The UK Climate Change Risk Assessment 2012
Evidence Report

The UK Climate Change Risk Assessment 2012 Evidence Report

Presented to Parliament pursuant to Section 56 of the Climate Change Act 2008

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The UK Climate Change Risk Assessment 2012 Evidence Report

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Statement of use

This report draws together and interprets the evidence gathered by the CCRA regarding current and future threats (and opportunities) for the UK posed by the impacts of climate up to the year 2100. The report is intended to inform policy-makers and other interested parties of the nature of the risk, the extent that the risks are currently understood (including the scale and time of onset of individual risks where possible), and the issues that influence the overall risk landscape for the UK. This report, along with the supporting Government Report, forms the CCRA Act Report laid before Parliament in January 2012.

The CCRA methodology is novel in that it allows for comparison of over 100 risks (prioritised from an initial list of over 700) from a number of disparate sectors based on the magnitude of the impact and confidence in the evidence base. A key strength of the analysis is using a consistent method and set of climate projections to look at current and future risks and opportunities.

The CCRA methodology has been developed through a number of stages involving expert peer review. The approach developed is a tractable, repeatable methodology that is not dependent on changes in long term plans between the 5 year cycles of the CCRA.

The results, **with the exception of population growth where this is relevant, do not include societal change in assessing future risks, either from non-climate related change, for example economic growth, or developments in new technologies; or future responses to climate risks such as future Government policies or private adaptation investment plans**.

Excluding these factors from the analysis provides a more robust ‘baseline’ against which the effects of different plans and policies can be more easily assessed. However, when utilising the outputs of the CCRA, it is essential to consider that Government and key organisations are already taking action in many areas to minimise climate change risks and these interventions need to be considered when assessing where further action may be best directed or needed.

Before reading this report it is important to understand the process of evidence gathering for the CCRA.

Eleven ‘sectors’ were chosen from which to **gather** evidence: Agriculture; Biodiversity & Ecosystem Services; Built Environment; Business, Industry & Services; Energy; Forestry; Floods & Coastal Erosion; Health; Marine & Fisheries; Transport; and Water.

A review was undertaken to identify the range of climate risks within each sector. The review was followed by a selection process that included sector workshops to identify **the most important** risks (or opportunities) within the sector. Approximately **10%** of the total number of risks (or opportunities) across all sectors were selected for more detailed consideration and analysis.

The risk assessment used UKCP09 climate projections, where possible, to assess future changes to sector risks. Some risks were analysed using single climate variables, for example temperature. Others, including flood risks, considered the combined effects of many climate variables and sea level rise.

This report draws together information from the eleven sectors and other evidence streams to provide an overview of risk from climate change to the UK, based around five themes (Agriculture & Forestry, Business, Health & Wellbeing, Buildings & Infrastructure, Natural Environment).

Neither this report nor the Sector Reports aim to provide an in depth, quantitative analysis of risk within any particular ‘sector’. Where detailed analysis is presented using large national or regional datasets, the objective is solely to build a consistent picture of risk to the UK and allow for some comparison between disparate risks and regional/national differences.

This is a UK risk assessment with some national and regional comparisons. The results presented here should not be used for re-analysis or interpretation at a local or site-specific scale.

In addition, as many impacts were analysed using single climate variables, the analysis may be over-simplified in cases where the consequence of climate change is caused by more than one climate variable (for example, higher summer temperatures combined with reduced summer precipitation).

In order to understand (a) the approach undertaken by the CCRA, including assumptions and confidence in the analysis, and (b) how the findings are presented, it is important to read Chapters 1, 2 and 3 before moving onto the findings for each of the themes and the conclusions.

Executive Summary

The Climate Change Risk Assessment (CCRA) presents the latest evidence on the risks and opportunities of climate change for the UK to 2100. For the first time, it provides a national overview of potential risks based primarily on the UK Climate Projections, which were published by Defra in 2009. Its findings, particularly related to those risks that require early action, will inform the development of adaptation plans by the UK Government and the Devolved Administrations.

This report draws together and presents evidence from individual CCRA sector reports, other studies commissioned by the project and recent research literature. The findings are presented for a range of possible future scenarios, including different levels of population growth, with an indication of our overall confidence in the results and areas where there are significant evidence gaps. Further research is needed on how global changes in climate may affect the UK and how climate, social and economic changes influence the 'risk landscape.' At the same time continued and improved monitoring of climate risks and adaptation outcomes are needed to support decision making.

Why is this report needed?

The UK Climate Change Act 2008 makes the UK the first country in the world to have a legally binding, long-term framework to cut carbon emissions[1]. It also requires a series of assessments of the risks of climate for the UK, under both current conditions and over the long term, to 2100. The CCRA provides the first of these assessments and was laid before parliament in January 2012. The risk assessment will be updated every five years so that new evidence can be considered, the UK's progress towards adaptation and resilience can be reviewed and National Adaptation Plans can be updated to reflect new evidence and any changes in Government policy.

This report provides evidence that can be used by national policy makers to support discussions on what action is needed to adapt to future climate change. In flood risk and coastal erosion management detailed and up to date guidance is already available on how to consider climate change in future planning[2]. In other sectors and for some parts of the UK that appear to be particularly vulnerable, the findings in this report provide a useful starting point for more detailed assessments and guidance.

What is in this report?

This report provides an overview of the risk assessment, including a synthesis of the key findings. It presents the best information available on the vulnerability of the UK to climate change, identifies notable risks and opportunities and gaps in our current understanding of climate risks. The assessment was undertaken across 11 'sectors' and drew evidence from literature reviews, expert elicitation and more detailed quantitative analysis, where the data allowed. It incorporated feedback from stakeholders in these sectors, to identify potential impacts and to select risks for more detailed analysis.

[1] The Climate Change (Scotland) Act 2009 provides a similar framework in Scotland.
[2] For example the Environment Agency has provided detailed guidance for England and Wales http://publications.environment-agency.gov.uk/dispay.php?name=GEHO0711BTZU-E-E

The 'Sectors' (or research areas) for collecting evidence for the CCRA were:

- Biodiversity & Ecosystem Services
- Agriculture
- Forestry
- Water
- Marine & Fisheries
- Floods & Coastal Erosion
- Built Environment
- Energy
- Transport
- Health
- Business, Industry & Services.

In this report we provide a summary of climate change evidence in Chapter 2 and the main biological and physical impacts of projected warmer conditions, changes in rainfall patterns, sea levels and ocean acidification in Chapter 3. We consider different greenhouse gas emissions scenarios and other major modelling uncertainties to present a range of future outcomes for the 2020s, 2050s and 2080s.

The main findings from the eleven sector reports are drawn together under five themes:

- Agriculture and Forestry – Chapter 4
- Business – Chapter 5
- Health and Wellbeing – Chapter 6
- Buildings and Infrastructure – Chapter 7
- Natural Environment – Chapter 8.

Finally, in Chapter 9 we provide an evaluation of future risks by comparing key characteristics, such as the magnitude of consequences, our overall confidence in the results and our current capacity for managing risks.

There is considerable uncertainty related to future climate change risks (Box ES1) but there is sufficient evidence to start planning adaptation action. In this report recommendations are made to inform ongoing work towards national adaptation programmes and to fill gaps in evidence through continued research and monitoring.

Box ES1 How confident are we about future climate risks for the UK?

Climate monitoring, climate modelling and risk assessment methods have improved significantly over the last two decades but there are still limits to our understanding of future climate risks. For example we do not know how fast greenhouse gas emissions will rise, how great the cooling effects are of other atmospheric pollutants or how quickly the ice caps may melt. These and other uncertainties result in a wide range of possible rates of warming and sea level rise. For example sea level rise for London is estimated to be somewhere between 20 cm and 190 cm (including the H++ scenario) by the latter part of the century, depending on which emissions scenario is considered (Lowe *et al.*, 2009).[3] Projecting changes in climate for specific regions is still a significant challenge for the current generation of climate models. In particular there is a growing body of evidence suggesting that loss of Arctic sea ice may have major consequences for climate in mid latitudes (Petoukhov and Semenov, 2010; Budikova, 2009; Francis *et al.*, 2009) that are not fully represented in existing models.

This assessment considers the uncertainties included in the UK Climate Projections (UKCP09) (Murphy *et al.*, 2009; Annex A) through to assumptions related to the management of individual risks, which are discussed further in the Sector Reports. It uses scenarios to present a wide range of possible outcomes for the UK and also attaches levels of confidence to all results. The overall confidence is generally 'low' to 'medium', with only risks that are

[3] From present day (1980-1999) sea level.

already experienced and those related to increased temperatures classified with 'high' confidence. A number of the emerging risks examined are potentially very significant but our current level of knowledge means that there are also large uncertainties. Therefore it is possible that changes may be outside of the range of outcomes presented in this report. This is particularly the case for complex systems such as ecosystems and business networks[4].

