include:

- Literature review (e.g. Foresight review into future flood risk).
- Workshops and review (using literature review as preparatory material) to assess, cluster, and prioritise drivers of change. The results of this will be used to construct higher level dimensions.

Stage 3 – Create a matrix of risks and dimensions of change

The aim of this stage is to systematically identify how each risk will be affected by the set of broad dimensions that have been identified. In the illustration below, the risks from the water sector are listed down one axis, while possible dimensions of change are listed on along the top. Where a risk is likely to be highly affected by the dimension, this is marked with an x.

	Demography	Economy	Population Distribution	Technology	Environmental attitudes	Global mitigation
Hydropower yields	x	x		X	x	x
Water-borne disease	x			X		
Increased demand	x	x	x	x	x	
Discolouration				x	x	
...	...	...	...	...	...	...

Stage 5 – Decide on approach

The CCRA will be considering a disparate range of potential risks. The matrixes created in stage 4 can help to identify whether they are clustered in terms of having certain dimensions of change in common. If they do have, for example, 2 dimensions largely in common, sets of scenarios can be constructed using the extremes of these dimensions in combination to form 4 distinct qualitatively different future scenarios (the few risks left can be individually tested against the most relevant dimensions).

a) Create scenarios

	Population	B	C	D	E	F
Risk 1	x	x		x	X	x
Risk 2	x			x		
Risk 3	x	x	x	x		
Risk 4	x			x	X	
...	...	...	...	...	...	...

Use of Scenarios
Scenarios can then be used to explore outcomes for *risks* under the different conditions of issues most likely to affect them. For example, many climate risks will be differently experienced if the population is largely urbanised. If ICT developments over decades lead to easy distributed working however, living location may no longer be so tightly

linked to workplace, and population distribution may be more dispersed. In giving advice on such risks, we will be able to flag up these important parameters, suggest how these different outcomes might be experienced, and indicate the signals of change for policy makers to have on their radar as they plan to manage risks.

Similarly, *policy options* can be explored in scenarios, giving decision makers information about how robust options are against different futures. Options that work well in all scenarios are very robust. Options that work well in only one scenario are least robust against an uncertain future. This does not necessarily mean that such options are to be avoided – rather they should be considered in light of their potential limitations. A very attractive policy that works well in only one future scenario might still be the best option, but it could be applied with a view to looking for signals of change, and being prepared to deploy planned contingencies should it become clear that a different scenario is developing. This possible approach to policy options will be worked up in more detail in the Adaptation Economic Analysis methodology report.

2.11 Account for anticipated adaptation

Step 11: Account for anticipated adaptation
Purpose: to account for autonomous adaptation *and* the effect that existing government policy already has on reducing the level of risk climate change poses. The combination of these is 'anticipated adaptation'.

Method

This is an iterative step closely linked to the development of social and economic forecasts and scenarios. The work on policy risk mapping (Step 2), social vulnerability (Step 5) and adaptive capacity (Step 6) will be used to revisit the assumptions made in (i) developing the response functions and (ii) the socio-economic baseline forecast, to identify whether autonomous adaptation and adaptation under current policy has been implicitly accounted for or not. In some cases this will result in a narrative setting out the assumed extent of adaptation. In other cases adjustments may need to be made to the risk computations leading to alternative outputs that take account of autonomous adaptation and adaptation that is already planned in current policy. This too will be accompanied by a narrative explanation as the adjustments are likely to be predominantly based on expert opinion.

Outputs: Clearly stated assumptions with respect to the level of autonomous adaptation and adaptation under current policy included within socio-economic forecasts and futures. Reanalysis of some metrics to estimate 'net' risks after autonomous adaptation.

Autonomous adaptation can be understood to be a non-public response made in reaction to a climate change risk. It is also generally understood to be undertaken by individuals, private organisations or natural systems. However, whilst conceptually separate from both climate risks and planned adaptation, these distinctions are not always clear in practice.

2.11.1.1 Incorporating autonomous adaptation generally

Many autonomous adaptations are considered 'impacts' in climate change risk assessment, as evidenced by previous national studies (e.g. in the US, Sweden, Canada, etc).

For example, reductions in the number of winter heating days or increases in the number of summer cooling days will occur as mean temperatures rise with climate change. These are often considered an autonomous adaptation, as heating bills fall or as cooling demand rises from increased air conditioning. Such autonomous adaptations are routinely included in climate change impact studies as 'impacts'. In contrast, the planned adaptation response may be a reduced investment in winter energy supply, or alternatives to mechanical air conditioning. Many sectoral studies of climate change include autonomous adaptation as 'impacts'. Illustrations of current practice in climate change risk assessments are presented in the table below.

Sector	Impacts/Autonomous Adaptation
Energy – cooling demand	Assessment of 'impacts' of kWh for cooling demand is primarily an autonomous adaptation, as the result of private increases in running air conditioning. Reduction in winter heating demand is completely autonomous through thermostatic control and reduction in heating use. All 'impact' studies quantify these autonomous adaptations as 'impacts'. Planned adaptation involves the changes needed to winter heating demand, and for summer cooling, alternatives through building regulations, passive ventilation and building design, spatial planning, etc.
Agriculture - crop yields	Farm level adaptation is an autonomous adaptation, and is commonly assumed to occur as there are no 'dumb' farmers, i.e. farmers will change things as crop yields decline, e.g. through swapping to alternative variants or other crops. Nearly all 'impact' studies include autonomous farm level adaptation. Planned adaptation involves higher level sectoral actions.
Ecosystems	Species migration is an autonomous adaptation, i.e. as the climate envelope for species shifts, provided there are no barriers, species will move ecosystems and ecosystems may change as a result. The impact models actually model the change in climate envelopes. Planned adaptation generally involves measures that provide buffer zones or increased connectivity.
Health	Future heat related mortality can be quantified as a risk, though recent studies account for autonomous physiological acclimatisation, in dose response functions used. This reflects that fact that future temperatures projected for the UK are not uncommon in mainland Europe, and there is evidence of physiological adaptation over time. Planned adaptation would be associated with shorter-term risks and heat extremes through heat alert systems.
Flooding	Flood risks are characterized by the damage to property as measured by the cost of replacing or repairing such property. For cases where the property owner's response is to repair/replace, these costs are more accurately categorized as the costs of autonomous adaptation.

Figure 2-14 Illustrative sectoral examples of treatment of impact-autonomous adaptation in existing climate change risk assessments

2.11.1.2 Autonomous adaptation in the CCRA

The distinctions between climate change risks, autonomous adaptation and planned adaptation are important because they shed light on how the adaptation response to the CCRA should be formulated.

In the overall CCRA, it is clear that there is a need to separately account for autonomous adaptation. This is because the recommended approach in Government appraisal is to define a policy baseline in light of what would happen without Government intervention. <u>The baseline for the CCRA must therefore include climate change risks and autonomous adaptation.</u>

Subsequent public planned adaptation – the focus of the economic evaluation of adaptation options - is then determined by both the size of the residual risk after autonomous adaptation, and the form of the autonomous adaptation itself. Thus, planned adaptation may be introduced on top of a baseline of autonomous adaptation, to further reduce the climate risk. Alternatively, autonomous responses may themselves necessitate a planned adaptation response, in cases where they lead to externalities,[16] or other market failures.

The examples above indicate that the treatment of autonomous adaptation and planned adaptation is best done on a sectoral risk basis. It will vary with sector and with existing practice in impact assessment in each case. It is important that Sector Champions are clear on the assumptions incorporated into each assessment.

For all sectors, the level of autonomous adaptation within the risk assessment will be reviewed to ensure that assumptions are clear and credible. For qualitative risk assessment this will result in a narrative setting out the assumed extent of adaptation. For the quantitative assessment, adjustments may need to be made to the risk computations and monetisation (where relevant) leading to alternative outputs that take better account of autonomous adaptation. For each climate change risk that is quantified explicit statements will be provided on:

- whether autonomous adaptation is incorporated directly in the risk assessment.
- to what extent the autonomous adaptation proxies for the true size of the risk.
- what form this adaptation takes.

For example in the pilot work there were a set of metrics related to the supply demand balance. The demand for water for public water supply is primarily driven by socio-economic factors, such as population, household size and GDP. With increased water scarcity some autonomous adaptation would be expected in response to changing costs of water and public attitudes towards water use. In the water sector these changes would be built into socio-economic forecasts and scenarios as follows:

- Population changes, GDP, household numbers and current per capita consumption form a socio-economic baseline .
- Under different socio-economic futures, attitudes to water use change, affecting per capita consumption directly as well as indirectly via household numbers, size etc….
- This adaptation takes the form of reduced frequency of water use, uptake of greater water saving technology, less outdoor water use and so on. This is built

[16] Externalities are economic costs that arise which are not borne by the goods or service in question. A classic example would be the environmental costs of pollution. For adaptation, it would relate to a case where action by one actor leads to economic costs that are borne by another, as might arise from shifting vulnerability.

into a narrative that describes the autonomous adaptation linked to a specific per capita consumption.

- Other potential adaptations which are left outside of this assessment might be promoted or implemented as part of planned adaptation by Government.

2.12 Monetisation

Step 12: Monetisation
Purpose: To enable some comparison of risks using a common metric so adaptation policy is well targeted and also to enable a comparison of climate risks with other pressures on Government.
Method: Based on standard HM Treasury Green Book approaches and other approaches based on existing evidence. For example, calculation of compensation costs.
Many risks will not be monetised in this cycle of the risk assessment because of a lack of quantitative data. Non-monetised risks will be included in the overall assessment in a qualitative way that as far as possible indicates the relative degree of risk they represent.
Outputs: A selection of monetised risk metrics for presentation alongside non-monetary risk metrics.

The generic methodology for monetary valuation of climate change risks and adaptation in the CCRA will primarily be based on that developed in the HM Treasury Green Book[17] and its Supplements[18] and for UKCIP by Metroeconomica (2004). At the outset of Tier 2, the CCRA will have identified a range of risks for each sector and selected 3 to 10 risks per sector for inclusion in the Tier 2 assessment. This is the starting point for the valuation analysis. As outlined in Section 2.7, some of the risks will be quantified and capable of being monetised and others will not. The approach is set out below and further detail is provided in the Appendices.

This monetisation step begins with an initial review of existing climate change risk monetary valuation for these selected risks. This will consider existing studies where valuation has been applied to climate change impacts and consequences. It will also include a wider review to consider whether there are studies that have valued the priority risks in non-climate applications, e.g. in other Government appraisal. The task will then map the selected risks against the potential for valuation, i.e. summarising the potential coverage.

The task will then assess the selected risks in monetary terms in Tier 2. It is stressed that valuation is determined (and constrained) by the level of quantified information in the Tier 2 sector assessments: where the CCRA produces quantified risk data, then valuation is potentially possible; but not where the CCRA provides estimates of burdens or qualitative risks[19].

For the selected risks at UK and Devolved Administration/English areas level that have been quantified in physical units, and that can be monetised based on the review above, the Tier 2 assessment will value consequences to infer the potential magnitude of risks. This will be primarily based on interpretation of previous analyses.

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[17] http://www.hm-treasury.gov.uk/data_greenbook_index.htm, and this is recognised as being the primary source of guidance for public sector economic analysts.
[18] http://www.hm-treasury.gov.uk/data_greenbook_supguidance.htm
[19] To illustrate, if the main CCRA provides estimates of cooling demand changes in kWh, or numbers of deaths from heat waves, then valuation is possible. However, if cooling demand changes are presented only in terms of cooling degree days - or instead of health impacts there are only estimates of the extra number of heat waves - then these do not provide consequences that the valuation study can monetise.

For the selected risks that have only been assessed in semi-quantitative terms, it may be possible to scale previous studies with economic values to the level of risks anticipated. However, in cases where there are gaps, or no quantified information on the potential scale of risks (i.e. qualitative information), a range of approaches will be considered. The potential for scoping an estimate of how significant economic costs could be will be considered. If this is not possible, climate change risks will be expressed either in qualitative or bio-physical terms only[20].

The task will also investigate possible approaches on how to compare and present monetary and non-monetary information alongside each other, considering previous approaches used in Government and the sector expert workshops. A table, with supporting description, will make explicit what is, and what is not, included in the monetised risk estimates. This simple approach will allow the assessment of the relative significance of risks, while making it explicit what is and what is not included in the monetised risk estimates. The same table is also to be used to present physical impact data. An example of the type of table being considered is given in Appendix 5.

In Tier 3, where the CCRA will produce more quantitative data in one or more sectors or Devolved Administrations or English areas, a more detailed version of the approach above will be used. This will consider the monetisation of individual climate change risks using different unit values for individual Devolved Administrations and English areas as far as the data exist.

For each individual climate change risk, justification will be given for the selection and combination of valuation data to be used in monetisation. An assessment of data quality will also be given. Value transfer procedures and other adjustments, including distributional considerations, will be based on those in the HM Treasury Green Book and the UKCIP Costing guidelines. Treatment of uncertainty will also follow guidance in these publications. As a minimum, the CCRA will use interval analysis and sensitivity analysis throughout.

Monetary data used in the CCRA will primarily be extracted from existing published datasets. A number of generic financial and economic data sets are compiled in the HM Treasury Green Book and its Supplements. Additionally, it is anticipated that sectoral-specific publications will be used, including those contained in the Central Government Departmental Guidance[21].

For each climate change risk where monetisation is possible, the source of the unit value(s) to be adopted in the CCRA will be recorded explicitly in the sector reports. Any subsequent adjustments will also be reported, as well as an indication of the reliability or quality of the data. The form of this recording will be consistent with the generic referencing system to be utilised in the CCRA. The project recording protocol will ensure that valuation data will be identifiable for subsequent validation, and referral in future CCRA cycles (see also details of data management in Appendices).

[20] For example biodiversity is recognised as an area where standard valuation techniques are difficult to apply
[21] See: http://www.hm-treasury.gov.uk/data_greenbook_detguidance.htm

2.13 Results, maps and tables

Step 13: Results, maps and tables
Purpose: To provide a basis on which to target adaptation policies by sector, geographically and by country.

Method: Present data at national levels and for smaller geographical areas (or major river basins for hydrology). In some cases this requires ‘upscaling’ or generalising detailed sub-regional data to the regional scale. In other cases, national estimates will be ‘downscaled’ or regionalised to provide data for smaller geographical areas.

Outputs: Regional tables and maps to summarise risks and understand the relative importance of risks in different geographical regions. Outputs need to reflect levels of uncertainty in the findings.

The CCRA must provide an assessment for the UK and assessments for England and each of the Devolved Administrations and the geographical areas in England.

UKCP09 climate change data are available at three scales – 25 km grid, a sub-national scale aligned with the administrative regions in use at the time and UK major river basins. Population and other socio-economic data are available at a variety of disparate national, sub-national and more detailed scales, for example Enumeration Districts. In either case, the CCRA must work at consistent scales, which will involve upscaling and downscaling of data.

2.13.1 Approach

For climate change the project will work at two scales – UKCP09 administrative areas and UKCP09 river basins.

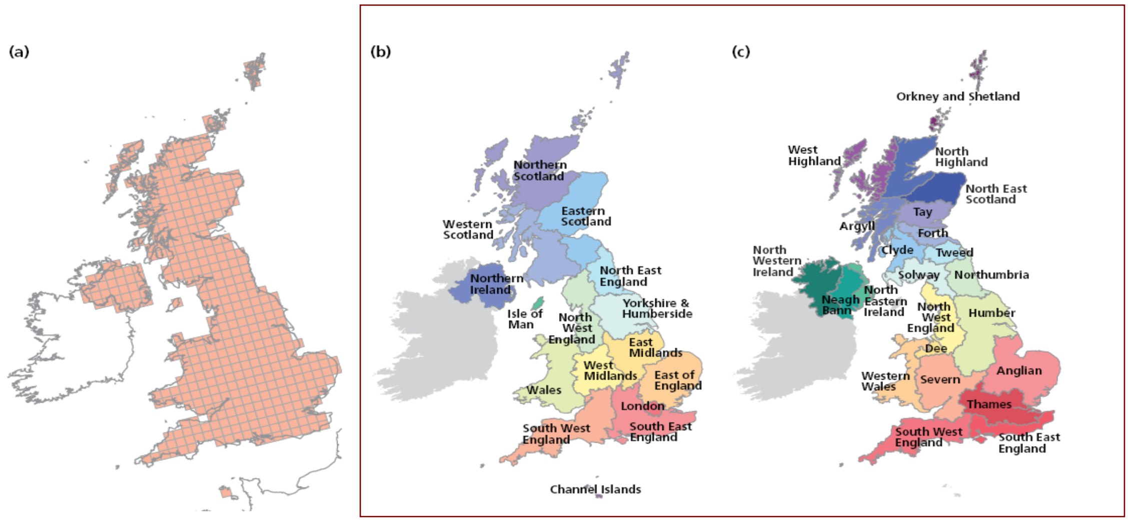


Figure 1.2: (a) Areas over which probabilistic projections are available: (a) the 25 km grid, (b) the 16 administrative regions and (c) 23 river-basin regions.

CCRA scale consistent with UKCP09

Figure 2-15 Reporting areas to be used for CCRA

For socio-economic data the project will aim to work as close to the UKCP09 sub-national scale as possible.

Pilot Learning

As part of the Water Resources Pilot it became evident that sub-regional data were required in order to provide a good national assessment of the consequences of climate change.

- Sub-national data on public water supply were collected simultaneously with national data because a single national data set was not readily available; data collection from multiple sources took months to procure.
- For other metrics the Environment Agency hold national data sets, GIS tools and modelling methods that can be used for the CCRA in collaboration with the Environment Agency.
- Some data sets, such as population, are available from different sources; ideally the CCRA should make use of consistent Government data, and for the near term, Government projections.

The outcomes of this for the methodology are:

- There is a need for a concerted effort to collect consistent Government data sets in June 2010.
- The project will aim to produce information, including tables and maps, for UKCP09 regions and for UKCP09 river basins for the floods and water sector.
- For the marine sector will we consider the UK seas in their entirety but associate coastal infrastructure with the appropriate English area.

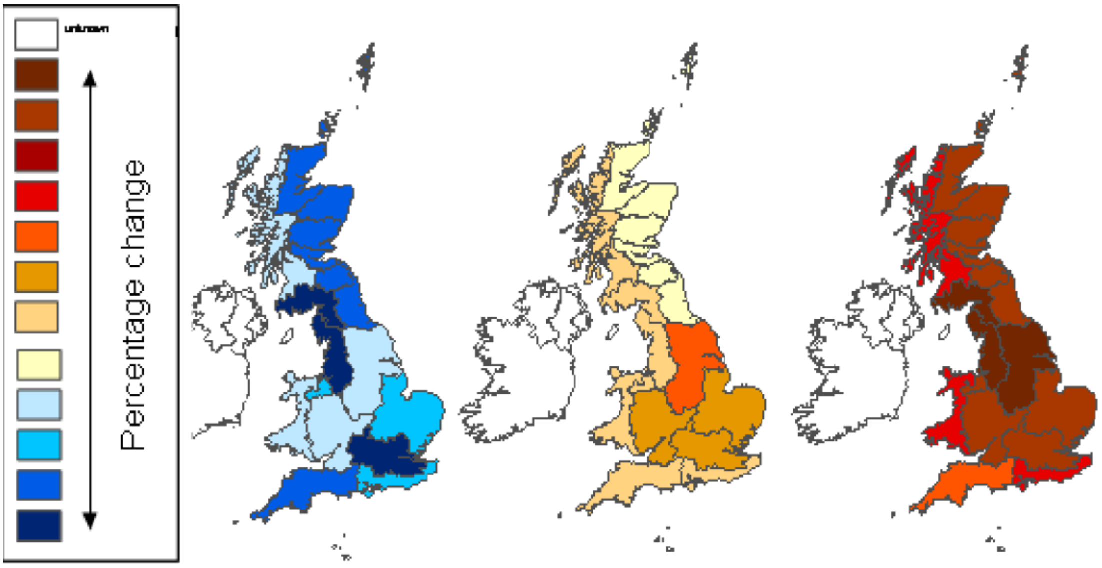


Figure 2-16 Illustrative mapped results for different climate projections (values deliberately left blank)

2.14 Report outputs

Step 14: Draft sector or Devolved Administration and English area report
Purpose: To bring all the analytical results together so that technical results are clearly presented to inform government about priorities for the Adaptation Economic Assessment and potential National Adaptation Programme implications. This includes risks that were not selected for Tier 2 analysis.

Method: Standard reports will be produced for sectors, working with sector champions, and a separate report for the Devolved Administrations and English areas, working with the funding partners, the CCRA Forum and other key regional stakeholders. The framework for presenting the sector reports is described in Appendix 6. In addition, it is recognised that the final report to formally report the risks, as required under the Act, will not necessarily be reported by sector. Some other choice of sub-division into themes may provide a better basis on which to communicate the CCRA findings.

Outputs: Standard reports for sectors or themes that emerge from the assessment and for the Devolved Administrations.

The risk assessment will initially be reported in a series of Sector reports. These will build on work undertaken in Tier 1 and incorporate the results of the Tier 2 assessment. These sector reports will subsequently be updated to incorporate the results of any Tier 3 assessment and the valuation of risks where this has been possible.

The purpose of these reports is to report the risks as identified and analysed to prepare the groundwork for further reporting. Stakeholders are likely to find these initial reports useful for an early sight of the broad range of results. There will be no attempt to prioritise or consider the relative significance of risks in these reports, either within sector or between sectors. A template for the Sector reports, which was developed as part of the Pilot Study, is provided in the Appendices.

2.14.1 Development of Risk Assessment Report for the UK

The risk assessment is being undertaken based on 11 Sectors, with due consideration to a number of cross-cutting themes. This will be followed by a re-appraisal of the risks based on geographical areas, as defined by the Devolved Administrations and areas of England. The decision to approach the problem in this way was largely driven by practical considerations of data access and tapping into existing community and organisational structures. However, it has always been recognised that sectors may not be the most suitable sub-divisions around which to formally report the risks as required under the Act.

We will therefore explore alternative taxonomies of classifying the risks, or clustering the risks identified. To do this we will make use of the outputs of the Policy Risk Mapping (see Section 3.4) and the Systematic Mapping (see Section 4.2) and the response to consultation on the Sector reports, as described above. It is quite possible that the systematic mapping will highlight clusters that provide alternative themes that cut across many sectors (e.g. water, health, energy) or that ownership and responsibility provides a more accessible means of reporting (e.g. local authority, national government or intermediate levels of geography). The format of the presentation of the outputs will be developed in consultation with the funders and stakeholders. This will need to reflect the types of information that will be generated by the assessment which is likely to range over the following four categories:

Type of risk	Outputs possible
Fully quantified risk with defined uncertainties (including valuation where appropriate).	Output is likely to include maps for UKCP09 areas or basins and tables defining the risk and is some cases will be accompanied by monetary valuation.
Partially quantified risk, where either the consequence or probability is known quantitatively, but the other is only described qualitatively.	Whilst maps and table may be possible for the quantified element and could be included if they are considered informative, these will need to be supported by suitable narratives.
The risk is described qualitatively based on evidence drawn from existing studies and expert opinion.	Maps showing high/medium/low level of variations may be useful for some metrics but the narratives will be increasingly important and should highlight the merit of further work to elaborate the risk in more detail.
The risk is considered to be significant, based on expert opinion, but there is insufficient knowledge to do more than identify the issue (e.g. the causative processes may not be sufficiently understood).	Maps are unlikely to be possible for the metrics in this category and the perceived risk will need to be described, along with some indication of how this might be investigated further, and the signals that might be used to provide indicators that the risk is changing (for better or worst).

The final structure and format of the CCRA report to be laid in Parliament in January 2012 will be developed in consultation with central Government Departments and the Devolved Administrations, who are the primary audience. Other supporting reports and summaries (e.g. fact sheets and sector assessments) will be developed in consultation with the relevant audiences. Important risks - those that are considered to be likely, high consequence and requiring urgent decisions - will be flagged to central Government and devolved Administrations as those for which consideration by risk managers would be most beneficial. Subsequent, more detailed consideration of individual risks by these risk managers (including some further appraisal of options to reduce risks and comparison to other risks the UK faces) will ultimately inform which climate adaptation strategies are preferable.

Tier 3: Further Quantitative Risk Assessment

2.15 Choose Tier 3 detailed analysis

Step 15: Exemplar analysis at Tier 3 level
Purpose: to undertake an explorative and exemplary detailed quantitative assessment of risk that will inform future cycles of the CCRA, other international or regional risk assessments and future research needs.

Method: Government will review the outputs of Tier 2 and may select a specific risk or geographical area for detailed Tier 3 assessment.

While the majority of work will have been completed in Tier 2 assessment, some additional detailed analysis is likely to be completed based on a fully quantitative assessment in one sector or English area. Previous steps will be repeated but with a greater emphasis on metrics that can be quantified and developing quantitative modelling.

The main difference between Tier 2 and Tier 3 is that, in the latter, UKCP09 projections will be applied with the selected socio-economic scenario and sensitivity analysis, to produce a fully quantitative risk assessment.

The main benefits of undertaking this step are:

- it may produce stronger evidence (higher pedigree),
- it may provide a better handle of uncertainties as they cascade through a process based model and
- it may identify new, more subtle consequences and complexities that highlight the need for further research.

There is insufficient time in the programme for CCRA 2012 to develop new quantitative risk models so Tier 3 assessment will need to make use of existing modelling tools, for example those developed for the Environment Agency in England and Wales or on recent Research Council research projects.

2.15.1 Selection of Tier 3 risks

The Tier 2 assessment will provide information on the magnitude of risks and an improved estimate of their likelihood, post application of the UKCP09 projections and socio-economic scenarios. At the end of Tier 2 some of the major outcomes of the study will emerge and at this stage Government will set criteria for selecting the risks for further assessment.

2.15.2 Repetition of steps for Tier 3

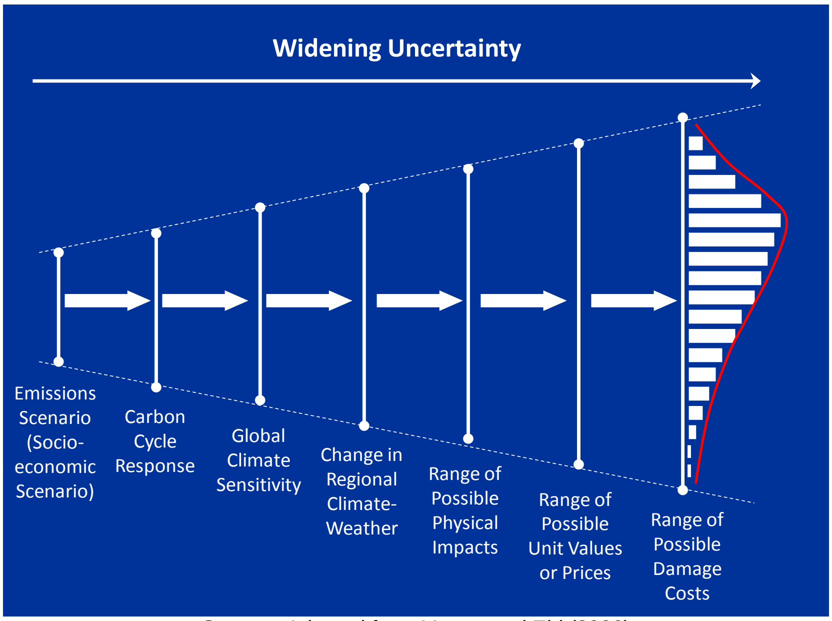
As part of more detailed assessment, steps 9 to 14 will be repeated for selected Tier 3 risks. Depending on what approach is taken and the models available, this assessment may be national, area or case study based.

3 Quality and audit

3.1 Uncertainty estimation

Full and proper consideration of uncertainties is an important theme throughout the CCRA. As part of the Tier 1 assessment, levels of confidence and pedigree scores were assigned to all the impacts and consequences identified. In the Tier 2 assessment and subsequent Tier 3 assessment and economic assessments, further calculations will be completed to quantify risks and costs. This must be accompanied with clear presentation of the wide ranging uncertainty in relation to future climate and impacts modelling.

The standard 'cascade of uncertainty' is summarised below. The treatment of each step in the uncertainty cascade is summarised below.



Source: Adapted from Menne and Ebi (2006)

Figure 3.1 Cascade of uncertainties in assessing impacts of climate change

- Emissions scenario uncertainty will be dealt with using standard Low, Medium and High emissions scenarios that have been incorporated in UKCP09. In addition the project will include qualitative narrative of a more aggressive mitigation scenario.
- Carbon cycle response, global climate sensitivity and changes in climate by area are, at least partially, addressed in the probabilities in the UKCP09 projections.
- Application of the UKCP09 projections will indicate wide ranging impacts but for any single climate projection there will also be additional uncertainty added by impacts models. Within our proposed method impacts modelling uncertainties are within the original evidence and then propagated and added to by using response functions for scaling.
- Similarly, impacts modelling uncertainties related to the influence of social and economic drivers will be inherent in the research used to support the assessment. The use of socio-economic scenarios will deal with uncertainties in the main social and economic drivers.

- For the economic analysis there are further uncertainties in unit costs, market prices and the damage costs in future forecasts and scenarios.