What are the current climate risks for the UK?

The Government monitors the risks faced by UK citizens over a five year period through the National Risk Assessment (NRA). Severe weather, major coastal and inland flooding are recognised in the NRA as significant risks to the UK, alongside those related to human health (such as pandemic diseases) and terrorist and cyber attacks. The CCRA shows that the current NRA risks related to extreme weather, such as flooding and droughts, will continue to pose a threat as the climate changes.

Recent weather events have highlighted the vulnerability of some sectors and vulnerable groups to climate risks, including:

- The 2007 summer floods in England and Northern Ireland cost the economy more than £3 billion. In August 2008, the Greater Belfast Area and parts of Antrim were affected by flooding again. More recently the Cumbria floods in 2009 resulted in £100s millions of damage, including the loss of twenty road bridges and long term disruption for local communities.
- The prolonged cold periods in 2009 and 2010 caused wide ranging problems for UK transport and water infrastructure. In Northern Ireland, thousands of households experienced difficulties with water supplies in December 2009 because of the freezing conditions. In December 2010, heavy snow across Scotland's Central Belt resulted in hundreds of motorists stranded overnight with the M8, M74 and A9 all badly affected. Hundreds of schools were closed across Scotland, Northern Ireland and north-east England.
- In Spring 2011, parts of the UK experienced much drier than average conditions, which caused problems for farmers as there was insufficient rainfall for some crops. During the same period, the higher temperatures, static weather pattern and increased sunshine hours also contributed to a pollution warning across England and Wales over the Easter weekend[5], much earlier in the year than normal. In Berkshire, forest fires were difficult to control due to the dry weather and led to the closure of businesses and schools and evacuation of homes.

In its second report, the UK Government's Adaptation Sub-Committee highlighted the vulnerability of the UK to extreme climate events (ASC, 2011b). It described how some sectors and some social groups are more vulnerable than others and how recent patterns of development in the built environment may have increased our vulnerability to climate change.

[4] Ecosystems are complex due to the uncertainty relating to non-linear responses to biophysical changes, the difficulty of assessing the capacity of species to adapt and changes in competition between species. We know that the distribution of species is likely to shift according to climate preferences and that migration patterns and the timing of life cycle events may change. In the business world, the behaviour of fund markets and supply chains pose similar levels of complexity. Whilst we have some understanding of these systems we are a long way from being able to predict outcomes with any degree of certainty

[5] http://www.defra.gov.uk/news/2011/04/21/summer-smog/

What are the future climate change risks for UK?

Whatever happens to future greenhouse gas emissions we are 'locked in' to a certain amount of warming due to inertia in the global climate system.

Adaptation is needed to reduce the costs and damages of inevitable warming and to take advantage of opportunities that arise in a changing climate.

Mitigation, through the reduction of greenhouse gas emissions, will contribute to risk reduction over the long term (100 years) and this assessment has shown that the consequences of a High emissions scenario are substantially greater for the UK than the Low and Medium emissions scenarios for the 2080s.

Therefore continued efforts to reduce global greenhouse gas emissions will benefit the UK as well as reduce the greater risks faced by vulnerable developing countries.

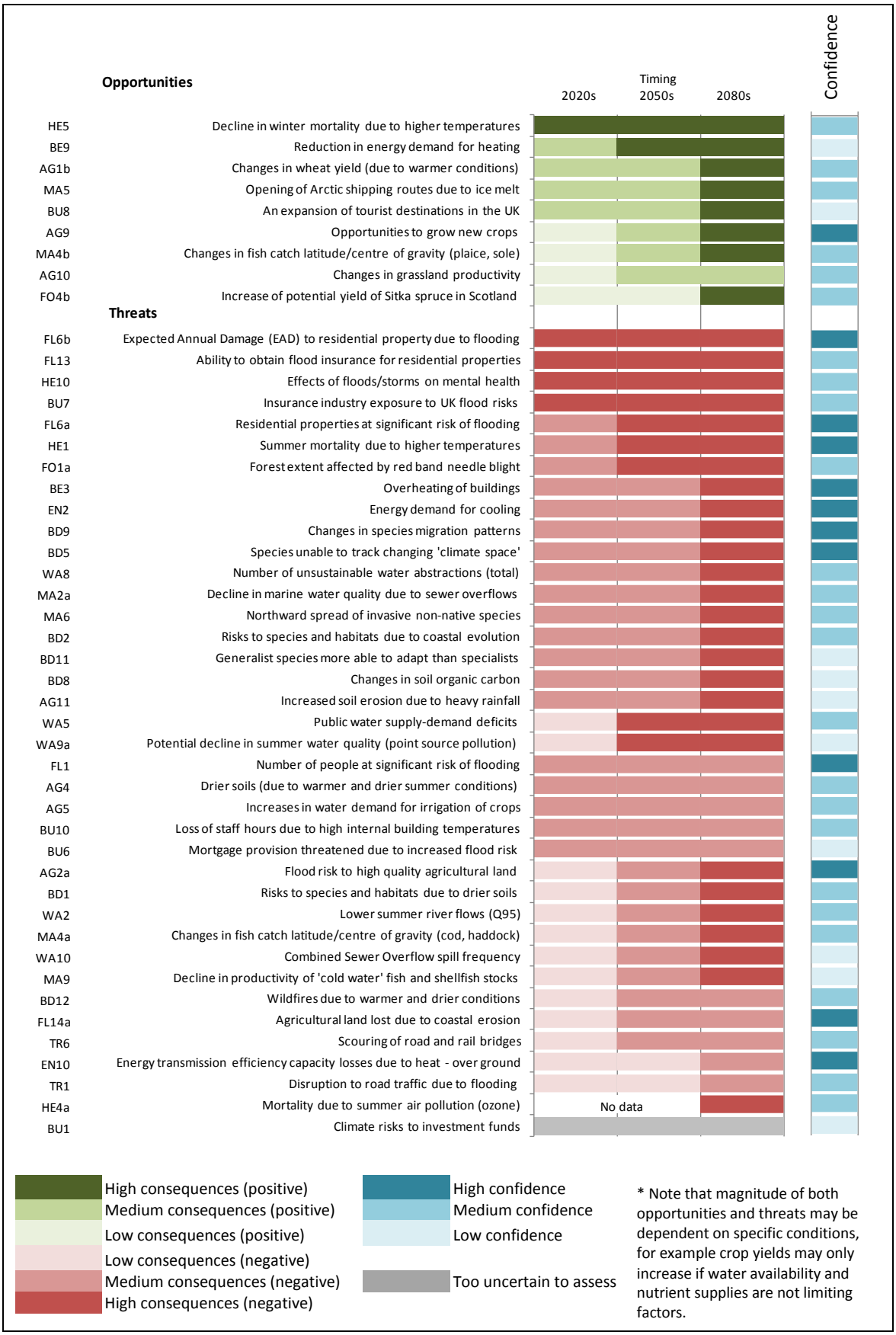
This assessment considered more than 700 potential risks and selected more than 100 risks for detailed review. A representative selection of threats and opportunities for the UK are summarised in Figure ES1. This lists potential risks according to whether they are regarded as a threat or opportunity; classifies each risk according to a broad 'order of magnitude' score from either an economic, social or environmental perspective; and also indicates whether confidence in the direction and magnitude is 'low', medium' or, 'high.' Full details of the methods used for categorisation of potential risks are provided in Chapters 2 and 9. Potential risk magnitude scores are provided for the 2020s, 2050s and 2080s so that the 'speed of onset' is indicated, although this may change for different emissions scenarios. While these plots provide a useful summary, decision makers also need to consider the full range of results for adaptation planning.

Figure ES1 shows a sub-set of potential risks and more detailed plots are included in later chapters in this report along with the magnitude scores for the 'UKCP09 range' considered in this study (Chapter 2). The metric codes (e.g. HE5) provide a link to the results in individual sector reports.

The UK will continue to be vulnerable to severe weather, including cold spells, floods and droughts. The potential benefits of milder winter conditions are significant because there may be a large reduction in (for example) cold weather related deaths and detrimental health problems. This is therefore presented as an opportunity (HE5). However the numbers affected by cold weather will still be significant for the 2020s (See Box ES2) and fuel poverty issues will remain. Flood risks will continue to be very significant and are projected to increase over time; the risk metrics shown at the top of the list of threats highlight continued issues related to flood damage, insurance and the health of flood victims (FL6b, FL13, and HE10). Some risks, which are already a concern, have the potential to become more significant over the next 20-30 years. These include increases in summer mortality due to heatwaves (HE1) and the prevalence of some pests and invasive non-native species (FO1a).