For the Tier 2 assessment, uncertainties will be dealt with using a range of techniques:
- The level of confidence and 'pedigree scoring' recorded in Step 1 will be maintained and carried through the assessment as much as possible. For example if a risk is selected for Tier 2 assessment that has a low score for 'pedigree' because assessments have not been published in the peer reviewed literature then this will be reflected as part of any expert elicitation (step 8) and in the reporting (step 14).
- In the construction of the consequence response functions, expert elicitation techniques will be used to capture a central estimate and range of consequences for each risk (Aspinall, 2010). The uncertainty in the consequences can then be combined with uncertainty in the climate projections in order to provide a range of possible outcomes for each emissions scenario and time period (see below).
- For the economic assessment, additional uncertainties related to unit values and damage costs will be handled using formal interval analysis and sensitivity analysis by the economics team.
- For Tier 3 assessment a more formal approach to uncertainty analysis based on interval analysis or sensitivity analysis will be completed.

Pilot Learning
An example of how uncertainty can be considered in a qualitative response function is "WA9: Net decline in water quality." For example the 'low flow' modelling results for a specific emissions scenario may indicate that reductions in Q95 will be somewhere within a 40 percent range for the 2050s. Therefore the uncertainty in changes in flow needs to be considered alongside the uncertainty in the effects of flow changes on water quality.

Magnitude class	Estimated change in metric (response can span classes)						
Very High	30	10	5	□	□	□	□
High	50	30	15	□	□	□	□
Medium	20	50	50	25	□	□	□
Low	□	10	30	50	10	□	□
Very Low	□	□	□	25	90	100	100
Change in Q95	-80%	-60%	-40%	-20%	No change	+20%	+40%

The qualitative response function would ask experts to estimate the impacts of low flows on water quality status

VH	10	5	0
H	30	15	0
M	50	**50**	25
L	10	30	50
VL	0	0	25
Q95 change -->	-60%	-40%	-20%
	0.3	0.5	0.2

Weights for climate variable for emissions scenario X

Climate scenarios might suggest changes in flow between -20 and -60%

VH	3	3	0	**6**
H	9	8	0	**17**
M	15	**25**	5	**45**
L	3	15	10	**28**
VL	0	0	5	**5**
Q95 change -->	-60%	-40%	-20%	100

In this example for illustration only, the changes in flow would have been modelled and therefore weights could be assigned reflecting the likelihood of different flow reductions. The values in the second table (right hand side) would then be weighted producing a set a probabilities of changes in flow and the consequences for ecological status of rivers. The rows can then be summed to provide an outcome for the specific emissions scenarios.

The most likely outcome in this example has a 'medium' consequence and is that between 1000 km and 10,000 km rivers nationally (less than 20 % of all rivers) decline in ecological status but the results also indicate the very wide range of possible outcomes.

Pilot Learning

The following learning points from the pilot are important:

- Asking experts to provide their best estimate and a range is more straightforward and more achievable than asking them to estimate the probability of the outcome falling in many different classes. Therefore the former approach will be the most appropriate in most cases and the questions used to develop the metrics should be well framed and possible to answer by giving upper and low limits.
- For quantitative functions, scaling of the evidence for different climate projections involves interpolation based on the selected climate variable and potentially some extrapolation. In such cases there may be a good argument to generalise the consequence response function to a qualitative matrix and use expert elicitation. As a general rule the quantitative form of function should only be retained in cases where it can be validated and has a high pedigree.
- For any metrics that can be monetised, it would be best to monetise based on the best estimates available and upper and lower limits and then generalise the results in the final outputs.

3.2 Auditing

The method, as described in the main text of this report, needs to be followed consistently for all sectors, Devolved Administrations (DA) and the English areas.

The approach described below seeks to ensure that the method has been followed appropriately. It does not consider whether the inputs and outputs of this method are of high quality – this is a subject for peer review at the appropriate time.

3.2.1 Approach

Internal audits will be undertaken at key stages during the risk assessment and adaptation assessment. The following stages are planned:

- Audit 1 - Sector workshops and preparation for the sector assessment work (leading to the delivery of the Tier 2 interim report).
- Audit 2 - Tier 2 sector assessment.
- Audit 3 – Tier 3 sector assessment.
- Audit 4 – DA and English area assessment.
- Audit 5 – Adaptation Assessment.

These will be undertaken by the contractor team, but by an organisation other than the one undertaking the assessment. For example, the Tier 2 sector assessment work is being led by both HR Wallingford and Entec, with each organisation responsible for half of the sectors. For Audit 2, work undertaken by Entec will be audited by HR Wallingford and vice versa.

Time will be set aside within the programme to accommodate the internal audit and any remedial work. The organisation being audited will provide working files, as well as the final outputs, to assist the auditor. All internal audits will be documented for future reference.

Separately, review of the quality of the analysis has been built in to the assessment at numerous points to facilitate iterative and incremental improvements as the assessment is undertaken, including feedback from policy makers, practitioners, academic and risk experts. The work of each sector will be peer reviewed formally by at least 2 and ideally 3 sector academics. The method as a whole and the presentation of the outputs that are produced will be reviewed by the Adaptation Sub Committee to the Committee on Climate Change, who also provide ongoing independent advice and scrutiny of the CCRA project.

3.3 Data Management

There are a number of aspects to collecting, collating and archiving data in a way that ensures that the data is captured efficiently, the provenance of the data is known, and that all data used on the project is archived in a safe and recoverable manner.

3.3.1 Data collection

The project requires a substantial amount of information to be collected and collated in a relatively short period of time. This has the potential to place a significant burden on those being asked to supply data. We will endeavour to keep this at a minimum by carefully co-ordinating the data gathering process. Following identification of the initial list of risk metrics, a consolidated list of metrics and associated data needs will be prepared. This will be used to set-up an organisation focussed data collection programme, ensuring that as few approaches as possible are made to any one organisation. The iterative nature of the method and the potential to identify additional metrics as a result of the systematic mapping, or the change of focus from sectors to the DAs and English areas, does however mean that more than one approach may be needed to some data providers.

3.3.2 Data provenance

A substantial quantity of data is to be analysed during the lifetime of the CCRA project. To ensure the conclusions of the project are traceable and auditable, it is important to unambiguously understand:

- What data has been used? The existence of a register of all data used to deliver the project.
- How the data is being used? The ability to understand how data have been used to derive project outputs or conclusions.
- How the data can be re-used? The ability to maximise the re-use of this evidence base post-project.

It is therefore essential that an adequate data management framework is in place to ensure that the data can be stored and accessed effectively. This encompasses technological, process and legal considerations.

3.3.3 Best Practice Guidance

Over recent years a number of best practice guides for environmental data management have been produced. These have recognised that for sustainable data management the full data lifecycle needs to be considered. The first widespread guide to tackle this issue was CIRIA C541 'Maximising the Use and Exchange of Coastal Data'. This guide introduced to the concept of five data management principles that can be used to categorise the factors that facilitate and restrict data use. The Five Principals are shown in the Figure below. Although this guide was written over ten years ago, it is still very relevant today.

The recommendations of C541 were subsequently used as the basis to the Environment Agency report FD2110. This report was written because of the problem of key (and expensive) data sets ceasing to be accessible after a project had closed. This best practice guide provided a 'step by step' guide to managing environmental data through its entire lifecycle.

This approach has subsequently been used to define management frameworks for both flood risk (Project Reference FD2320) and the environmental impacts of aggregate extraction for the dredging industry (Project reference MEPF 04/03).

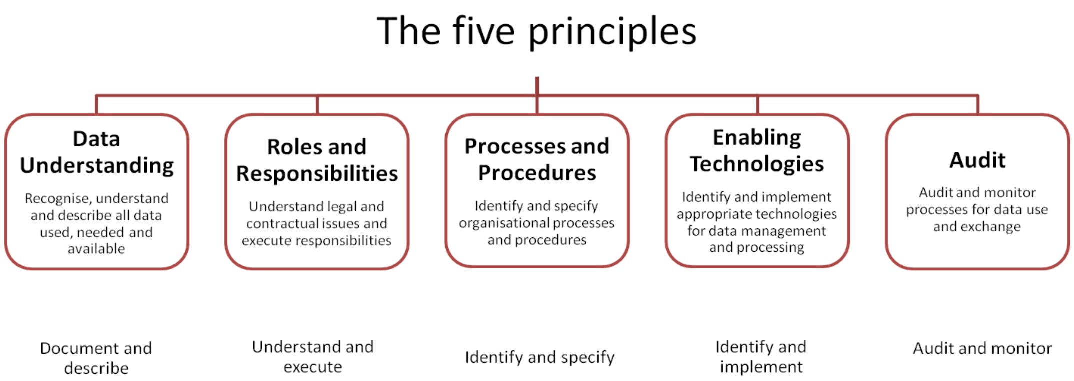


Figure 3-1 Five Principals For Data Management

3.3.4 International Data Standards

Data standards provide the cornerstone for consistent data management. These include standards for data encoding, content (e.g. metadata) spatial-temporal referencing systems, data services and parameter dictionaries amongst others.

For the types of data associated with the CCRA project, the international normative reference is the ISO19000 series of standards. In particular, ISO 19115 (Geographic Information – Metadata; see below) and ISO 19139 (XML encoding of ISO 19115). The use of this standard also has a legal basis in the context of INSPIRE. INSPIRE is an EC directive (2007/2/EC) for a pan-European spatial data infrastructure that would lay down legal requirements for data specifications and standards as well as associated data services. This directive is currently being transposed into UK law in the context of the UK Location Programme.

3.3.5 Geographic information - Metadata

ISO 19115:2003 defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data.

ISO 19115:2003 is applicable to:

- the cataloguing of datasets, clearinghouse activities, and the full description of datasets;
- geographic datasets, dataset series, and individual geographic features and feature properties.

ISO 19115:2003 defines:

- mandatory and conditional metadata sections, metadata entities, and metadata elements;
- the minimum set of metadata required to serve the full range of metadata applications (data discovery, determining data fitness for use, data access, data transfer, and use of digital data);
- optional metadata elements - to allow for a more extensive standard description of geographic data, if required;
- a method for extending metadata to fit specialized needs.

Though ISO 19115:2003 is applicable to digital data, its principles can be extended to many other forms of geographic data such as maps, charts, and textual documents as well as non-geographic data. ISO19115 is very comprehensive, and is commonly profiled to a reduced form within a given community. The INSPIRE Directive for example defines a profile of ISO19115 for pan-European data discovery.

3.3.6 Data Management approach

The CCRA study will make use of the Five Principles for data management and also make use of International standards for metadata to describe data used on the project, as follows:

Principal 1: Data Understanding. The CCRA project recognises that data to be used will exist in a range of representations and forms. This may include structured numeric datasets, documents such as spreadsheets and reports, images, maps and charts. This data will be relevant to a particular geographic extent and temporal extent. The project will consider all data and filter it according to its appropriateness for use on the CCRA project.

Principal 2: Roles and Responsibilities. Staff working on the CCRA project will be responsible for cataloguing any incoming data for use on the project as potential reference material. This cataloguing will be in accordance to the metadata standard ISO 19115. Importantly this cataloguing will describe the conditions by which the data can be used on the CCRA project and also potentially post project.

Principal 3: Process and Procedures. ISO19115 will be used as the metadata standard to describe the data that is used on the CCRA study. The metadata will cover the citation aspects of the dataset (title, author, owner etc.) as well as the access and use constraints of the data as outlined in Principle 2. The elements of the metadata that are also particularly pertinent to the CCRA study is the classification of the data via keywords and the ‘lineage’ that formally describes how a data set has been processed or derived.

Principal 4: Enabling Technology. The CCRA project will adopt two key technologies for data management. First is the Subversion version control repository for storing received data. The ticketing facility of this application will be used to describe issues and actions related to this data. The second piece of enabling technology is the metadata editor Metadata Maestro which provides and easy to use form based interface for completing and validating metadata records.

Principal 5: Audit. The use of the version control and metadata tools enables audits on the data management process to be undertaken. The metadata tool contains in-built validation to check accuracy of each record. The version control tool provides a traceable audit of any changes and new versions of datasets. At a process level, check points will include ensuring that any data set derived on the project contains in its metadata the required lineage describing source datasets and a reference to the processing methodology (e.g. a report) describing how the data was generated.

3.3.7 Data storage and archiving

All data received and outputs created will be stored in a revision control system, so that any changes or modifications are recorded in the repository log. On completion of the project, a copy of the repository will be provided to the funders, subject to any restrictions imposed by data providers. A full copy will also be archived at HR Wallingford and maintained for a minimum of 5 years.

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Appendices

Appendix 1 Literature review and additional sources

Questions posed to Sector Champions

Question 1 (current risks): What are the current climate and non-climate (economic, environmental, technological, regulatory) risks in your sector? What have been the consequences of extreme weather conditions on your sector? What people, activities or places are particularly vulnerable? How significant are climate-related risks compared to other risks for your sector? (20)

Question 2 (future risks): What are the future economic, environmental and physical risks in your sector in the short term (5+ years), mid term (2050s) and long term (2100)? What evidence is available to link climate to impacts and to monetise impacts? Can you identify key thresholds going forward? (20)

Question 3 (adaptation - "who" and "how"): Who are the key stakeholders in your sector and are they actively taking adaptation measures? How is climate change and adaptation being considered? Please provide examples of key decisions and information about adaptation measures being adopted. (20)

Question 4 (adaptation – "issues"): What are the barriers and enablers to taking adaptation decisions? Can you identify any barriers in legislation? What about institutional barriers (either internal or external barriers)? What enabling mechanisms exist? (20)

Question 5 (future risks): What are the main international climate impacts and adaptation issues, which will affect you sector? (10)

Question 6 (research gaps): What research gaps need to be filled to enable a better assessment of climate risks and adaptation measures? (10)

For all the questions above, where information is available stakeholders are asked to provide sources of evidence:

What studies and data sets are available now?

What evidence is available on cross-sectoral risks?

What studies are underway and what studies are planned?

Are there studies or options – particularly "real options" that have considered climate change uncertainty

Are quantitative impacts data available?

Are impacts monetised?

Other sources of information used

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Appendix 2 Selection Scoring Criteria

The scoring system used to identify the main risks for Tier 2 was primarily based on qualitative information about the magnitude of consequences, their likelihood and the urgency of decision making. These three criteria were equally weighted and combined to provide a guide for selecting impacts to be taken forward to Tier 2 of the assessment.

The basic principles of the scoring guidelines are broadly similar to the Cabinet Office's National Risk Assessment[22], although more general, given the wide ranging impacts of climate change. Guidance on High, Medium and Low scores are presented in the tables below, which are appropriate scales for the geographical breakdown intended in this assessment. A "Very High" class will be used if required for some national impacts and the weighting method will be adjusted accordingly.

	Economic	**Environmental**	**Social**
Weight for Magnitude	1/3 x 1/3 = 1/9	1/3 x 1/3 = 1/9	1/3 x 1/3 = 1/9
Considers	- Asset damage - Consequences on business and the functioning of the economy - Transport disruption	- Valued species and biodiversity - Ecosystem services	- Risk to life, health and wellbeing - Consequence on disadvantaged groups - Disruption to services - Cultural and symbolic consequences

Table 0-1 - Guidance on classification of relative magnitude: coverage and weighting of economic, environmental and social criteria

[22] NRA methodology is restricted so any detailed comparisons cannot be made here.