Other potential risks are projected to become more significant by the latter half of the century. These include greater demand for cooling (BE3, EN2), reduction in water availability and quality due to low river flows (WA2, WA5, WA8, WA9) as well as changes in marine water chemistry and a potential decline in quality due to pollution (MA2a, MA3). Businesses will experience both threats and opportunities. Opportunities include the expansion of tourism (BU8) or investment in adaptations, such as greater water efficiency; whereas threats include a greater potential for disruption to the supply chain, particularly due to the impacts of climate change internationally. Potential opportunities for the UK also include cost savings associated with shipping through the Arctic (MA5) but such benefits are small when compared to global impacts of melting ice and potential effects on mid-latitude climates, including the UK. The findings of the CCRA for the UK as a whole are summarised in Box ES2.

Figure ES1 A selection of potential risks (threats and opportunities) for the UK based on the Medium emissions scenario



Box ES2 What are the most significant findings of the CCRA?

- **The UK is already vulnerable to extreme weather including severe winters, heatwaves, flooding from rivers and the sea and storms and gales**. Insured losses from extreme events in the UK cost an average of £1.5 billion per annum and the costs associated with flooding in summer 2007 were estimated as greater than £3 billion in England alone. Other potential risks, such as heatwaves, water scarcity and disruption of ecosystems are becoming increasingly important. Continued action is needed to manage these risks even without additional pressures due to climate change.

- **The global climate is changing and warming will continue over the next century.** Most climate scientists agree that much of the observed increases in global temperatures and rising sea levels in recent decades are due to increasing concentrations of heat-trapping greenhouse gases in the atmosphere caused by human activities. Global temperatures may rise by between approximately 1 and 6°C by the end of this century (IPCC 2007). Estimating regional changes is more difficult but the latest projections for the UK include increases in summer temperature of between approximately 1 and 8°C in the South East of England by the 2080s[6], as well as increases in winter rainfall and the number of days with heavy rainfall over most of lowland UK (Murphy *et al.*, 2009). In addition, relative sea level in London is estimated to increase by around 20 to 70 cm by 2095, although under the highest (H++) scenario this may increase to between around 90 and 190 cm (Lowe *et al.*, 2009).[7]

- **The risks of flooding are projected to increase significantly across the UK**. The expected annual damage to properties caused by flooding from rivers and the sea is currently approximately £1.3 billion per annum for the UK as a whole and £1.2 billion for England and Wales[8]. New analysis for England and Wales, which have the most detailed data sets, showed that future potential risk estimates are within the following ranges:
    - £1.5 billion to £3.5 billion by the 2020s
    - £1.8 billion to £6.8 billion by the 2050s
    - £2.1 billion to £12 billion by the 2080s.[9]

  Increases in the frequency of flooding would affect people's homes, the well being of vulnerable groups in society, the operation of critical infrastructure systems, such as transport, energy and water supply and disrupt a wide range of businesses located in the floodplains.

- **There are significant potential health risks related to hotter summer conditions as well as other risks that may place an additional burden on the NHS.** Sustained hot summer conditions, which may be exacerbated by overheating in city buildings and transport systems, have measurable health impacts. Our analysis shows that there may be between 580 and 5,900 premature deaths per year by the 2050s in hotter summer conditions (without further adaptation of buildings or health services). The risks are greatest for vulnerable groups, such as the elderly, and in London and southern England where the highest temperatures are likely to be experienced. Conversely, our analysis also shows that by the 2050s between 3,900 and 24,000 premature deaths per year due to cold may be avoided with milder winters.[10] The CCRA Health Sector assessment also describes potential increases in the numbers of flood victims suffering mental health problems, risks of greater respiratory hospital admissions due to summer temperatures and summer air pollution and other potential health risks that may place an additional burden on the NHS.

[6] The wider UKCP09 range for the Medium Emissions scenario is 2 to 6.5°C; there is also some geographical variation across the UK. http://ukclimateprojections.defra.gov.uk/content/view/910/499/

[7] These figures include uncertainties around the central projection for the Low and High emissions scenarios. Central estimates of relative sea level rise are available on the UKCP09 web site. http://ukclimateprojections.defra.gov.uk/content/view/2145/499/ and http://ukclimateprojections.defra.gov.uk/content/view/1849/500/ for the H++ scenario description The top of the range is regarded as very unlikely to occur in the 21st century

[8] Note that accurate estimates are only available for England and Wales so the UK wide estimate is approximate and considers the additional numbers of properties at risk and population estimates for Scotland and Northern Ireland.

[9] These estimates assume continued investment to maintain the condition of existing flood defences but do not include other flood risk management measures. Future risks of flooding will depend upon the location and pattern of future development and level of additional investment in flood risk management (by government and local communities), as well as changes to the hydrological cycle and rates of sea level rise. Future targeted investment may substantially reduce these damage costs. These estimates include increases in population.

[10] Although confidence in the projections for cold related deaths is not as high as for heat related deaths.

Box ES2 What are the most significant findings of the CCRA?

- **There will be increasing pressure on the UK's water resources due to changes in hydrological conditions, population growth and regulatory requirements to maintain good ecological status**. For public water supplies our analysis projects major supply-demand deficits in five river basin regions – Anglian, Humber, Severn, North West England and the Thames basin. The Thames river basin region, which provides the current water supply to London of around 2,000 megalitres per day (Ml/d) as well as supplies to areas of the Home Counties, is estimated to face the largest deficits of 478 Ml/d (0 to 1,040 Ml/d) in the 2020s, and 1700 Ml/d (773 to 2,570 Ml/d) in the 2050s based on a central population projection. Planned improvements in water efficiency and new supply schemes are likely to be sufficient to manage risks in the near term (2020s) but the widening supply-demand gap presents a considerable challenge for the 2050s. The potential risks are greatest in England and Wales and may affect people through changes in the service offered by water companies, changes to the costs of water and the environmental quality of rivers and lakes.

- **Sensitive ecosystems that are already threatened by land use changes may be placed under increasing pressure due to climate change.** The main direct impacts relate to changes in the timing of life cycle events, species distribution and ranges and potential changes in hydrological conditions that may affect aquatic habitats. The impacts on species may have knock-on affects on habitats, ecosystem function and the goods and services humans receive. Whilst some species would benefit from these changes, many more would suffer. Species that can cope with a range of conditions, known as generalist species, are likely to fare better than specialist species that depend on niche environments, resulting in lower biodiversity. Habitats that require cooler and wetter summer conditions may be particularly vulnerable, for example the occurrence of peat forming conditions may decline significantly, affecting the soils ability to store carbon. However understanding ecosystem changes is particularly complex; there may be tipping points in land, aquatic and marine ecosystems that have major and possibly irreversible changes, which we currently know little about.

- **Potential climate risks in other parts of the world are much greater than those in the UK.** For example, rapid rises in sea level would present a far greater risk for Small Island Developing States (SIDS), low lying and densely populated countries like Bangladesh and even major cities, such as Shanghai (Met Office, 2011)[11]. International risks could be as important as those that directly affect the UK and include climate impacts on global health, political instability and international supply chains that we depend on (Foresight, 2011a). Climate may also play a role in environmental degradation and international human migration patterns, which could affect the UK (Foresight, 2011b). Global markets present some opportunities for UK businesses to provide expertise in climate services, adaptation advice, and insurance and financial products to hedge climate risks.

- **Some climate changes projected for the UK provide opportunities to improve sustainable food and forestry production, use resources more efficiently and provide services to manage risks.** For example, agri-businesses may be able to increase the yields of some crops and introduce new crops and forests in some parts of country could become more productive as long as pests and diseases are effectively controlled. UK businesses may have a comparative advantage over drier parts of Europe. As part of the low carbon economy there will be strong drivers for both energy and water efficiency. There may also be opportunities for projects to incentivise changes in behaviour to support sustainable consumption, develop climate forecasting and warning services and to develop engineering schemes, e.g. sustainable drainage systems and flood defences, where these are needed to manage climate risks.

- **Although we do not know the likelihood of specific changes in the future UK climate, we know enough to present a range of possible outcomes, which can be used to inform adaptation planning.** For this purpose potential climate risks to the UK have been categorised according to their magnitude, 'confidence' and the 'urgency for action', as part of the first CCRA cycle, which enables a simple classification to support the development of the National Adaptation Programme. This includes the monetisation of some of the most significant risks related to flooding, water and health. If these factors are all considered, then early action is needed on potential risks related to five themes, which are all categorised as 'high risk' with sufficiently robust

[11] In 2011 the UK Met Office was asked by DECC to review evidence on climate observations, projections and impacts in 20 countries. The reports are available in-line: http://www.metoffice.gov.uk/climate-change/policy-relevant/obs-projections-impacts

Box ES2 What are the most significant findings of the CCRA?

evidence to act (Box ES3 & Chapter 9). In every case decision makers need to understand climate sensitivities, including thresholds, consider a range of possible outcomes and for key decisions, will need to complete further analysis using appropriate decision making methods (HM Treasury Green Book; Ranger *et al.*, 2010).

- **There is strong evidence to support our analysis related to flooding, water and health, but there are also significant evidence gaps. Further research and monitoring is essential to support both National Adaptation Programmes and the next CCRA**. Good progress has been made in recent years in developing detailed models for specific risks. However, it is evident that significantly more research is needed to help us understand the relationships between risks so that more integrated assessments can be carried out in the future at the national scale.

Will there be greater impacts on some people than others?

Vulnerable groups of people such as those affected by poverty, poor health and, disabilities will tend to experience disproportionate negative effects from particular climate impacts. This assessment concludes that social vulnerability to climate change is likely to reflect existing patterns of inequality. However, the location of vulnerable communities is an important factor; for example, there are a disproportionately high number of vulnerable communities located in coastal floodplains in the East of England at increased risk of coastal flooding. There are also vulnerable low income groups located in parts of London and in other UK cities that may be disproportionally affected by flooding, overheating of buildings and pollution episodes. Understanding the consequences of climate change for vulnerable groups will be important for adaptation planning.

How prepared is the UK for dealing with future climate change?

The level of risk that will be experienced in the future depends on ‘adaptive capacity’, which can be defined as our ability to respond to information about expected future impacts. The UK Adaptation Sub-Committee has developed methods for assessing the UK’s preparedness for climate change and is working towards a set of indicators for monitoring progress. In their first report, the committee identified issues in several sectors, including land use planning and water supply (ASC, 2011a).

The CCRA started to consider adaptive capacity using a different approach based on detailed questionnaires and interviews in a selection of UK sectors. Early findings suggest that capacity varies significantly and that there is room for improvement in all of the sectors surveyed. This work is being taken forward as part of the ongoing Economics of Climate Resilience study and the need for further capacity building will be included in the National Adaptation Programme.

Box ES3 Which potential risks require early action?

Overall, the findings of the CCRA indicate that the greatest need for early adaptation action (i.e. within the next 5 years) is in the following areas:

- Flood and coastal erosion risk management;
- Specific aspects of natural ecosystems, including managing productivity and biodiversity (the management of forest pests and diseases, low summer river flows and the movement of plants and animal species are all highlighted as high priorities for action (Chapter 9));
- Managing water resources, particularly in areas with increasing water scarcity;
- Overheating of buildings and infrastructure in the urban environment;

Box ES3 Which potential risks require early action?

- Health risks associated with heatwaves and other risks that may affect the NHS; and
- Opportunities for the UK economy, particularly to develop climate adaptation products and services.

These findings should only be considered as preliminary, as the rationale for Government action is subject to another ongoing study, the Economics of Climate Resilience (ECR).

What are the main benefits of this assessment?

The benefits of this assessment are:

a. It gives decision-makers an improved understanding of climate change risks to the UK and the uncertainty associated with its assessment.

b. It brings the best available evidence together using a consistent framework that describes the sensitivity, vulnerability and potential risks related to climate change.

c. It has developed a practical method to meet the needs of the first CCRA and this provides a starting point for further research and potentially improved approaches for the next assessment.

This assessment is the first national assessment of climate risks and goes further than previous reviews (CCIRG, 1996; West and Gawith *et al.*, 2005) by drawing together different strands of evidence, comparing risks and providing a preliminary evaluation of the consequences of climate from social, economic and environmental perspectives. Prior to this assessment, much of the evidence was based on either narrowly focused research studies or regional scoping studies that relied heavily on anecdotal evidence, with minimum quantification of the consequences of climate change. As each study adopted a different methodology (often using different climate and socio-economic information), comparison between regions, or developing a national view, was difficult. Outside of the UK, other national assessments have typically relied on synthesis of available research rather than providing a comparative assessment.

What next?

This assessment, together with a Government overview, forms the CCRA report laid before Parliament in January 2012, as required under the UK Climate Change Act 2008. This is the first in a five year cycle of assessments, with the second CCRA report due to be completed in 2017.

A second follow-on report to this CCRA is also being prepared to examine the economics of adapting to the risks identified in this assessment. The Economics of Climate Resilience (ECR) study will consider the options for adaptation and seek to identify where early action may be able to reduce adaptation costs and where forward planning may enable opportunities to be fully realised. This is due to be completed in 2012. The outputs from the CCRA and the ECR will be used by the UK Government and Devolved Administrations (Northern Ireland, Scotland and Wales) to inform the development or update of their own policy programmes for adaptation. This is likely to be a particular focus of activity during 2012.

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1 Introduction

Aspects of the UK economy, society and environment are already vulnerable to extreme weather, both when it occurs in the UK and overseas. The unusually severe winters in 2009/10 and 2010/11, extensive flooding in 2007 and 2009 and periods of drought in parts of England in 2011 demonstrated just how much damage and disruption extreme weather can cause to roads, railways, buildings, agriculture, and services such as electricity and water supplies. The UK's transport networks, flood risk management systems, and drainage infrastructure have all been tested by weather extremes over the past few decades and their vulnerabilities highlighted (Section 1.1).

Furthermore, major storms, floods or droughts elsewhere in the world can also affect the UK, through the disruption of trade or supply chains, affects on global commodity or food prices and increases in the exposure of UK businesses[12].

Global average surface temperatures are approximately 0.5 ^{o}C higher than the 1961-1990 period (Brohan *et al.*, 2006) and a higher rate of warming is evident in global data sets over land (Box 1.1). Climate change, which may see global temperatures rise by between two and six degrees by the end of this century (IPCC 2007), could lead to shifts in annual and seasonal climate (Section 2.2) as well as changing patterns of floods, droughts and heatwaves (Chapter 3). Some further warming is inevitable due to inertia in the climate system[13] and therefore some adaptation will be needed to manage potential climate risks.

Most climate scientists agree that much of the observed increase in global temperatures and rising sea levels in recent decades is due to increasing concentrations of heat-trapping greenhouse gases in the atmosphere caused by human activities. Unless we can find ways to reduce this continued warming, we may see significantly increased risks to economies around the world, particularly in developing countries (Foresight, 2011a).

Future projected changes in climate for the UK for the Medium emissions 2080s scenario[14] include:

- Increases in mean summer temperature of between 1 and 8°C;
- Changes in summer rainfall between 16% and minus 65%;
- Increases in winter rainfall of between 3% and 73%; and
- Increases in the number of heavy rain days over most of the lowland UK, several-fold for winter months and up to two-fold in summer months.

In addition, for a wider range of emissions scenarios, relative sea level in London is projected to increase by 21 to 68 cm and under the highest (H++) scenario this may increase to between 93 and 190 cm by 2095.[15]

These possible changes in average conditions would be superimposed on the UK's variable climate with its distinct seasons and natural swings from warmer to colder conditions, between wetter and drier years and changes in the frequency and severity of storm conditions.

(Source: UK Climate Change Projections 2009 (UKCP09). Further information is provided in Section 1.2 and Annex A.)

[12] For example, the recent flooding in Thailand affected production at Honda's Swindon plant.
[13] Current emissions indicate an unavoidable global temperature rise of 1.4 ± 0.3˚C above pre-industrial levels by around the 2040s but many commentators argue that limiting warming to the current 2°C target is optimistic.
[14] http://ukclimateprojections.defra.gov.uk/content/view/511/499/
[15] http://ukclimateprojections.defra.gov.uk/content/view/2145/499/
The top of the range is regarded as very unlikely to occur in the 21st century

This report is primarily concerned with the potential risks of climate change in the UK to its economy, population and natural environment. It builds on a programme of work, led by the Cabinet Office, aimed at increasing UK resilience to extreme weather[16]. However, it takes a longer term view with the overall aim of supporting the development of policies to build climate resilience and adapt to the most significant risks related to future climate change (Section 1.3).