Class	Economic	Environmental	Social
High	- Major and recurrent damage to property and infrastructure - Major consequence on regional and national economy - Major cross-sector consequences - Major disruption or loss of national or international transport links - Major loss/gain of employment opportunities *~ £100 million for a single event or per year*	- Major loss or decline in long-term quality of valued species/habitat/landscape - Major or long-term decline in status/condition of sites of international/national significance - Widespread Failure of ecosystem function or services - Widespread decline in land/water/air quality - Major cross-sector consequences *~ 5000 ha lost/gained* *~ 10000 km river water quality affected*	- Potential for many fatalities or serious harm - Loss or major disruption to utilities (water/gas/ electricity) - Major consequences on vulnerable groups - Increase in national health burden - Large reduction in community services - Major damage or loss of cultural assets/high symbolic value - Major role for emergency services - Major impacts on personal security e.g. increased crime *~million affected* *~1000s harmed* *~100 fatalities*
Medium	- Widespread damage to property and infrastructure - Influence on regional economy - Consequences on operations & service provision initiating contingency plans - Minor disruption of national transport links - Moderate cross-sector consequences - Moderate loss/gain of employment opportunities *~ £10 million per event or year*	- Important/medium-term consequences on species/habitat/landscape - Medium-term or moderate loss of quality/status of sites of national importance - Regional decline in land/water/air quality - Medium-term or Regional loss/decline in ecosystem services - Moderate cross-sector consequences *~ 500 ha lost/gained* *~ 1000 km river water quality affected*	- Significant numbers affected - Minor disruption to utilities (water/gas/electricity) - Increased inequality, e.g. through rising costs of service provision - Consequence on health burden - Moderate reduction in community services - Moderate increased role for emergency services - Minor impacts on personal security *~thousands affected* *~100s harmed* *~10 fatalities*
Low	- Minor or very local consequences - No consequence on national or regional economy - Localised disruption of transport *~ £1 million per event or year*	- Short-term/reversible effects on species/habitat/landscape or ecosystem services - Localised decline in land/water/air quality Short-term loss/minor decline in quality/status of designated sites *~ 50 ha of valued habitats damaged/improved* *~ 100 km of river water quality affected*	- Small numbers affected - Small reduction in community services - Within 'coping range' *~thousands affected*

Figure 0-1 Guidance on classification of relative magnitude: qualitative descriptions of high, medium and low classes

Class	Likelihood (based on confidence scores)
High	Likely that consequences will occur within the next century *(i) High confidence - greater than about 7 out of 10 chance*
Medium	About as likely or not to occur in the next century *(i) Medium confidence - between 3 and 6 out of 10 chance*
Low	Unlikely that consequences will occur within the next century *(i) Low confidence - less than 3 out of 10 chance*

Figure 0-2 Guidance on classification of likelihood

Supporting notes:

- Guided by IPCC WG2 (i) level of confidence (captured in consequences table)
- Consider the likelihood after autonomous adaptation
- Consider all emissions collectively – this is not a precise exercise at this stage and requires expert judgement by analysts that have worked in the specific sector being considered.

The urgency of decisions is a difficult concept given the uncertainties related to climate change. In very simple terms its aims to identify those decisions required before 2020 and areas with a shortfall in adaptive capacity. It also needs to deal with issues related to flexibility of decisions, the risk of 'lock in' and potential adaptation pathways. The criteria are set out in summary and more detailed form below. By focusing on 'urgent' decisions, the CCRA will help to avoid the risk of maladaptation to climate change.

Class	Summary urgency description	Response description
High	Major decisions required before 2020 that affect future resilience to climate change There is a significant shortfall in adaptive capacity	- Act now
Medium	Major decisions required before the 2050s that affect future resilience to climate change There is some shortfall in adaptive capacity	- Watch carefully
Low	No major decisions required prior to the 2050s that affect future resilience to climate change There is little or no shortfall in adaptive capacity	- Wait and see

Class	Urgency
High	• Major policy, investment or other decisions required before 2020[23] that will either undermine or strengthen the future resilience of infrastructure, investments, communities, biodiversity etc. • The objectives of these decisions may be undermined by the speed of climate consequences relative to the decision's payback period, whether measured in financial, environmental or social value. • Decisions have limited flexibility, e.g. development of 'long life' assets with 'lock in' to a specific adaptation pathway. • There is low understanding of the risks and / or of the options to adapt to them. There is a significant shortfall in adaptive capacity with a likelihood of locked-in maladaptation unless action is taken to raise adaptive capacity very soon.
Medium	• Major policy, investment or other decisions will be taken before 2050 that will either undermine or strengthen the future resilience of infrastructure, investments, communities, biodiversity etc. • The objectives of these decisions may be undermined by the speed of climate consequences relative to the decision's payback period, whether measured in financial, environmental or social value. • There is medium understanding of the risks and / or of the options to adapt to them. • Decisions have some flexibility and there is some potential for incremental adaptation over the long term. There is some shortfall in adaptive capacity with a limited risk of locked-in maladaptation unless action is taken to raise adaptive capacity.
Low	• Major policy, investment or other decisions are not required before 2050. • There is high understanding of the risks and / or of the options to adapt to them. • Decisions have high flexibility with potential for incremental adaptation over time. There is little or no shortfall in adaptive capacity with limited or no need to raise adaptive capacity to avoid maladaptation.

Figure 0-3 Guidance on classification of the 'urgency of decisions'

The criteria are applied using a scoring and weighting method, as shown in the figure below.

[23] 2020 is chosen to cover the set of decisions that will be taken, or are likely to be initiated, prior to the next CCRA in 2017. Major decisions typically take three years or more from initiation to finalisation and are increasingly difficult to influence during this period. This means 2017 to 2020 decisions would be very hard to influence as a result of the next CCRA, which would be more likely to influence decisions taken between 2020 and 2025.

Criteria	Score	*Weight*
Magnitude: economic	High = 3; Medium = 2; Low = 1	***1/3 x 1/3 = 1/9***
Magnitude: social	High = 3; Medium = 2; Low = 1	***1/3 x 1/3 = 1/9***
Magnitude: environmental	High = 3; Medium = 2; Low = 1	***1/3 x 1/3 = 1/9***
Likelihood of the consequence occurring	High = 3; Medium = 2; Low = 1	***1/3***
Urgency with which a decision needs to be made	***High = 3; Medium = 2; Low = 1***	*1/3*

Figure 0-4 Criteria scoring and weighting

The following formula is used to combine scores:

$$100*\left(\frac{\text{Social}+\text{Environmental}+\text{Economic}}{9}\right)\left(\frac{\text{Likelihood}}{3}\right)\left(\frac{\text{Urgency}}{3}\right)$$

The descriptors of classes for the Low, Medium and High scores was logarithmic but this was not carried through to the scoring, e.g. by using scores of 1, 10, 100, because it was found that this introduced considerable bias in combined scores with the effect that only impacts that had consequences which were selected for the 'high magnitude' class would be selected[24]. Feedback from workshops and sector experts who had undertaken similar exercises was virtually unanimous that the best option was not to carry through the logarithmic scale to the scoring.

From a risk perspective, considering logical rules related to risk AND urgency is more appropriate but practically we found that this makes little difference in terms of which risks are selected for Tier 2. Although the theoretical and presentational benefits of a binary operation were identified, as in practice this made very little difference and as there was further more qualitative refinement to still be applied it was decided not to re-score the risks.

The following examples show how the risk assessment selection is scored for three theoretical impacts, A, B and C.

Impact	Social	Environmental	Economic	Likelihood	Decision Urgency	Total
A	Medium	High	Medium	Medium	Medium	
B	Medium	Medium	High	Low	High	
C	Low	Low	Low	High	Low	

Consequence	Social	Environmental	Economic	Likelihood	Decision Urgency	Total
A	2	3	2	2	2	35
B	2	2	3	1	3	26
C	1	1	1	3	1	11

[24] It could be argued that the scoring of magnitude classes should reflect the logarithmic progression of the described magnitudes for each class. However, this was considered on balance to be undesirable as the consequences had initially been deliberately forced in to logarithmic categories for a deliberate and practical rather than analytical purpose.

The lowest possible score is four[25], an average score for the impacts identified in the CCRA is around 30, and 100 is the highest theoretically possible.

Opportunities are the opposite of threats but the same score system is applied. The only difference is that opportunities are treated as positive and threats are assigned negative scores. A consequence which exhibits no change can be assigned zero magnitude. Hence the scale extends from +100 through zero to -100. The selection process focuses on those consequences that score towards the upper or lower end of the scale.

This scoring scheme will be applied by the Sector Champions to all identified risks within their sector. The resultant lists identifies the consequences in descending order based on the selection score.

However, it is recognised that this approach could lead to a false sense of precision in the scoring. There are then a number of further steps required to ensure consistency of scoring across sectors and a less technocratic, more balanced, process of refinement to select those risks to be examined in more detail as part of the Tier 2 assessment, as follows:

- The sector lists are reviewed against the Sector reports and Sector Workshop reports to check for completeness;
- The resultant lists will be combined and within sector scores will be compared to identify any apparent biases in scoring. Any adjustments to the scoring are made in discussion with the Sector Champion;
- Overlaps between sectors are identified and a “lead” sector defined for each consequence;
- The sector scores are then used to identify those consequences that should definitely be included in the final selection. This selection is then moderated to ensure that there is a reasonable balance across sectors;
- An iterative process is then used to agree additional consequences that should be included. These may be included because although not a priority in a particular sector:
    - they are still likely to be more significant than similarly scored consequences in other sectors for other reasons; or
    - they occur in several sectors.

Emergent System Property Risks

Causal links as a consequence of climate change are the basis of the systematic mapping and the risk identification process. This approach works well for a range of bio-physical impacts that in turn result in socio-economic consequences. These process based cause-consequence links form the core of the analysis. However, some risks arise through the collective influence of climate change on society. These may arise as a result of a range of incremental changes or a societal response to extreme events in areas of society that are not directly linked to the causal event (or sometimes even the evidence). These are in effect emergent system properties. For example, if the net effects of climate change projections are underestimated, this could affect investment performance, insurance, etc. Similarly, if the collective public perception of the climate change risk militates against strong governance and management across a range of sectors, then the capacity to adapt will be constrained. Thus, adaptive

[25] Lowest score would be 3.7 and mid score 29.6 ~ the quoted low and mid figure are rounded

capacity (or the lack of it) can be seen as an emergent risk rather than a cause-consequence process based risk. These risks will be identified as a separate group (not linked explicitly to climate change variables) and will feed into the assessment of adaptive capacity as an explicit qualification of the risks in the sector.

4.1.1.1 Refinement

The method outlined above for weighting and applying the criteria is a considered approach balancing pragmatism, simplicity and technical transparency. It is likely that after applying this method there will be three sets of risks:

- Risks that should definitely be selected for detailed assessment (well above the 'threshold' for selection),
- Risks that should definitely not be selected for detailed assessment (well below the threshold) ,
- A set of risks with marginal scores that do not exceed the selection threshold for UK-wide assessment but may be of interest for particular Devolved Administrations, English areas or within individual sectors.

The marginal impacts will be optional for further assessment within English areas and Devolved Administration scale and/or be highlighted as areas requiring further research for CCRA 2.

The project team, experts and review groups spent considerable time discussing, testing and refining initial scoring criteria. Through this process we learnt that:

- this is a necessary but particularly difficult task in the absence of consistent detailed evidence on many risks
- it requires considerable expert and stakeholder input
- that risk and urgency criteria are most logically combined using an 'AND' rule rather than multiplication

Appendix 3 Systematic mapping detail

This appendix provides some further background to the rationale and structure behind the systematic mapping.

Introduction

The methodology for the CCRA sets out the need to undertake a systematic mapping of consequences. The intended purpose of the systematic mapping is to identify as many consequences of climate change as possible, both within and across sectors. Subsequently, the mapping will be used to elaborate, qualitatively or quantitatively, the magnitude of the consequences and their likelihood. As such, the requirement is inherently reductionist in character and this is why the process has been referred to as a systematic mapping rather than a system mapping.

At their simplest, systems models are abstractions at some chosen level that identify entities that are interconnected and say something about the linkages (von Bertalanffy, 1968; Huggett, 1980; Odum, 1983). By making the abstraction at a very high level, the system model provides a very accessible way of describing, modelling and presenting the interactions within any system. However, as a greater and greater number of entities are introduced such system models rapidly become highly complex. Given the desire to consider impacts at the sector level and the interactions between sectors, it is considered that a single integrated system model would be difficult to construct, manage and communicate in the time available, without losing much of the detail that may later turn out to be important. The approach proposed therefore seeks to identify as many linkages as possible in a way that is tractable in the timescale. It may also provide a basis for developing system model descriptions in the future (possibly by suitable synthesis and simplification of the outputs).

Conceptually the approach to be used is a form of forward chaining. Starting with a top level cause (a change in a variable) the associated consequence(s) are identified. The consequences are then the causes for the next level and will give rise to a new set of consequences, and so on. Each cause will be mediated by some process to give rise to the consequence. In systems analysis this is often considered in terms of input-process-output, which for impact assessments is typically described in terms of driver-pathway-receptor. The work flow is illustrated in Figure 4.1 (see Section 4.2). The mapping exercise will focus on identifying linkages between input variables (causes) and output variables (consequences) and a description of the linking process; in some cases it may be possible to define such linkages using more detailed process models (e.g. flood risk) but we will focus on understanding what the linkages are rather than the ability to represent or model the linkages.

This note develops the concept of cause-process-consequence mapping in more detail. This serves to:

- ensure that the aims of the exercise are clearly defined;
- constrain the exercise so that it can be undertaken in an efficient and timely manner;
- define the level of system abstraction to be identified;
- identify the information that needs to be captured in the mapping exercise.

By way of introduction, some of the concepts and definitions that systematic mapping is based on are explained, before providing a more detailed definition of the mapping attributes and some consideration of how the results of the systematic mapping will be utilised.

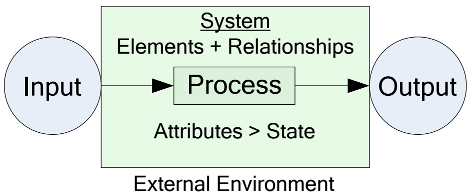
Concepts and definitions

In order to achieve a consistent level of mapping across sectors, the basis for defining causes and consequences needs to be constrained as much as possible but not in such a way that important links are missed. The mapping therefore combines two aspects:

- a relatively rigid classification of the causes of change, the process, effect or pathway that bring about the change and the resultant consequences; and
- a supporting narrative of the cause, process and consequence.