It includes some brief discussion related to international risks that may affect the UK but these are covered in more detail in the Foresight International Dimensions of Climate Change (IDCC) study (Foresight, 2011a). More broadly, the risks of climate change on developing countries are the subject of international deliberations. Within the UK, this is being addressed by the UK Government's Department for International Development (DfID) and policies for reducing global and UK greenhouse gas emissions by the Department for Energy and Climate Change (DECC).

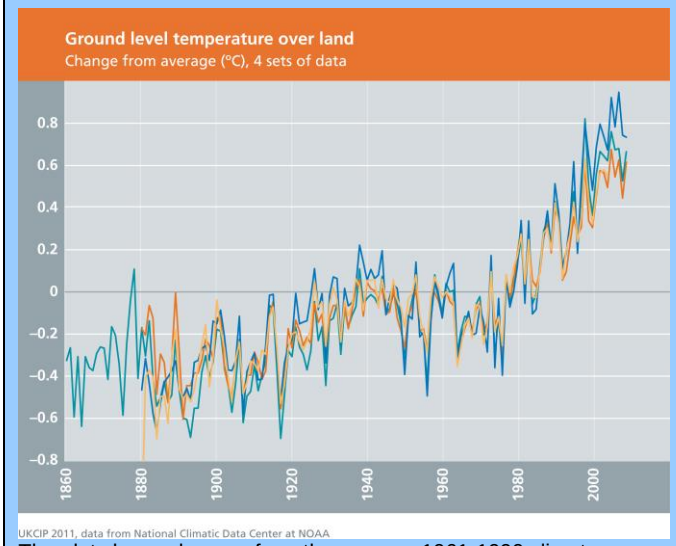
The UK Climate Change Risk Assessment shows that adaptation planning needs to be mainstreamed in all sectors affected by climate change. The uncertainty associated with projected climate change and the number of variables that could influence vulnerability to climate impacts mean that 'low regrets' decisions that perform well in a wide range of possible future climate and socio-economic scenarios will be needed. Major short-term investment or policy decisions need to avoid 'lock-in' to outcomes which could increase future risks and expenditure. The UK already has some excellent examples of good practice in adaptive decision-making, such as the TE2100 project[17]. Practical tools such as those developed by the UK Climate Impacts Programme (UKCIP) and those used in the water resources planning process (Environment Agency, 2011; Christierson *et al.*, 2011) can also help. The use of these tools and practices need to be extended to other sectors and regionally to support the National Adaptation Programme, which will be published by the Government in 2013.

This chapter presents a short overview of the evidence for global climate change (Box 1.1), the present day risks related to extreme weather events and climate variations (Section 1.1), projections of climate change for the UK (Section 1.2) and the UK Government's response in the Climate Change Act (2008) and other ongoing and future programmes of work (Section 1.3). Chapter 2 provides more information on the main sources of evidence (Section 2.1), how we completed the CCRA (Section 2.2), including dealing with uncertainties in the climate and risk assessment models (Section 2.3), and the structure of the rest of this report and supporting documents (Sections 2.4 and 2.5).

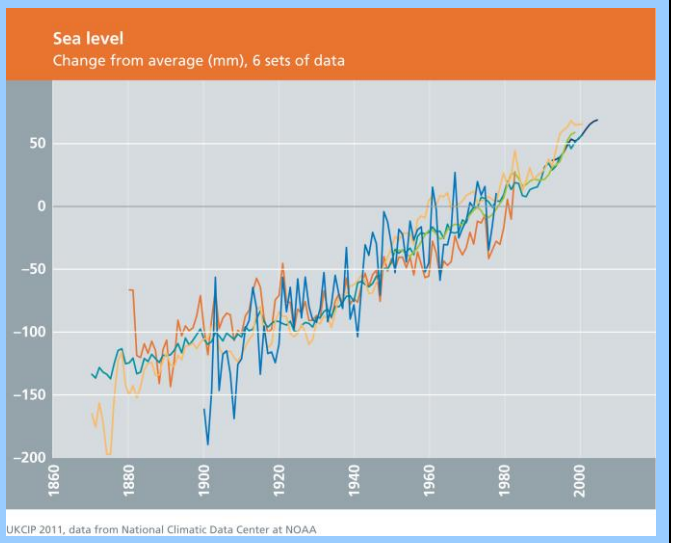
[16] http://www.cabinetoffice.gov.uk/ukresilience
[17] http://ukclimateprojections.defra.gov.uk/content/view/1889/500/

Box 1.1 Evidence of global climate change and projections of global temperatures for different emissions scenarios (reproduced from UKCIP, NOAA and IPCC sources)

Observed global changes in temperature over land and sea level



The plot shows changes from the average 1961-1990 climate. Temperatures have increased since the 1970s. There are other periods of warming, e.g. between 1920 and 1940, but warming in the last two decades is more pronounced. There is broad agreement between different data sets. (Datasets: CRUTEM3, NASA/GISS, Lugina *et al.*, NOAA/NCDC. Change relative to 1961–1990).



This shows approximately 50 mm of sea level rise between 1970s and 2000 and broad agreement between data sets since 1980. Local rates of rise also depend on land movements. Recent observed rates of rise are consistent or higher than those in climate models, raising concerns that sea level may be rising at a faster rate than previously thought. (Datasets: Church & White, Gornitz & Lebedeff, Holgate & Woodworth, Jevrejeva *et al.*, Leuliette *et al.*, Trupin & Wahr. Change relative to 1961–1990).

Projected future changes in global temperature for a range of models and different emissions scenarios (Source: IPCC, 2007, Working Group 1, Figure SPM5)

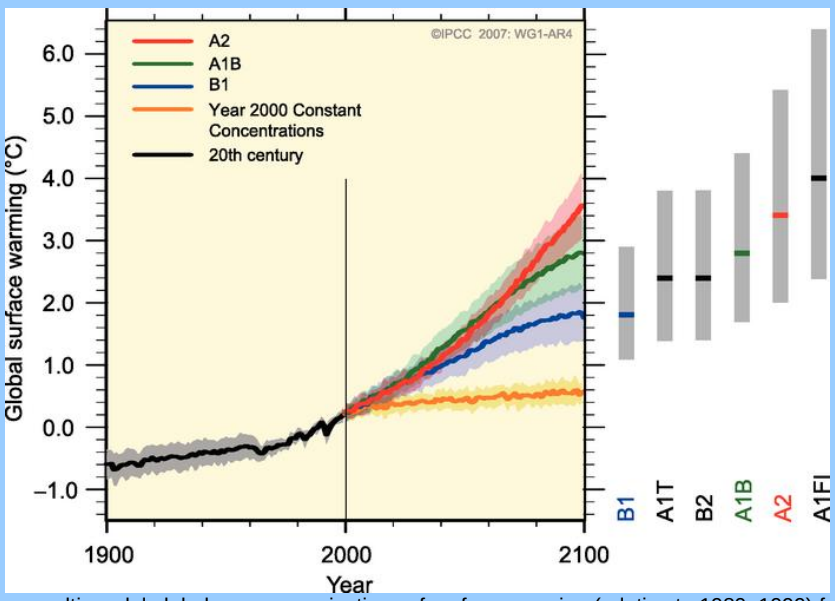


Figure SPM.5. Solid lines are multi-model global average projections of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1 (NOTE that the CCRA uses A1FI, A1B and B1 to give the widest IPCC range of emissions scenarios). Shading around each line denotes the ±1 standard deviation range of individual model annual averages. The orange line is for an experiment where greenhouse gas concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate of the level of temperature rise (solid line within each bar) and the likely range assessed for the six SRES marker emissions scenarios for the year 2100. For more information on this figure, see IPCC 2007.

1.1 Present day risks and vulnerability in the UK

The Cabinet Office's National Risk Assessment in 2008 (updated in 2010) highlighted the magnitude of risks related to coastal flooding, inland flooding and severe weather. A major coastal flood event is regarded as one of the most significant risks to the UK, alongside pandemic human disease and terrorist attacks (Cabinet Office, 2010a).

The 2012 Climate Change Risk Assessment confirms that extreme weather is still predominant among potential risks related to climate change but that other risks, such as overheating of buildings and water scarcity, are becoming increasingly important.