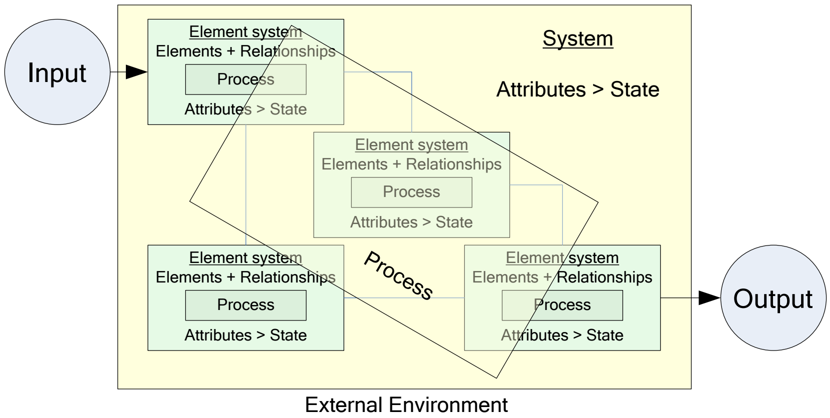
The former allows the process to be controlled to some degree and the latter permits a richer level of information to be captured on specific processes and consequences.

The basic concept of a system is an abstraction at some level in order to encapsulate the behaviour of elements of interest. At any given level of abstraction, there is the environment of the system, the system itself and sub-components. At each level, there are elements (or entities) with relationships to other elements that collectively can be characterised by attributes to define a system state. The boundary of a system may be spatial where there is a transfer of energy or matter. However, it can also be conceptual as, for example, with many social constructs like society, democracy, etc, that involve the transfer of information between the elements, which in this case might be citizens. Importantly, except for isolated systems, the connection between input and output requires a process of some sort that, as a rule, involves the transfer, transport or exchange of energy, matter or information, or some combination.

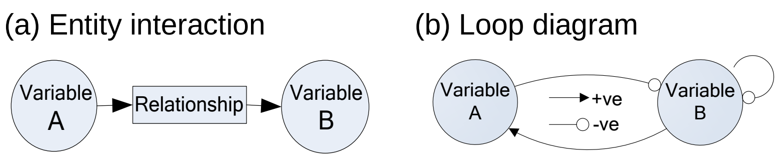


A single input-process-output (I-P-O) can link to several others. One input variable can drive several processes and an output can be the input to another I-P-O. There can also be feedback from outputs to inputs.

Clearly because of the abstraction process, elements that make up a particular system may themselves be composed of elements with their own relationships and attributes that define the state of the element (i.e. a hierarchy or cascade of elements that combine through relationships to give rise to a dynamic system at each given level). This is illustrated in the following diagram which shows a system comprising four elements that are themselves systems at the next level of detail (denoted Element systems). At the level illustrated, the Element systems have relationships with each other defined by the connectivity. Whilst processes are occurring in the Element systems, the process at the level of interest is the one that involves some combination of the Element systems to bring about some transformation in the state of the System.



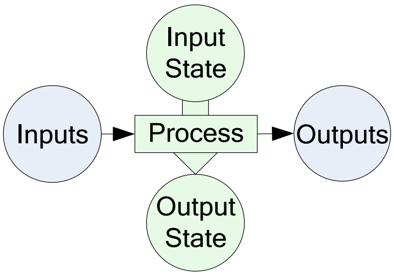
The elements within a system can take many different forms: physical, chemical, biological, structural, formless, conceptual, continuous, discreet, etc. Relationships between the elements may be spatial or topological, may entail exchanges, transfers or flows, or involve reactions or other forms of transformation. The best way to represent a particular system depends on the problem of interest. For example, the relationship between geomorphological features (river, coast, catchment) is most easily represented by a conventional spatial map. Other physical systems may not need to retain strict spatial relationship but simply the connectivity – the London Underground map is a good example of this type of relationship mapping. Many systems comprise entities, whether real or conceptual, and system mapping is one way of building a picture of these inter-relationships, where one maps the connectivity between elements or the causal loops. The richness of the English language means that this basic construct can be expressed in many different ways. In the field of impact assessment, for example, this may often be defined in terms of source-pathway-receptor. The basic structure can also be defined as:

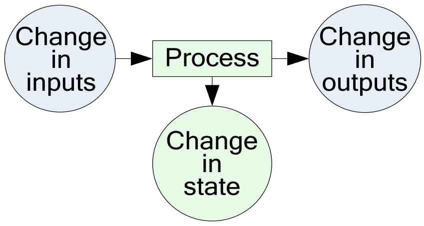


The relationships shown could equally represent interactions between two agents as used in Agent Based Models (ABMs). The diagrammatic representation is sometimes further simplified so that the connecting arrow represents the process (as in (b) above).

The behaviour of the system is determined by the inputs and any internal self-regulation processes (positive or negative feedback). Thus in a dynamic environment, as the inputs change, so the outputs and the state of the system are likely to adjust in response. Depending on the purpose of the systems analysis, interest may focus on the outputs, the change in state of the system, or both, Table A2.1. For example, where the inflows to a system comprise energy and matter and outflows are heat and waste matter, interest may focus on how the inputs affect the state of the system, rather than the waste products. In a different application, minimising the waste products may be the primary consideration.

Take, for example, a river basin catchment for which there is an increase in rainfall. One of the immediate and direct processes is run-off of water over the land. The output is increased water into the rivers and the change in state is that the land becomes saturated. In this case, both may be of relevance to the analysis of impacts on the wider system. In examining climate change impacts it is therefore necessary to consider both system state and outputs, as appropriate for the particular case. The aspects of the system of particular interest are therefore the inputs, outputs, input state and output state. In an impact or risk assessment the primary interest is the change in output or change in state as a consequence of changes to the inputs, as illustrated below.

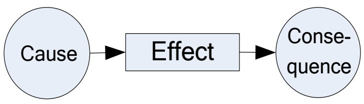




System	Process	Input(s)	Attribute of interest	Change in State	Output
Plant	Photosynthesis	Sunlight Water Carbon dioxide Nutrients	Biomass	Growth Death	Oxygen
Beach Dune	Sand transport	Wind Offshore sand	Beach volume Dune volume	Accretion Erosion	Heat
NGO	Lobbying	Human energy Values Information	Membership	Influence	Publicity
Insurance company	Financing loss	Premiums Reinsurance	Financial cover No of policies	Solvent Bankrupt	Profit

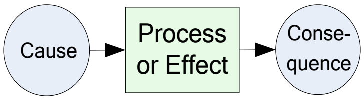
Figure 0-5 Examples of system property characterisation

When using a narrative approach, cause and effect is more immediately accessible linguistically than defining a system and identifying the inputs and outputs of relevance. This idea is extensively used in operational research and business management, through the use of Fishbone or Ishikawa diagrams. When used for more formal analysis, as in cause-consequence failure analysis, the *effect* is typically an intermediate result or outcome that flows from the defined causes and gives rise to a set of one or more consequences.



For some systems it will be easier to identify the effect (e.g. for a structure that is overloaded it is easier to note the overloading as an effect rather than detail the internal process that causes it to fail), whereas for other systems the process is the more obvious link (e.g. transport of sediment is the process that gives rise to erosion or deposition). The aim here is to identify the basic causal links, so that the representation of the system is captured by considering the cause of change, the process or effect that brings this about and the resulting consequences (which could be system outputs or changes in state as discussed above[26]).

[26] Whilst one system *output* may affect the *state* of another system, this can be addressed by redefining the system to include both (ie reviewing the level of abstraction), or defining two sequential models, one defining how the cause alters the *output* of the first system and the other capturing the process by which the *state* of the second system is altered. The iterative process of systematic mapping should ensure this is captured.



Mapping Attributes

The **cause** is defined by the variable that is changing, together with the nature, direction and magnitude of the change. In order to map the consequences of climate change, it is only necessary to define the order, or range of change to be considered, rather than, say, the predicted change over defined time intervals, as may be obtained from the UKCIP09 data set.

The description of the cause is made up of five attributes:

Cause **(**climate variables in 1st iteration)	A short classifier that defines the variable that is changing. These are predefined for each iteration of the mapping process. For the 1st iteration these will be climate variables. They can either be a primary variable of the climate system, or a compound variable that is a result of the interaction of primary variables (e.g. humidity), or interaction with the earth system (e.g. waves). For the 2nd and subsequent iterations they will be rationalised lists derived from the consequences of previous iterations.
Measure	Variables can be described in many ways to reflect trends, cycles (amplitude or frequency), event sequences, or discrete state changes[27] and this attribute is to identify the measure of change that is of most relevance to the particular consequence being mapped (mean, extreme (high or low), frequency, etc)
Property	The measure may apply to various properties of the variable such as its magnitude or direction for continuous properties, the occurrence of discrete events or simply the state (exist, not-exist) of the system.
Direction	This defines the nature of the change (gain, loss etc) in terms of: increase or decrease for progressive changes; and exist or not for discrete state changes
Magnitude	The mapping exercise is not intended to look at specific scenarios or outcomes. However, to determine whether a change is likely to have any effect on a particular system or entity, it would be useful to know the potential magnitude of change. This attribute provides a simple indication of the possible range of change over the next century (large or small). This can be expanded on in the narrative where values can be expressed qualitatively or quantitatively (e.g. as a percentage change). For discrete state changes, such as extinction, some measure of the scale of the event could be given.
Narrative	Additional explanatory text and reference to sources of further information or data.

The attributes combine to provide an expression that is able to describe the particular cause. For example:

The {*Measure*} {*Property*} of {*Cause*} is {*Direction*} {*Magnitude*}, causing ….

Which results in statements like:

“The mean magnitude of pressure is increased a little, causing ....”

Or “The frequency of occurrence of storms is decreased a lot, causing ....”

[27] Note that “discrete state change” is used to describe a switch between alternate discrete states (eg exist/not-exist, dead/alive, etc), as distinct from progressive changes in the state of the system.

Or in subsequent iterations, for the variable of, say, ‘habitat’ this might be:

> “The existence state of habitat is lost partially, causing ....”

A **process** is an operation (or event) that results in a transformation in a physical or biological object, whether substance or organism, resulting in a change in the state of the system. As such they are the essence of dynamic systems. Every representation of a process is characterised by input and output variables and can be described in terms of the system attributes (properties defined by variables and parameters). Processes can be autonomous or controlled and are classified in many different ways, such as: continuous or discrete, stable or unstable, convergent or non-convergent, cyclic or non-cyclic, linear or non-linear. However, it should be noted that the recognition of a process is an arbitrary and subjective abstraction that depends on prevailing paradigms, the observer’s perception and the tools available to investigate the process.

Processes involve the flow of energy, matter and/or information, so that, at some scale, there is always a transfer or exchange taking place between one entity (or location) and another. This can be at a local scale, such as the intake of energy by a plant or animal, at larger scales, such as the transport of water in a catchment, or at a national scale, such the migration of people, flora or fauna. There are a huge number of descriptors for processes and it was concluded that, to begin with, it would be better to restrict the number of process descriptors to a minimum set of words that describe movement, transfer, consumption and reaction. Those entering data are encouraged to provide a sector specific description of the process involved. These will be examined as part of the data analysis, to see if a richer set of process descriptors can be identified. A somewhat more extensive list of constituents has been defined but these remain at a relatively high level, again in order to promote generality across sectors with the opportunity to add sector specific narratives.

The description of the process is made up of two attributes:

Process Defines the means by which a change in the system is brought about, typically involving the transfer or transformation of matter, energy or information.

Constituent Variable to describe the medium that is involved, which is not constrained to be a physical attribute but will predominantly entail matter, energy or information (including concepts) of some form.

Narrative A text field to capture a more detailed description of the process.

The attributes combine to provide an expression that is able to describe the particular process. For example:

the {*Process*} of {*Constituent*}

Which might results in statements like:

“the transport of water”

The **consequences** of interest are either:

(i) what the system exchanges with its environment as a result of the process, or

(ii) how key attributes that, in the particular context, characterise the state of the system are altered. This may entail changes in magnitude of the attributes, or a change in state (eg. living or dead, etc).

The change may or may not be significant. Depending on how the overall system is disaggregated, particular outputs or consequences will give rise to secondary effects, so the output or consequence of one process can be the input to another process. It follows that the description of consequence attributes must be capable of being replicated as cause attributes.

The description of the consequence is made up of the same five attributes used for the causal definition:

Consequence	A short classifier that defines what is being altered or affected. As far as possible the classifier should not be value laden as this is captured in the attributes that follow (eg. use "habitat area" rather than "loss of habitat").
Measure	Variables that describe a characteristic or attribute of a system can be delineated in many ways to reflect trends, cycles (amplitude or frequency), event sequences, or discrete state changes and this attribute is to identify the measure of change that is of most relevance to the particular consequence being mapped (mean, extreme (high or low), frequency, etc)
Property	The measure may apply to various properties of the variable such as its magnitude or direction for continuous properties, the occurrence of discrete events or simply the state (exist, not-exist) of the system.
Direction	This defines the nature of the change (gain, loss etc) in terms of: increase or decrease for progressive changes; and exist or not for discrete state changes.
Magnitude	For the range of change defined for the cause, this attribute is intended to capture the possible order of change for the particular consequence. This attribute provides a simple indication of the possible change over the next century (large or small). This can be expanded on in the narrative where values can be expressed qualitatively or quantitatively (eg as percentage change). For discrete state changes, such as extinction, some measure of the scale of the event could be given. It should be noted that the mapping exercise is not intended to look at specific scenarios or outcomes. However, this assessment will be used to describe the magnitude of the cause in subsequent iterations of the mapping process.
Narrative	A text field to capture a more detailed description of the consequence, together with references to sources of further information.

The attributes combine to provide an expression that is able to describe the particular consequence. For example:

With the consequence that the {*Measure*} {*Property*} of {*Consequence*} is {*Direction*} {*Magnitude*}

Which might results in statements like:

> "With the consequence that the extreme (low) magnitude of set-down in estuaries is increased a little".
>
> where the consequence is the 'set-down in estuaries'.

Pulling together the expression for cause, process and consequence we obtain the following statement:

The {Measure} {Property} of {Cause} is {Direction} {Magnitude}, causing the {Process} of {Constituent}, with the consequence that the {Measure} {Property} of {Consequence} is {Direction} {Magnitude}

Which results in statements like:

“The extreme (high) magnitude of winter precipitation is increased a little, causing the transport of water, with the consequence that the mean magnitude of inland flooding is increased a little.”