Flooding, severe winters, storms, heatwaves and droughts are all hazards that affect the UK. Assessment of flood risk and individual extreme weather events shows that:

- Insured losses from extreme events cost the UK an average of £1.5 billion per annum (ABI, 2009).
- The flooding in Summer 2007, which affected England, Wales and Northern Ireland, cost approximately £3.2 billion in England alone and had severe consequences for flood victims, many of whom were without homes for long periods (Environment Agency, 2007).
- The cold winters in 2010 and 2011 showed that the UK was not well prepared for dealing with snow and ice conditions. The average annual costs of winter disruption have been estimated at £1 billion per annum (DfT, 2010).
- The higher than average mortality rate at the beginning of August 2003 has been attributed to the effects of the heatwave that occurred at that time (Cabinet Office, 2010a).

Figure 1.1 summarises the main risks associated with the current climate based on evidence from the CCRA analysis and a number of other Government sources. It indicates the relative magnitude of damage and disruption costs and the most likely direction of long term change, based on changes in the main climate 'drivers' as discussed in Section 1.2. The current risks related to severe winters are very high and although they are anticipated to reduce in future, the risks will still be high to medium in the short and medium term.

Key term

Risk – combines the likelihood an event will occur with the magnitude of its outcome.

In the CCRA risks are presented as threats, with adverse costs or damages, or opportunities that may benefit specific sectors.

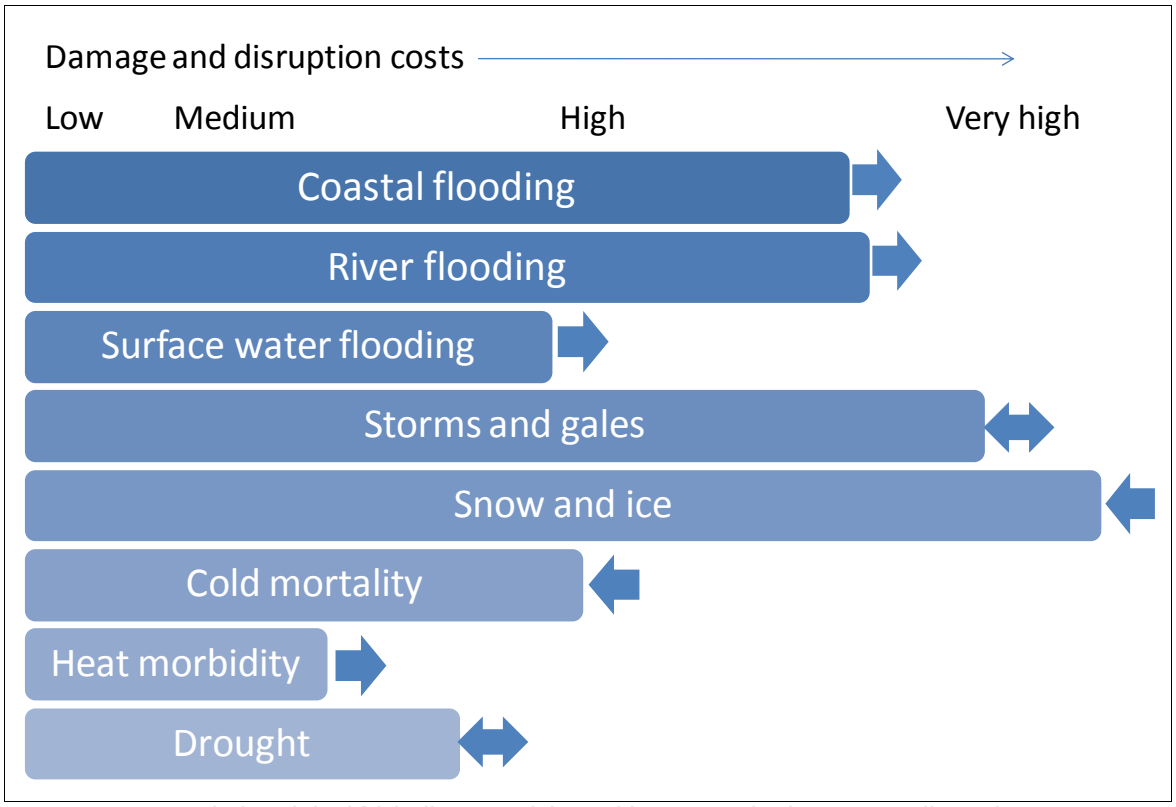
The magnitude of risk is evaluated in social, economic or environmental terms using 'risk metrics', i.e. the costs of damage, number of people affected or areas of land affected by a specific climate effect.

Due to the difficulties of defining the likelihood related to future emissions scenarios, changes in climate and socio-economic factors, the assessment focuses on the magnitude of risks for a wide range of plausible scenarios[18]. These are described as 'potential risks' because they are dependent on specific conditions of unknown likelihood.

[18] The results of the CCRA are therefore presented as a range from a lower estimate of magnitude to an upper estimate of magnitude. More information on what is included in this range and the possibility of more extreme changes is discussed in Section 1.2. Users of the CCRA should consider the range of results based on all the scenarios considered to gauge overall risks.

The CCRA has taken a closer look at current risks from climate and the UK's vulnerability to floods, heatwaves and droughts. This assessment indicates that most sectors of the UK economy are well adapted to historical **average** seasonal climate conditions and that current risks are mostly related to extreme events, including 'all sources' of flooding, extreme cold conditions, heatwaves, droughts and storms.

Figure 1.1 Summary of extreme events, current damage and disruption costs and most likely direction of change



Note: Arrows pointing right (→) indicate anticipated increases in damage or disruption. Arrows pointing left(←) decreases, and those that may increase or decrease are indicated by ←→. The thresholds for medium, high and low costs are £10, £100 million and £1 billion but a more detailed analysis is needed to determine comparable expected annual damage costs.

The most significant climate risks, based on economic damage and disruption, under current climate conditions are:

- **Flooding from the sea and estuaries**: Expected annual damages of over £200 million and the greatest risk in terms of the areas affected and potential loss of life. The 1953 flood disaster along the east coast still ranks as one of the worst environmental disasters experienced in the UK.
- **Flooding from rivers**: Expected annual damages of over £400 million in England and Wales and severe consequences for flood victims, essential services and businesses. Flooding in Summer 2007 and most recently in Cumbria in 2009 demonstrated the wide-ranging risks to people, property, critical infrastructure and agriculture.
- **Cold mortality influenced by extreme cold conditions**: Estimates of 26 to 57 thousand premature deaths each year in the current climate (Health Sector

Report). Although premature deaths appear to have fallen over the last decade, risks are still significant if combined with high rates of influenza[19].

- **Snow and ice conditions**: The Government's independent review of recent cold spells indicated annual average transport disruption and welfare costs of £1 billion per annum (DfT, 2010) [20]. Snow and ice conditions are expected to decline in the long term with warmer conditions, but cold extremes will still occur due to the natural variation of climate.
- **Heat morbidity caused by extreme hot conditions**: Estimates of an average of 100 thousand patient days per year under the current climate and much greater numbers during heatwaves as well as excess deaths.
- **Storms and gales**: Average annual insured losses from UK windstorms are £620 million (ABI, 2009). The storms in 1987 brought down approximately 15 million trees and subsequent events in 1990, 2001 and 2007 caused substantial property damage, disruption to energy supplies and loss of life.

Droughts are also a concern in the UK. Drier conditions in parts of South East England in spring 2011 caused a reduction in crop yields, which caused problems for many farmers. While these problems are significant in extreme drought years, the average expected damages for UK droughts are far less than for flooding. Elsewhere in Europe, drought in 2003 had severe consequences for agriculture. It also affected energy supplies in the Netherlands and Germany, as a lack of water for cooling and the requirement to meet environmental discharge consents which limit the temperature of water that can be released back into water courses meant that power stations had to work at lower capacities. More severe droughts are possible in the UK even under current climate conditions and would have far greater consequences for public water supplies, industry, agriculture and the environment than the recent examples of UK drought (Jones *et al.*, 2006; Wade *et al.*, 2006; Marsh and Wilby, 2007). The problem of water scarcity and other notable risks related to climate variability are summarised in Figure 1.2.