“The mean magnitude of cloud cover is decreased a little, causing transfer of energy, with the consequence that the mean magnitude of indoor lighting requirements is decreased a little”

The frequency of occurrence of summer precipitation is decreased a little, causing transport of water, with the consequence that the mean magnitude of sewer flows is decreased a little”

The definition of classes for each of the key attributes are given in the table below. As many of the attributes can be described in other ways, a list of synonyms is included in the table below:

Cause 1 - Climate Variable	**Measure**	**Property**	**Direction**	**Magnitude**
Aridity Carbon dioxide Cloud cover Drought plus intense rain Growing season Humidity Lightning Mist / fog Ocean pH Precipitation Pressure Intense rain plus high temperature Sea level Sea temperature Snow Storm surge Storms Summer precipitation Summer temperature Temperature Waves Wind speed Winter precipitation Winter temperature	Duration of Existence of Extreme (high) Extreme (low) Frequency of Mean Sequence of	Magnitude Direction Occurrence State	Changed Decreased Gained Increased Lost Unchanged	*Free text/value to indicate the percentage, or order of magnitude of change anticipated*
Process	**Constituent**			
Consumption Exchange Migration Reaction Transfer Transmission Transport	Chemical Data/information Energy Fauna Flora Genetic material Money/value Pathogens People Sediment Water			
Consequence	**Measure**	**Property**	**Direction**	**Magnitude**
Sector defined consequences (*entries to be rationalised into a set of input Cause Fields following each iteration of the process*).	Duration of Existence of Extreme (high) Extreme (low) Frequency of Mean Sequence of	Magnitude Direction Occurrence State	Changed Decreased Gained Increased Lost Unchanged	*Free text/value to indicate the percentage, or order of magnitude of change anticipated*

Figure 0-6 Definition of Cause-Process-Consequence attributes (excluding Narrative)

Attribute	Synonyms
Measure	
Mean	average
Sequence of	grouping of
Extreme (high)	maximum, greatest, highest
Extreme (low)	minimum, smallest, lowest
Frequency of	rate of, recurrence of, periodicity of
Duration of	period of
Existence of	continuance of, presence of, survival of
Property	
Magnitude	amplitude, amount, size, quantity
Direction	aspect, bearing, drift, path, trajectory, trend
Occurrence	event, episode, incident, instance, manifestation
State	circumstance, condition, form
Direction	
Increased	more, raised
Decreased	less, reduced
Lost	demise, death, extinction
Gained	arise, birth, creation
Changed	altered, modified
Unchanged	unaltered, unmodified
Process	transformation, effect, pathway
Transport	conveyance, carriage, move, transfer
Exchange	replace, interchange, convert, transaction, trade, swap
Consumption	devour, use, intake, uptake
Reaction	response, rearrangement
Migration	movement, exodus, flight, passage, shift
Transfer	convey, move, pass on, relocate, transpose
Transmission	convey, communicate, transmit, send
Constituent	element, component

Figure 0-7 Synonyms for cause-process-consequence mapping

Mapping Synthesis

There are potentially a very large number of processes and consequences that can be associated with the climate forcing and these could all be described in subtly different ways by different groups or contributors. Whilst the structure described above will go some way to minimising this, it is likely that further rationalisation will be needed. The ultimate aim is a specification of a shared conceptualisation that is as formal and explicit as possible, and, as such, is close to the definition of an ontology (Gruber,1993).

The attribute values detailed in Table A2.2 have evolved as a result of the testing undertaken as part of the pilot study. Although this focussed on the water sector, mapping was also carried out for a number of other sectors, in order to examine how the interactions between sectors were likely to be captured. The definitions should therefore provide a useful starting point but are likely to evolve as the data capture is undertaken for all sectors. Once the data analysis to meet the needs of the Tier 2 risk assessment has been completed, the database will also be examined in two ways.

Firstly we will explore whether an ontology provides a useful formalisation of the definitions that have been defined through the systematic mapping process. To do this we will import existing ontologies that are relevant, such as some of the components of SWEET[28], and use Protégé-OWL[29] to construct a CCRA ontology. If successful this

[28] http://sweet.jpl.nasa.gov/ontology
[29] http://protege.stanford.edu/overview/protege-owl.html

should further constrain subsequent iterations of the systematic mapping. It should also facilitate more detailed analysis of the resulting “systems” and provide a better foundation to link to modelling descriptions of particular processes. It should therefore be a useful basis on which future CCRAs can build. However, it must be stressed that this is experimental at this stage and it may not be possible to develop a robust ontology in the time available. If this is the case, the progress made can be used to inform any future research requirement.

Secondly, the options to simplify the data into forms that can be used to illustrate relevant aspects of the system and communicate key issues will be explored. This will examine the potential role of more sophisticated tools for the analysis, synthesis and filtering of the information collected (eg topic mapping tools based on ISO 13250). Although the primary analysis will be done on the defined key words, such tools would also allow a more detailed exploration of the narrative text, which provide a much richer description of the overall system. It must again be stressed that this will not be a full implementation but an exploration of what can be achieved, in order to make recommendations as to how the data might usefully be explored in future CCRAs.

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Appendix 4 Socio-Economic Scenarios

Introduction
The future effects of climate change are strongly influenced by socio-economic change. This arises for two reasons, both relevant to the CCRA.

- Socio-economic factors (such as population, technological change and economic growth) determine future greenhouse gas emissions, and so affect the level of climate change. There are existing global socio-economic scenarios that drive the UKCP09 projections.
- The same socio-economic factors influence the vulnerability of social and economic systems to projected climate change, and may also determine the nature of adaptation response.

By way of background, the following section describes these relationships in further detail and outlines the methodological issues posed by current data availability. The third section outlines alternative approaches applicable to the context of the CCRA and makes a recommendation for a preferred approach.

Background

The UKCP09 Projections and socio-economic scenarios

The global emission projections used in the UKCP09 projections are based on future scenarios developed by the IPCC Special Report on Emission Scenarios (SRES) (Nakicenovic et. al. 2000). These scenarios were constructed using plausible future storylines, which were in turn used to generate projections of future energy use and resulting GHG emissions. The SRES developed four main storylines (A1, B1, A2, B2) with some sub-themes.

It is stressed that none of the SRES scenarios include climate emission mitigation initiatives.

The UKCP09 projections use emissions profiles from the global A1 and B1 SRES scenarios.

The A1 storyline describes a world of rapid economic growth, global population that peaks mid-century and then declines, and features the rapid introduction of new and efficient technologies. It has a dominant theme of social and economic convergence amongst regions, capacity building and increased cultural and social interactions with a significant reduction in per capita differences between regions. There are three technological sub-themes: the A1FI scenario is fossil-fuel intensive, the A1T scenario is non-fossil fuel intensive, and the A1B scenario represents a balance across all fuel sources.

The B1 storyline also describes a convergent world, again with population that peaks mid-century, but with rapid changes towards a global service and information economy, with reductions in material intensity, and the introduction of clean and efficient technology. The emphasis is on global solutions to sustainability, improved equity, though without climate mitigation initiatives.

More specifically:

- The UKCP09 Low Emissions scenario is based on the B1 scenario.
- The UKCP09 Medium Emissions scenario is based on the A1B scenario, implying a mix of fossil and non-fossil sources.
- The UKCP09 High Emissions scenario is based on the A1FI high fossil fuel scenario.

The 'tradition' in global and more local impact assessments has been to match up the socio-economic scenarios and climate scenarios in analysis. To illustrate, an impact study that uses the low B1 climate projection will also use the same assumed population, GDP assumptions, and other socio-economic data that input into the B1 climate projections. In principle, this also extends to non-quantitative aspects of socio-economic change that are identified as important in determining vulnerability and exposure. This matching is essential in global studies to ensure consistency, i.e. otherwise the future scenario would not be consistent with the input assumptions.

This tradition has also fed through into national assessments, particularly where the country is assumed either to be determining global trends itself or is judged likely to be strongly influenced by global socio-economic trends. Thus, the majority of UK risk assessments have used socio-economic assumptions consistent with the underlying SRES scenarios. To further facilitate this in the UK, the UKCIP coordinated the development of four socio-economic scenarios for the UK (UKCIP, 2001), which link to the global emission scenarios[30]. These scenarios build upon other exercises, such as the Foresight scenarios (DTI, 2002) and provide data sets, on population, economic growth, household density, etc. for the time-slices centred on the 2020s and the 2050s. The BESEECH project (Dahlström and Salmons 2005) further developed and up-dated the UKCIP socio-economic scenarios.

		Socio-economic Scenarios			
		Global Sustainability (GS)	Local Stewardship (LS)	National Enterprise (NE)	World Markets (WM)
Emission Scenarios	Low	S,C	S		S
	Medium-Low		C		
	Medium-High			C	
	High	S	S		S,C

Notes: 'S' may be combinations used in sensitivity analysis; 'C' may be combinations used if consistency between scenarios is considered.

Figure 0-8 UKCIP Recommended climate - socio-economic scenario combinations

Note that the UKCIP Socio-Economic Scenarios (SES) provide a fairly limited quantitative data set which is unlikely to meet the needs of the CCRA. This would therefore have to be supplemented by sectoral and other data sets that were judged to be valid by the project team.

[30] Note, although there is no direct correspondence between the UKCIP02 scenarios and the SRES, not least because the SRES are specifically aimed at the UK whereas the emissions scenarios used in UKCIP02 are global emissions scenarios, an approximate correspondence can be drawn

The influence of socio-economic change on risks

Future socio-economic change will result in a change in vulnerability and/or exposure to risks, even in the absence of future climate change. As an example, the ageing of the UK population would be expected to alter the vulnerability of the population to heat related extremes, or ozone pollution, even if the climate remained unchanged in the future, because older age groups are more susceptible to these effects.

Socio-economic change will also influence the exposure to any future climate signal. To illustrate, the future impact of extreme events such as floods or storms will be determined by the increased wealth of individuals and assets (driven by socio-economic growth) but also changes in exposure as land-use changes, e.g. if there is housing development in areas that are more susceptible to flood risk. Indeed, the Foresight study (Evans et al, 2004) found that socio-economic change could be a more significant driver in determining future flood risks than climate change. In some cases, socio-economic changes may in fact affect the sign (+/-) of damages.

Over the course of longer time periods (the 2050s time-slice, or especially the 2080s) there can be significant differences between the various socio-economic scenarios. As an example, household occupancy / numbers of households varies between the UKCIP LS and WM scenarios significantly by 2050, with 24 million households under the LS scenario and 33 million under the WM scenario, even though the population numbers are relatively similar for the two scenarios (62 and 66 million respectively).

These very large differences will affect the size of the potential risks from climate change, for example in relation to energy use, as well as influencing vulnerability. The key drivers in the socio-economic scenarios that are most relevant in any future CCRA include:

- GDP growth rates;
- Income, and income distribution indicator;
- Population, household, household size;
- Land use;
- Sector specific metrics (e.g. value added in economic sectors, passenger transport, etc).

There is therefore a need to include socio-economic scenarios to assess future risks. It may also be useful to split out this socio-economic component to identify the ‘net’ impacts attributable to climate change, as well as the ‘gross’ impacts due to the combination of ‘climate + socio-economic change’, most relevant to the determination of adaptation responses.

There are also strong linkages between socio-economic development and adaptation. As an example, income and wealth are important in adaptive capacity. Different patterns of socio-economic development are also likely to affect the cost or availability of different adaptation options. Note that – as with emissions - there are also major uncertainties in future socio-economic trends, which affect the magnitude and probability of any potential impact.

Thus, whilst there is limited experience of using socio-economic scenarios in vulnerability, impact or adaptation assessments, any UK risk assessment will be flawed if it does not include such scenarios, since this would imply that projected future climates will take place in a world with today’s socio-economic profile.

A key requirement of the CCRA is to make sure that the same socio-economic data is used in each sector in impact assessment. Failure to do this will lead to greater risks in some sectors than others which are driven by underlying socio-economic scenarios.

Application of Socio-Economic Scenarios in the UK CCRA

There are a number of challenges in socio-economic scenarios for the CCRA. These are outlined below.

1) Data availability

There are two aspects of data availability that should be highlighted.

1. Coverage of future time periods. Whilst the UKCP09 data exists to 2100, existing socio-economic projections are available at most until the middle decades of this century.

2. Lack of “low-carbon future” scenario. As highlighted above, existing socio-economic data sets for the UK are based on future scenarios without mitigation. However, the Government has announced short and long-term policy commitments, towards an 80% reduction in GHG by 2050, as set out in the Climate Change Act and the Low Carbon Transition plan. The business as usual scenario, i.e. the ‘with current policies’ scenario, is therefore now this mitigation reduction trajectory. This is likely to result in a significant inconsistency since in many sectors their future profiles will be radically different in 2050 from the picture today as it effectively involves a complete decarbonisation of the economy. Consequently, this may have major effects on the vulnerability of the UK to future climate change.

2) Data consistency

There are four aspects of data consistency that should be highlighted.

1. Out-of-date data. The development of the new UKCP09 climate projections was not accompanied by an update of the socio-economic scenarios. This means that for some socio-economic variables, the data that does exist are out of date. For example, it is clearly inappropriate to apply data from UKCIP (2001) that does not match observed data in the period up to 2010.

2. UKCIP (2001) inconsistencies with current government projections. The CCRA is a Government risk assessment, with an associated adaptation assessment focused on Government planned adaptation. However, it is clear that there are discrepancies between projections used in existing government forecasts and the UKCIP SES. In practical terms, the short-term socio-economic data in the project needs to be consistent with Government projections, i.e. it is clearly not appropriate for the CCRA to use population or economic forecasts (in the short-term at least) which are different to those of Government or HM Treasury.

3. Policy baseline consistency. Closely associated with the previous point, and the lack of a low-carbon baseline above, existing socio-economic scenario data do not incorporate current announced Government policy. This requires the analysis of future impacts need to be based on the existing baseline, including announced policies. Related to this, a further consistency issue arises in aligning the CCRA and adaptation assessment to the recommended approach for Government appraisal.

4. Lack of consistent approach to uncertainty across Climate and Socio-economic scenarios. The probabilistic data available from the Climate Projections has to be combined with socio-economic data. However, this would seem to imply that the analysis should also use probabilistic socio-economic data. This is likely to be beyond the remit of this first CCRA phase though the issue remains of how to capture uncertainty in socio-economic data, to avoid an inaccurate representation of uncertainty around climate projections only.

Possible approaches for incorporating socio-economic futures in the UK CCRA

A number of options are available for the CCRA which each partially address the issues above.

1) Adopt the conventional approach that links climate projections with corresponding socio-economic data sets that currently exist.

> This approach adopts the UKCP09 projections and applies the socio-economic scenarios consistent with these projections, according to Figure 0-1, above. For example, the UKCP09 high scenario would use the UKCIP (2001)/BESEECH world market scenario data, and so would assume the UK takes a 'high' fossil emission path. Similarly, for the UKCP09 low scenario, it would use UKCIP (2001)/BESEECH low (global sustainability) data and assume the UK was on a sustainable path. Note that Figure 0-1 also makes suggestions for combinations that effectively test the importance of the socio-economic determinants in the risk assessment.
>
> This approach ensures that common assumptions regarding both quantitative and qualitative socio-economic drivers would be made across all sectors. However, the approach would contradict existing UK low carbon policy and other current policies. The data given in these scenarios is also somewhat dated in certain aspects and is inconsistent with current Government projections.

2) Treat the UKCP09 climate projections as independent from UK socio-economic futures

> An alternative approach is to assume that the future UKCP09 projections are future projections of global action that the UK might be faced with, determined independently of socio-economic development in the UK.
>
> Under this approach, it is more straightforward to incorporate current Government projections and data for the short-term. The major problem with this approach is that is breaks the consistency link between the emission projections, i.e. it would not be internally self-consistent. A second problem is that the Government data does not always extend out to the 2050s, resulting in a data gap.