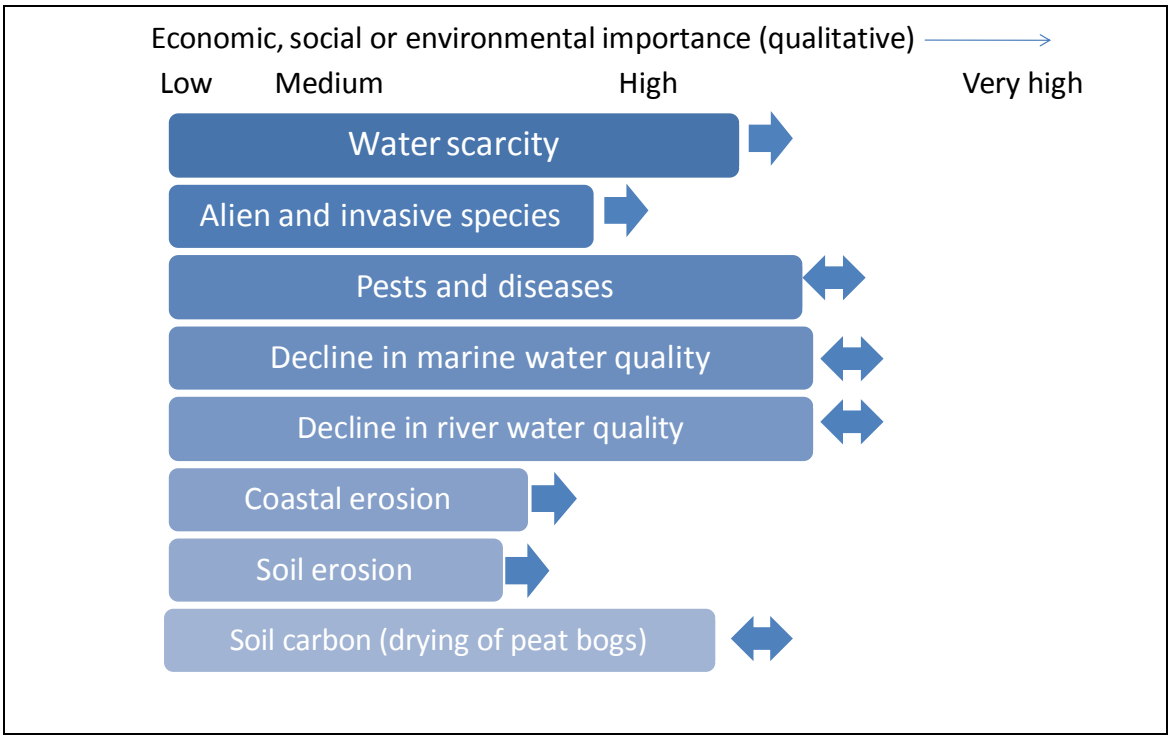
Figure 1.3 presents the observed temperature data during the hottest UK heatwaves in 1976, 2003 and 2006. The left hand side shows the maximum temperatures observed. The right hand side shows the maximum temperature on the coolest day to indicate sustained high temperatures above this threshold. Human health suffers when temperatures rise above approximately 20°C for a sustained period without dropping below this temperature at night time. The elderly and young infants are particularly vulnerable. Sustained high temperatures are unusual in the UK but temperatures above 20°C occurred across large areas of the UK in all three heatwaves presented.

Variations in climate and extreme weather events will compound present day risks in other less well recognised areas of the economy. *The National Ecosystem Assessment* has shown that the loss of ecosystem services due to the combination of land use pressures, climate and other factors is already important (Watson and Albon, 2010). The contribution of natural climate variability is small compared to land use change and is particularly difficult to quantify. However, climate factors such as soil erosion from heavier rainfall events and declining summer river flows in warmer and drier conditions are important and current risks need to be managed, as the consequences in some cases may be irreversible. The economic costs of soil degradation are estimated at between £250 and £350 million per year for England alone (Foresight, 2010a). The loss of ecosystem services would have significant consequences, for example the drying of peat bogs and potential loss of carbon would

[19] The Office of National Statistics provide data on excess winter mortality for England and Wales http://www.statistics.gov.uk/cci/nugget.asp?id=574
[20] http://transportwinterresilience.independent.gov.uk/

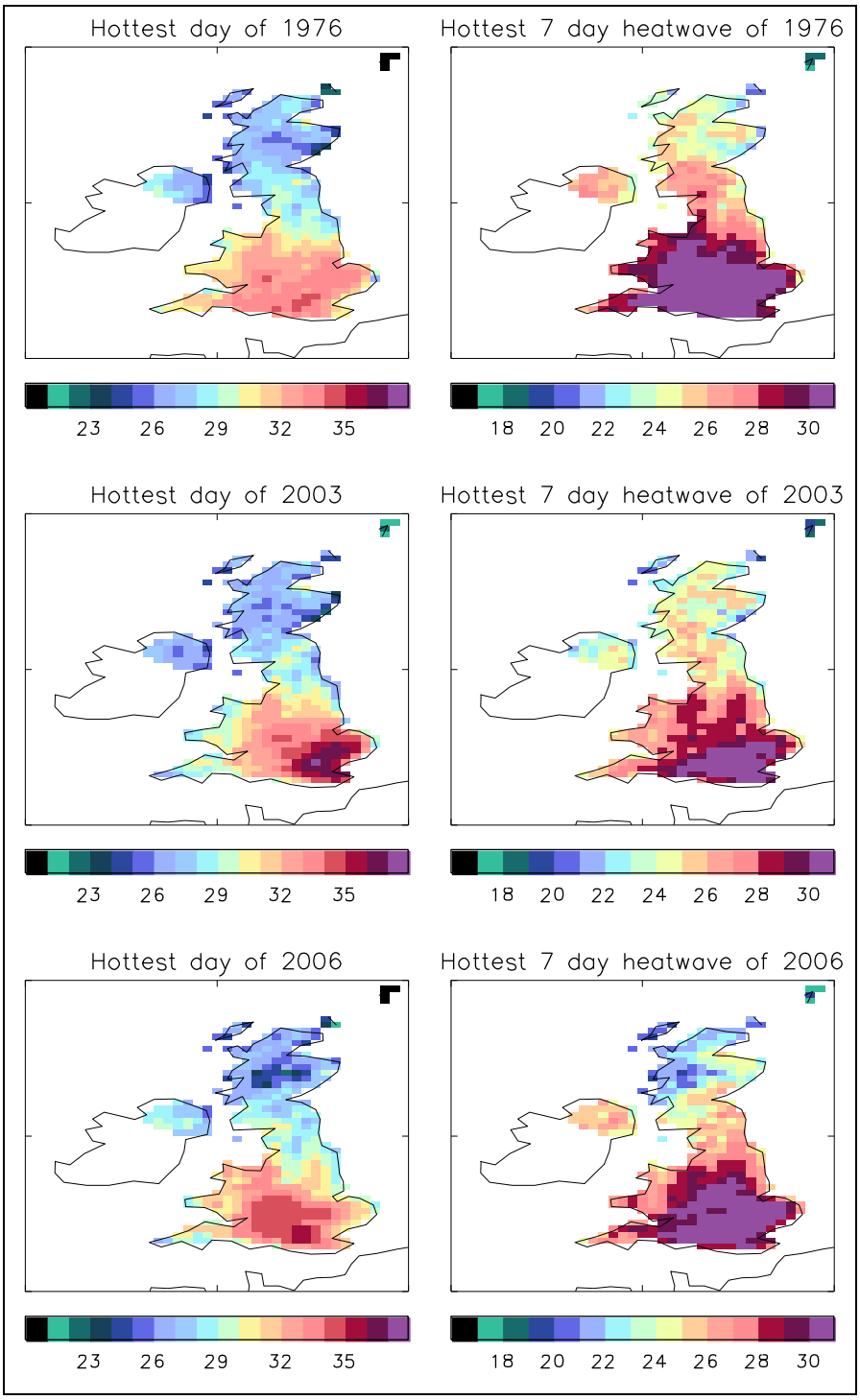
be detrimental to the Government's Greenhouse Gas Emissions (GGE) targets. These are discussed in more detail in Chapter 8.

Figure 1.2 Summary of other notable risks and the expected direction of change due to climate change effects



Note: These risks were classified based on stakeholder feedback at CCRA workshops. These have been discussed in more detail in the recent National Ecosystem Assessment (Watson and Albon, 2010).

Figure 1.3 Observed (at 25km gridded resolution) hottest daily maximum temperature (°C, left hand column) and maximum temperature (°C) on the coolest day during the hottest heatwaves of 7 day duration (right hand column) in 1976, 2003 and 2006 (note the different scales)
(Source: Met Office)



1.2 Climate change projections for the UK

The CCRA makes use of the UKCP09 climate projections that represent a range of possible future changes in UK climate. The range of possibilities is necessarily wide to take account of uncertainties in natural climate variability, how the UK's climate may respond to global warming, the future trajectory of emissions, and how these might magnify any regional climate change effects. This section provides a short overview of UKCP09 and how the CCRA interpreted the projections for the risk assessment, in the context of high uncertainty and evolving science.