3) Apply a compromise approach

> The CCRA is proposing to consider the Medium UKCP09 projection only, for the 2020s, because the difference between the various projections is relatively insignificant. This is a useful framing for the socio-economic data as well. A pragmatic approach is therefore to use available Government data projections and policy for this initial time period, supplemented by the UKCIP(2001)/BESEECH scenarios where it is important to capture a broader range of uncertainty in the quantitative data, or where qualitative drivers need to be described.
>
> For more distant time periods, Government data sets, where they exist, could be used. However, it is also likely to be necessary to use the UKCIP (2001)/BESEECH socio-economic data, as well as other relevant data sets, in order to investigate the influence of alternative data and sector assumptions through sensitivity analysis in each of the three UKCP09 emissions scenarios (low, medium, high). This would explore the importance of socio-economic uncertainties and allow a key question to be answered of 'what makes a difference to the overall risk?'.
>
> For the 2020s and 2050s, an additional variation could also be introduced, which would be a socio-economic scenario based on a low carbon future. This is announced policy, though not all sector forecasts currently account for this.

Additional socio-economic scenario development work would therefore be required to address this fully. This is likely to be qualitative within this first CCRA cycle, and would explore the differences in quantitative and qualitative aspects of existing scenarios that were consistent with the low carbon transition plan.

This approach could be extended to the 2080s. However, in addition to this, there is a discussion of a new futures scenario exercise, see Section 2.10.3.

Summary and Recommended approach

The future effects of climate change, both in terms of impacts and vulnerability, are strongly influenced by socio-economic change. Previous studies have shown that differences between socio-economic projections can be as important as, or more important than, differences between climate projections in determining the absolute scale of impacts.

There are also strong linkages between socio-economic development and adaptation. Finally, there are also major uncertainties in future socio-economic trends, which affect the magnitude and probability of any potential impact.

As the UKCIP acknowledges, there is far less experience of using socio-economic scenarios in vulnerability, impact or adaptation assessments. However, any UK risk assessment will be seriously flawed if it does not include them, as this implies that projected future climates will take place in a world similar to today.

The need for additional socio-economic scenario work is a key priority to inform the next CCRA cycle. However, this would not be ready in time for this first phase, and an alternative approach is needed. This invariably involves some trade-offs, centred around various issues of consistency.

On the basis of the potential options, the study team is recommending a pragmatic approach. This involves the use of existing Government data sets and assumptions for the short-term analysis (2020s), which has broad consistency with the use of a single climate projection being used in the CCRA for this period. A set of consistent data is needed for use in all sector assessments as part of this. A wide range of socio-economic variables are required, some are fundamental (such as population and GDP), while other variables are needed for particular sectoral assessments (e.g., mortality rates for impacts on human health).

For the 2050s this involves the extension of this data set, but with sensitivity analysis to test future socio-economic assumptions that include consideration of more self-consistent futures with the projections. A further qualitative consideration of the UK's low carbon future is also recommended.

The team is currently compiling common data sets in discussion with Defra. These are likely to include:

- Population projections, including age distribution.
- Household assumptions.
- Economic forecasts, GDP growth, per capita income, income distribution, etc
- Land use.

A key focus will be investigating data sets currently in use in Government. These will be used to provide a consistent central set of assumptions. We are also gathering:

- UKCIP00/01 data sets
- BESEECH data sets
- Other SES data sets

These will be used to provide data sets for sensitivity analysis. In addition, the sector champions are investigating

- Sector specific data sets based on government projections
- Research work and data assumptions
- Existing futures work (e.g. there is work in Flooding, Health, etc)

References

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Appendix 5 Monetary valuation

Introduction

The generic methodology we intend to use in the monetary valuation of climate change impacts and adaptation in the UK CCRA and AEA will be based on that developed for UKCIP by Metroeconomica[31]. In turn, this is based on the principles described in the HM Treasury Green Book[32] and its Supplements[33]. The methodology will include both monetary values obtained on the basis of market prices as well as those that exist in relation to changes to welfare that are not reflected in market prices i.e. non-market values. The methodology will also set out approaches for comparing monetary and non-monetary information, given that it will not be possible to monetise all of the potential risks identified in the CCRA.

Purpose of monetary valuation

Climate change adaptation decisions that are designed to reduce climate change risks inevitably involve making trade-offs concerning the use of scarce economic resources. To the extent that economic efficiency is an important criterion in informing such decision-making, it is useful to express climate change risks in monetary terms so that they can be assessed and compared directly (using £ as a common metric) and so that they can be compared against the costs of reducing such risks by adaptation.

In the context of the UK CCRA, monetisation, through the use of a common metric, allows an initial comparison of the relative importance of different risks within, and between, sectors. Since it is a metric with which people are familiar, the use of monetisation may also serve as an effective way of communicating the possible extent of climate change risks in the UK and help raise awareness.

At the outset of Tier 2, the CCRA will have identified the priority risks for each sector. It is anticipated that this will include 3 to 10 priority risks per sector, which will be assessed in the Tier 2 CCRA analysis. This is the starting point for the valuation analysis.

The valuation task will begin with an initial review of existing climate change risk monetary valuation for these priority risks. It will also include a wider review to consider whether there are studies that have valued the priority risks in non-climate applications, e.g. in other Government appraisal. The task will then map the priority risks against the potential for valuation, i.e. summarising the potential coverage.

This will allow us a) to compare monetary values directly against the physical climate change risks identified to b) identify where there is existing evidence for use in Tier 2 and Tier 3 assessments.

Tier 2 will then assess selected risks in monetary terms in order to infer the potential magnitude of the economic costs of the risks. It is stressed that valuation is determined (and constrained) by the level of quantified information in the Tier 2 sector

[31] Metroeconomica, (2004), Costing the Impacts of Climate Change in the UK: Implementation Report, UKCIP Technical Report, UK Climate Impacts Program, Oxford.
[32] The UK Treasury publishes the revised 'The Green Book' - Appraisal and Evaluation in Central Government (HMT, 2003), available at:
http://www.hm-treasury.gov.uk/data_greenbook_index.htm, and this is recognised as being the primary source of guidance for public sector economic analysts.
[33] See the series of documents at: http://www.hm-treasury.gov.uk/data_greenbook_supguidance.htm

assessments: where the CCRA produces quantified impact data, then valuation is potentially possible; but not where the CCRA provides estimates of burdens or qualitative risks only. To illustrate, where the main CCRA provides estimates of cooling demand changes in kWh, or numbers of deaths from heat waves, then valuation is possible. However, where the main CCRA provides partial or non-quantified data, such as cooling demand changes presented only in terms of cooling degree days - or health impacts only presented as the extra number of heat waves - then monetisation will be more complex and may not always be possible.

Monetisation will be applied in the UK assessment and, where the physical modelling allows geographical disaggregation of quantified risks, monetisation will be applied in the Devolved Administration and sub-national level assessments. In this case, unit values will be used that are either common to all areas or, where possible, geographically disaggregated themselves. The precise number of risks to be monetised is likely to vary between sector depending on the complexity of the valuation required, the data available and the resource constraints.

For priority risks that have only been assessed in semi-quantitative terms, it may be possible to scale previous studies with economic values to the level of risks anticipated. However, in cases where there are gaps, or no quantified information on the potential scale of risks (i.e. qualitative information), a range of approaches will be considered. The potential for scoping estimate how significant economic costs could be will be considered. If this is not possible, climate change risks will be expressed either in qualitative or physical terms only.

The task will also investigate possible approaches on how to compare monetary and non-monetary information, considering previous approaches used in Government and the sector expert workshops.

A table, with supporting description, will make explicit what is, and what is not, included in the monetised risk estimates.

In Tier 3, where the CCRA is likely to produce more quantitative data, a more detailed version of the approach above will be used. This will consider monetisation of individual climate change risks using different unit values for individual DAs and English areas as far as the data exists. Only the sectors that have a Tier 3 quantified analysis can be valued at Tier 3 level.

Key Principles

Objectives

The key objective of the CCRA valuation task, as set out in the project specification from Defra, is to provide '*a monetary estimate of the total impacts of climate change on the UK, broken down by sector and... [a sub-national scale]... where possible'*

Basis in social preferences

The CCRA Valuation aims to capture the value to society of the economic, social and environmental changes that result from identified climate change risks. The use of monetary values is designed to capture the strengths of preferences relating to such risks across the affected population. The values assigned to each risk are based on the preferences of individuals in the affected population, and the total value to society of any risk is taken to be the sum of the values of the different individuals affected. This distinguishes this system of values from one based on 'expert' preferences, or on the preferences of political leaders.

Individual preferences are expressed in two, theoretically equivalent, ways. These are:

- the minimum payment the individual is willing to accept (WTA) for bearing the risk, or;
- the maximum amount an individual is willing to pay (WTP) to avoid the risk.

In the context of the UK CCRA for example, the WTP measure of value reflects the maximum people would be willing to pay to avoid a particular climate change risk; WTA is the minimum compensation people would accept to live with the risk.

Valuation of incremental changes in quality or quantity
The valuation approach adopted in the CCRA assumes that any one climate change impact under consideration is 'marginal' (or relatively small). This means that while a range of goods and services could be affected by a single climate impact, any one climate impact will not be big enough to affect the prices of these goods/services, which are assumed to remain unchanged. Subject to this assumption, the benefit or cost of a climate change impact on an exposure unit (an exposure unit being the physical entity that is affected, e.g. the number of mega litres of water available to households, or the number of people who suffer heat stroke) is valued by multiplying the anticipated aggregate physical impact on the exposure unit by the appropriate initial economic value per unit ('economic unit value'). This is known as the 'partial equilibrium' approach. An example of this approach is in the case of domestic property subsidence resulting from more frequent drought conditions under climate change scenarios. The risk assessment may result in a projection whereby the annual number of property subsidences in the UK is increased by 10,000 as a result of climate change. This is the aggregate physical impact per year. The economic unit value on households is assumed to be £8,000. Thus, the annual monetary value of climate change-induced property subsidence is £80 million (10,000 X £8,000).

In a small minority of cases however, climate change risks may be expected to result in 'non-marginal' (or relatively large) impacts on an exposure unit, which may in turn be significant enough to change its price, or current economic unit value. Depending on the nature of interrelationships between different exposure units, a change in the economic unit value pertaining to one exposure unit may have knock-on effects for the prices, supply and demand for other goods and services throughout the economy. In these cases some form of integrated economic modelling exercise – a 'general equilibrium' approach - may be more appropriate than the partial equilibrium approach. However, this approach is beyond the scope of work in the current CCRA, and where this situation arises we highlight that our approach limits the scope of the risk valuation exercise.

Fully functioning markets
The prices individuals pay for goods and services can be determined purely by the market ('market prices'), or they might be subject to controls or levies which distort the market price. For example, the price of bread is mainly determined by the market, whereas the price of water is regulated and subject to controls. Where market prices are used as the basis for the unit values adopted in this CCRA, it is assumed that these prices fully reflect individual's market preferences. However, where the climate change risk valuation utilises unit values from markets that are subject to price (or quantity) regulation, taxes or subsidies, or other form of distortion, we will seek to account explicitly for the distortion in accordance with existing sectoral practice.

Roles

The monetisation of climate change risks in the UK CCRA requires involvement of a range of team members and project partners; we expect specific roles to be adopted by the following:

The project analyst – Overall co-ordination of data gathering, processing and reporting of the economic valuation exercise;

Defra and other CCRA Project Partners – Guidance on current best practice in regulatory impact assessments that have utilised, or are utilising, monetary valuation of risks common to the CCRA, and ex post validation.

Sectoral Champions and Stakeholder Groups - Supply of relevant monetary data, where not commercially confidential.

We expect that the vast majority of data to be used in the UK CCRA will be obtained from published sources. Consequently, data requests to stakeholder groups are anticipated to be kept to a minimum.

Establishing Metrics and Core Values to be used

Matching physical impacts and metrics with monetary metrics

Climate change risks that have been quantified in physical units will be expressed relative to some reference, or baseline, case. For these to be valued in money terms, it is essential that the unit values used are applicable to the physical impacts. For example, if water quality deteriorates from "very good" to "poor" under a given climate projection, the valuation must correspond to individuals' preferences for this change.

A common problem with valuation is the "correspondence problem", where the change in physical impacts does not correspond to available valuations. In practice, we expect this to be less of a problem in the context of market goods and services, which have an observable price, but more of an issue where there are non-market risks. In the latter case, whilst the project team will ensure consistent metrics are used wherever possible, where it proves impossible to reconcile the physical units with available unit values, the climate change risks will be expressed either in qualitative or physical terms only.

The presentation of monetary and non-monetary information together is a common issue in appraisal and there are methods available to address this. One simple approach to help decision makers assess the relative significance of risks, both within and across sectors, while making it explicit what is and what is not included in the monetised risk estimates, is to present the results in a tabular form. The same table is also to be used to present physical impact data. This approach is commonly used across Government and there are examples in air quality appraisal in Defra, transport appraisal in the Department for Transport, and others. The Defra National Air Quality Strategy provides a good example of this, below, where monetised risks are presented alongside key threshold criteria for ecosystems (critical loads exceedence).

Economic analysis of the Defra AQS

The Economic Analysis of the Defra Air Quality Strategy undertook cost-benefit analysis, but it reported impacts in physical terms (e.g. numbers of life years lost) as well as monetary values from baseline air pollution in the UK. It also compared the effects on ecosystems, looking at baseline exceedence of critical loads, presenting information in quantitative but not monetised terms. The study also compared different options for air quality improvement using the same approach. An example is given below for measure A (one of the options considered).

Table 3.3: Quantified impacts of implementing Measure A[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1,225 – 2,338	203	203	(277) – (25)	(320) – (29)	(500)

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

Table 3.7: Annual costs and benefits of implementing Measure A in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
382 – 389	469 – 1,183	80 – 801

[a] Numbers in brackets represent negative values.

Table 4.4: Impacts of additional measures on acidity in ecosystems[a]

	area exceeded for critical loads (km²)	% reduction against baseline	accumulated exceedence of critical load (keq/yr)	% reduction against baseline
Baseline	30,742	–	1,875,050	–
Measure A (Euro low)	30,204	1.8	1,797,517	4.1

All non-monetised aspects were included in a table at the end, combining the economic information (net present values) with non-monetised information.

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure A (Euro low)	80 – 801	Between 44% and 100% reduction for individual objectives	Significant positive impact	SI+

Such tables list all identified risks, and then for each future time period considered, report a sterling value (if quantified and valued) or "NQ" (if not quantified) – with physical units reported for the latter. Additionally, project reporting will:

- Explain why any qualitative (quantitative) risks could not be quantified (monetised);
- Describe the timing and likelihood of such risks;
- Discuss the strengths and limitations of the available qualitative information.

The key benefit of presenting the results in this manner is that users of the CCRA **do not conclude** that the sectors with the highest (£) value are those most "at risk".

Where monetary valuation of risks is not possible in the UK assessment, the project partner for valuation will undertake a scoping assessment to illustrate the potential significance of the risks in monetary terms. The partner will also investigate possible approaches on how to scope out these risks in non-monetary terms, considering previous approaches used in Government (e.g. as part of the National Risk Register which considers the number fatalities, the human illness/impacts, the social disruption and economic damages), as well as considering the information from the sector expert workshops.

More complex approaches of comparing monetary and non-monetary information are available. These can include multi-criteria analysis or multi-attribute analysis and ranking. These involve much more intensive analysis, expert inputs, and have significant time and resource implications. However, they are potentially valuable in subsequent CCRA cycles and the first phase will investigate and report upon their potential application in specific sectors such as ecosystems and biodiversity as part of the Tier 2 analysis.

For those risks that have been monetised, we will identify, either in the same table or a separate table:

- The main climatic driver (e.g., mean temperature, mean precipitation, extreme temperatures, extreme precipitation, storms (wind), growing season, drought, etc).
- The proxy measure of change in value to society used to monetise the risks (e.g., heat-related mortality valued on the basis of "WTP-based Value of a Life Year Lost", changes in agricultural yields valued on the basis of "market prices, gross margin").
- An indicator of relevant uncertainties or level of confidence the study team places on the results, using a simply alphabetical or numerical scale as developed by the IPCC.

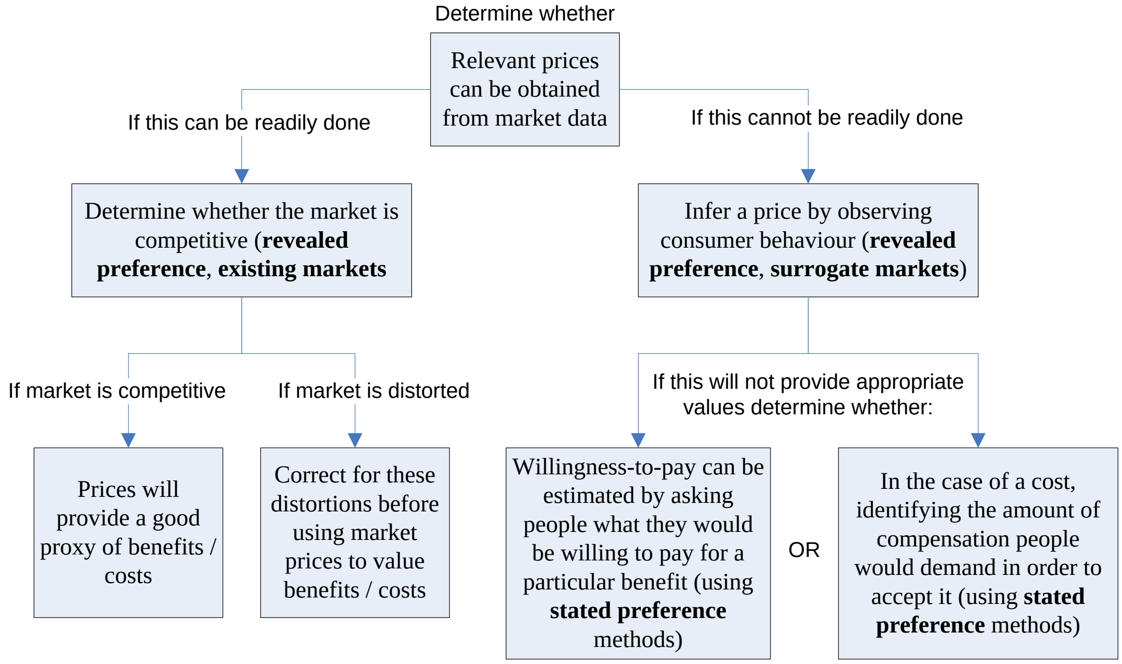
A key principle will be that, as far as possible, individual sectoral and cross-sectoral risks prioritised in the Tier 2 level assessment will be expressed in both non-monetary and monetary terms.

Use of market and non-market monetary unit values

For each individual climate change risk, justification of selection and combination of valuation data to be used in monetisation

As noted above, capture of the value of the economic, social and environmental change resulting from individual climate change risks may be undertaken through use of market-based values or non-market values, depending on the nature of the risk. A hierarchy of methods – in the form of a decision tree - is presented in HM Treasury (2003), and presented in Figure 1, below. The hierarchy reflects a preference among decision makers for use of real or estimated market prices in the valuation of costs and benefits. The left hand branch of the tree is followed for market impacts - impacts on marketed goods or services that are directly included in GDP. The right hand branch of the tree should be followed for non-market impacts **-** impacts on goods or services that have no observable market price and are not included in GDP. The UK CCRA will report market and non-market damages separately and as a total.

Decision Tree for Selection of Valuation Methods for Primary Studies



Assessment of data quality

In accordance with HM Treasury guidance, monetary data used in the CCRA will primarily be from published data. Market data will be derived from that currently used in sectoral policy analysis. Non-market values will, ideally, also be those used in current sectoral policy analysis. Where this is not available, non-market values will be derived from the peer-reviewed literature as far as possible. Non-peer reviewed data will be used in sensitivity analysis only.

Transfer of values derived in one historical context to be used in the present context

Unit values that are to be utilised in the CCRA may be derived from previous research undertaken in a location different from the present context. If the data is historic, the values will also have to be adjusted to current prices. The transfer of monetary data from one context to another is termed 'value transfer' or 'benefit transfer' and though applicable to the transfer of both market and non-market valuation data, is most frequently used in the latter context. Although there are no generally accepted practical transfer protocols, a guide to current best practice is provided in a recent Defra-sponsored publication (Entec, 2010).

Adjustments to unit values to account for future socio-economic change

The general price level and the relative price of goods and services at risk to climate change will vary over time. This implies that the cost of climate change, adaptation options, and residual damages, will also change with time. This gives rise to two issues that must be dealt with:

- The need to define a base year; and
- The need to account for increases in the relative value of goods and services over time.

In this CCRA, all economic data will be specified in 2010 constant UK Sterling.
Some affected goods or services will attract a higher valuation over time relative to the general level of prices. This might be because the good or service in question is particularly scarce relative to demand and can command a higher price, or has a positive income elasticity of willingness-to-pay (i.e. it becomes more valued as individual incomes rise). If the relative price of an affected good or service is expected

to change over the study's time horizon, then this change in its real value should be allowed for when estimating damage costs, and justification for the rising (or falling) relative valuations should also be given. Otherwise, consistent with the HM Treasury Green Book, it is implicitly assumed that all cost data remain constant in real terms.

Use of discount rates and alternative discounting regimes
Discounting is the usual technique used to add and compare environmental costs and benefits that occur at different points in time. Discount rates currently used in public sector economic appraisal are presented in the HM Treasury Green Book. The Treasury has also recently published supplementary guidance on Intergenerational Wealth Transfers and Social Discounting, which allows the use of alternative discount regimes to test the sensitivity of costs and benefits to the discount rate used in economic appraisal (HMT, 2008). Further discussion about the discount rate(s) that should be used in the context of climate change analysis is provided in the UKCIP Costing Guidelines (Metroeconomica, 2004).

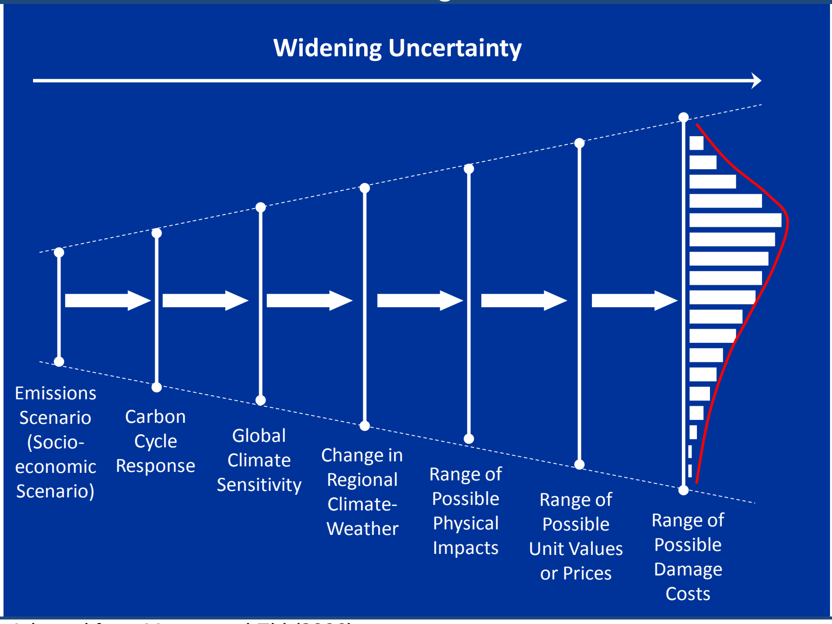
It is intended that all monetised risk estimates will be presented as both undiscounted (their £ value in the future) and discounted (how much their future £ value is worth to society today) totals in year 2010 prices.

Treatment of geographical differences and wider distributional issues, including equity
The burden of climate change impact and adaptation costs will be differentiated according to the possible consequences for public and private sectors, and for different income groups, as far as is possible in the CCRA. This exercise will be based on extrapolation of current institutional arrangements and divisions of provision responsibility between public and private sectors to the future time periods being considered according to the socio-economic scenarios – as far as these scenarios can be interpreted to this end. Results of this exercise will necessarily be crude and indicative only. However, where possible we would look to express results for the geographical, income distributional and public/private aspects of this issue using the distributional matrix and stakeholder analysis frameworks described in the UKCIP Costing Methodologies Guidelines, as well as in the HM Treasury Green Book.

Treatment of Uncertainty

As shown in Figure 1, uncertainty increases from greenhouse gas emissions, to global climate change, to changes in regional climate and weather, to physical impacts on various humans and natural systems, and to economic valuation of those impacts. Assessing the costs of climate change and adaptation responses must therefore be undertaken in an environment of high uncertainty.

Figure 1: Cascade of Uncertainties in Assessing Impacts of Climate Change



Source: Adapted from Menne and Ebi (2006)

In addition to working with more than one socioeconomic (baseline) and climate scenario, several methods exist to convey key uncertainties that underpin the monetised risk estimates, including:

- Interval analysis;
- Sensitivity analysis; and
- Monte Carlo (simulation) techniques.

Descriptions of these methods are provided in generic terms in the HM Treasury Green Book. Examples of applications in the climate change risk context are presented in Metroeconomica (2004). Ideally the CCRA will:

- For each scenario combination provide ranges for estimated physical impacts and associated monetised risks, and use interval analysis to approximate the absolute lower and upper bounds of the range, where they can be constructed.
- Employ sensitivity analysis to test the robustness of estimated outcomes to key input variables and modelling assumptions.

Data management

Sources of data

As indicated above, monetary data used in the CCRA and AEA will primarily be extracted from existing published datasets. A number of generic financial and economic data sets are compiled in the HM Treasury Green Book and its Supplements. Additionally, it is anticipated that sectoral-specific publications will be used, including those contained in the Central Government Departmental Guidance[34].

Reporting/Recording of values used

For each climate change risk where monetisation is possible, the source of the unit value(s) to be adopted in the CCRA will be recorded explicitly in the final reporting documents. Any subsequent adjustments to e.g. base year will also be reported, as well as an indication of the reliability or quality of the data. The form of this recording will be consistent with the generic referencing system to be utilised in the CCRA.

[34] See: http://www.hm-treasury.gov.uk/data_greenbook_detguidance.htm

Storage
The project recording protocol will ensure that valuation data will be identifiable for subsequent validation and referral in future CCRA cycles.

Monetisation References

Eftec (2010) Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal. Report submitted to Defra. On-line at: http://www.defra.gov.uk/environment/policy/natural-environ/using/valuation/index.htm

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Appendix 6 Sector Report Template

This is a suggested guide to the final report template for each Sector. The use of separate sections, particularly sections 7-9, may make the discussion unnecessarily drawn out. If so, a shorter template may be used as long as the methodological steps are identifiable and all assumptions are clearly stated.

x. Standard Preface

1. Introduction
    a. Scope of this sector and relationship with others
    b. Extent of consultation/review – list names in Appendix 1
    c. Structure of report – generic for all sector reports

2. Scoping of impacts
    a. Reference Tier 1 report and summarise
    b. Simple figure highlighting main impacts areas
    c. Any relevant workshop feedback – include write-ups in Appendix 2

3. Policy risk mapping
    a. Main policy stakeholders
    b. Key policies in place
    c. High level summary table – details in Appendix 3 or separate project report
    d. Any gaps for Government to consider in NAP?

4. Selection of Tier 2 consequences
    a. Standard paragraph on selection process – cross-ref to methods report
    b. Comments from workshops – write ups in Appendix 2
    c. Magnitude, likelihood, urgency scoring – figure or simple table with outcomes in three classes – scores in Appendix 4
    d. Selected risks

5. Systematic mapping to identify cross-sectoral and indirect consequences
    a. Standard paragraph– cross-ref to methods report
    b. Updates to Tier 1 and Tier 2 lists
    c. Outcome – new risks identified? Taken forward?
    d. Possible maps in Appendix 5.

6. Identify risk metrics (including vulnerability metrics)
    a. Impacts (direct bio-physical effects)
        i. Identify key metrics *e.g. relative aridity, river flow and groundwater recharge for the pilot*
    b. Consequences (social-environmental-economic effects)
        i. Identify metrics
        ii. Use short paragraphs to cover rationale with all details in Appendix 6
        iii. Comments on social consequence/vulnerability – checklist could be Appendix 6 – rationale method doc and separate paper
        iv. Comments on adaptive capacity and any effect on risk – reference any detailed work on adaptive capacity and cross-reference to Section 9.

7. Develop quantitative or qualitative impact or consequence response functions, as appropriate
    a. Summarise functions – details in Appendix 7.

8. Estimate change with selected climate scenarios
    a. Summarise key UKCP09 data – refer to full science report and other relevant research
    b. Summarise sensitivities – possible maps/response function plots – all details in Appendix 8

9. Estimate socio-economic influence on the projected consequences
    a. Summarise key socio-economic projections/sensitivity
    b. Summarise sensitivities – possible maps/response function plots – all details in Appendix 9
    c. Comment on current level of adaptive capacity – evidence in separate report
    d. Summarise assumptions made about autonomous adaptation

10. Costs of climate change
    a. Explain how climate and socio-economic assessment is combined – refer to method document for Stage 3: Assess risk
    b. Summarise monetisation – details in Appendix 10

11. Future impacts of climate change
    a. Expected risk with uncertainty bands for 2030, 2050 and 2100
    b. Summarise non-monetised outputs
    c. Overall summary table – include monetised outputs
    d. Other factors that could affect the risk

12. Conclusions

Summary report could be based on Sections 1, 11 and 12 only.

List of Figures