Chapter 2 summarises how we actually used UKCP09 and other climate models in the assessment. Further technical details are provided in a Met Office paper prepared for the CCRA (Annex A) and in the UKCP09 scientific reports (Murphy *et al.*, 2009).

The UKCP09 web pages provide a series of technical reports, climate change data for the UK and a series of updates and additional guidance since the launch of the projections in 2009: http://ukclimateprojections.defra.gov.uk/.

1.2.1 Possible climate futures for the UK: a range of estimated changes

Projecting future climate change and variability is fraught with uncertainty, especially at the relatively small scales of the UK. The climate varies naturally from year to year and decade to decade, and confidently projecting the details of these fluctuations is largely beyond current scientific capabilities. In the longer term, for a decade and beyond into the future, the rise in greenhouse gas concentrations is expected to continue to cause a global warming trend over and above year-to-year natural variability. However, it is still extremely hard to forecast how regional climates in the UK will respond, especially for changes in precipitation (rainfall and snow).

UKCP09 projects a range of changes in UK climate over the 21st Century, accounting for both natural variability and the uncertain response of regional climates to global warming. In the near-term (next one to two decades), most of the uncertainty range is associated with natural variability, and while the long-term average temperatures are expected to be warmer than present, periods of cooler temperatures are also likely at times with our variable climate. As for precipitation, season-to-season variability means that there could be wetter or drier periods, once again reflective of our variable climate.

In the medium term (mid-century), the build up of greenhouse gases is expected to be significant enough for systematic shifts in the UK climate to start to become evident even though year-to-year variability will still occur. This implies a clear shift toward warmer temperatures, although with natural variability cold winters can still occur. A shift towards generally wetter winters is expected, but the future response of UK summer rainfall is less well-understood. UKCP09 suggests that there is a greater likelihood that summers will be drier, but wetter summers are not ruled out. Nevertheless, whatever happens to seasonal averages, a greater fraction of precipitation is expected to fall as heavy events.

The future trajectory of emissions is also uncertain, but the range of plausible emissions scenarios does not significantly affect the range of possible UK climate changes until the latter part of the 21st Century, because the different emissions pathways do not start to diverge until mid-Century in terms of their effects on temperature rise. We know that higher emissions lead to greater warming, but it is harder to predict what may happen to annual and seasonal rainfall patterns.

1.2.2 Emissions scenarios

The CCRA has followed a standard approach to emissions scenarios based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES; Nakićenović *et al.* 2000). These are referred to throughout this report as “High”, “Medium” and “Low”, and are described in Table 1.1 below.

Table 1.1 CCRA emissions scenarios and respective IPCC Fourth Assessment Report AR4 code names

Scenario name		Description
IPCC	**CCRA**	
A1FI	High	A future world of very rapid economic growth with a global population that peaks in mid-century and declines thereafter, with convergence among regions and decreasing global differences in per capita income. New technologies are introduced rapidly, but with a continued intensive use of fossil fuels.
A1B	Medium	Similar to the A1F1 scenario in its underlying assumptions, except that global energy production is more balanced between fossil fuels and other sources.
B1	Low	The same pattern of population change as the A1F1 scenario but with much greater emphasis on clean and resource-efficient technologies, with global solutions to economic, social, and environmental sustainability and improved equity.

Although the Low scenario considers the case of a large proportion of energy being derived from non-fossil fuel sources, there is no explicit inclusion of emissions reductions policies in this or any of the emissions scenarios. More recently, in order to understand the extent to which emissions reductions policies could avoid climate change, further scenarios have been developed and applied in climate models. These “aggressive mitigation” scenarios have not been examined in detail in the CCRA. However, we found that the lower rates of warming in the UKCP09 Low emissions scenario provided a reasonable proxy for the upper rates of changes in temperature projected under an aggressive mitigation scenario.

1.2.3 UKCP09

The UK Climate Projections (UKCP09) provide probabilistic projections of climate change for the Low, Medium and High emissions scenarios and for seven overlapping time periods. The CCRA used projections near the upper and lower ends of the UKCP09 range for each emissions scenario, as well as the central projections. Rather than being used as an indicator of the likelihood of particular outcomes, these were interpreted in the CCRA as plausible scenarios illustrating a range of possible changes. The CCRA does not assign probabilities to any future projections or risks.

Are some scenarios more likely than others?

- In UKCP09, and in the CCRA, no judgements are made on the relative probability of different emissions scenarios. It is too early to establish whether actual emissions are following any particular emissions scenario.
- The projections provide an indication of the spread of possible outcomes for each emissions scenario but it is possible for there to be changes outside of the projected range in UKCP09. As the science improves, new modelling results may indicate changes that are higher or lower than those presented in UKCP09.

What baseline conditions and future time periods are used in UKCP09?

- As a result of natural climate variability, estimates of the past or a future climate cannot be made using short time periods of a few years and need to be made over a longer time period. Convention in climate change science is to consider average changes over 30 year time periods, which is considered a long enough period to provide good estimates of annual average and seasonal climate variables.
- This approach has therefore been used in UKCP09 projections, with the baseline maintained as the 1961-1990 baseline used for previous UK climate projections (UKCIP02). However, the requirement for the CCRA to assess changes in climate risk relative to a 'present-day' baseline means that additional climate data were also used to establish a baseline that was suitable for 2010[21,22]. The development of the Met Office decadal forecasting model will provide improved estimate of present day and near term climate change risks for future assessments.
- UKCP09 provides projections of climate change over seven overlapping time periods from 2010-2039 to 2070-2099. The CCRA focuses on the three non-overlapping 30-year time periods covering the 90 year period between 2010 and 2099, each of which are referred to using the central decade of the 30-year period (see Table 1.2).

Table 1.2 30-year time periods assessed in the CCRA

UKCP09 30-year period	Defined period for CCRA
2010-2039	2020s
2040-2069	2050s
2070-2099	2080s

1.2.4 Scenarios of future changes in mean climate variables from UKCP09

The previous UKCIP02 climate change scenarios characterised a future UK climate with, on average, hotter, drier summers and milder, wetter winters. UKCP09 provides a range of outcomes for a given emissions scenario, and in many cases this range is larger than the difference between emissions scenarios. UKCP09 still projects warming at all time periods and all locations in the UK, relative to the 1961-1990 baseline, although the projected range in precipitation changes includes a potential increase in summer precipitation. Although UKCP09 estimated the probability of different climate projections, it is emphasised that CCRA did *not* make use of these to assign probabilities to different risks. Instead, UKCP09 was used to provide a range of changes which are considered plausible enough to warrant inclusion in this risk assessment. Actual future changes may be well within these ranges, but nevertheless changes outside these ranges cannot be ruled out.

[21] The UKCP09 projections do not provide data between the 1961-1990 baseline and the first time period considered 2010 to 2039. An equivalent data set for 1990 to 2019 or 2000 to 2029 may provide a suitable climate baseline. As these data were not available other observed data sets were used within each sector to provide reasonable estimates of average climate and frequency of more extreme events for a base year of 2010. The lengths of records, the extent of overlap with the UKCP09 baseline and the availability of data on climate risks were all important considerations, which influenced the specific approach in each sector (see Sector Reports for full details).

[22] In most sectors the climate baseline was around 2010 and made use of a range of historic climate data to provide a reasonable estimate of average climate and frequency of more extreme events. For future UKCP09 projections the absolute climate values were used or 'change factors' with an adjustment to account for the warming that has occurred since 1990. No adjustments were made for changes to hydrological variables as the scientific evidence at the national scale is limited. The UKCP09 trends report provides some information on how the 1961-1990 baseline compares to the 1971-2000 period but a similar analysis for 1981 to 2010 is not yet complete.

Some of the key aspects of climate change considered in the CCRA are presented here, and full descriptions for each region of the UK are provided on the projections web pages. For the Medium emissions scenario in the 2050s:

- Projected warming of mean temperature ranges from approximately 1°C to 3°C in winter and from 1°C to 4°C in the summer (Figure 1.4).
- However, the uncertainty in the projected precipitation changes is large, and indeed for summer precipitation the sign of the changes (either a decrease or increase in precipitation) varies between projections.
- Projected changes in summer precipitation averaged over administrative areas (Figure 1.5) typically range from decreases of 20%-40% to increases of approximately 1%-7%.
- Projected changes in winter precipitation shows a more consistent signal of increase, from approximately 5% to 30% (Figure 1.5).

Figure 1.4 Range of changes in 30-year mean winter and summer mean temperature considered in the CCRA, averaged over administrative regions, by the 2050s under the Medium emissions scenario
(Source: Met Office)

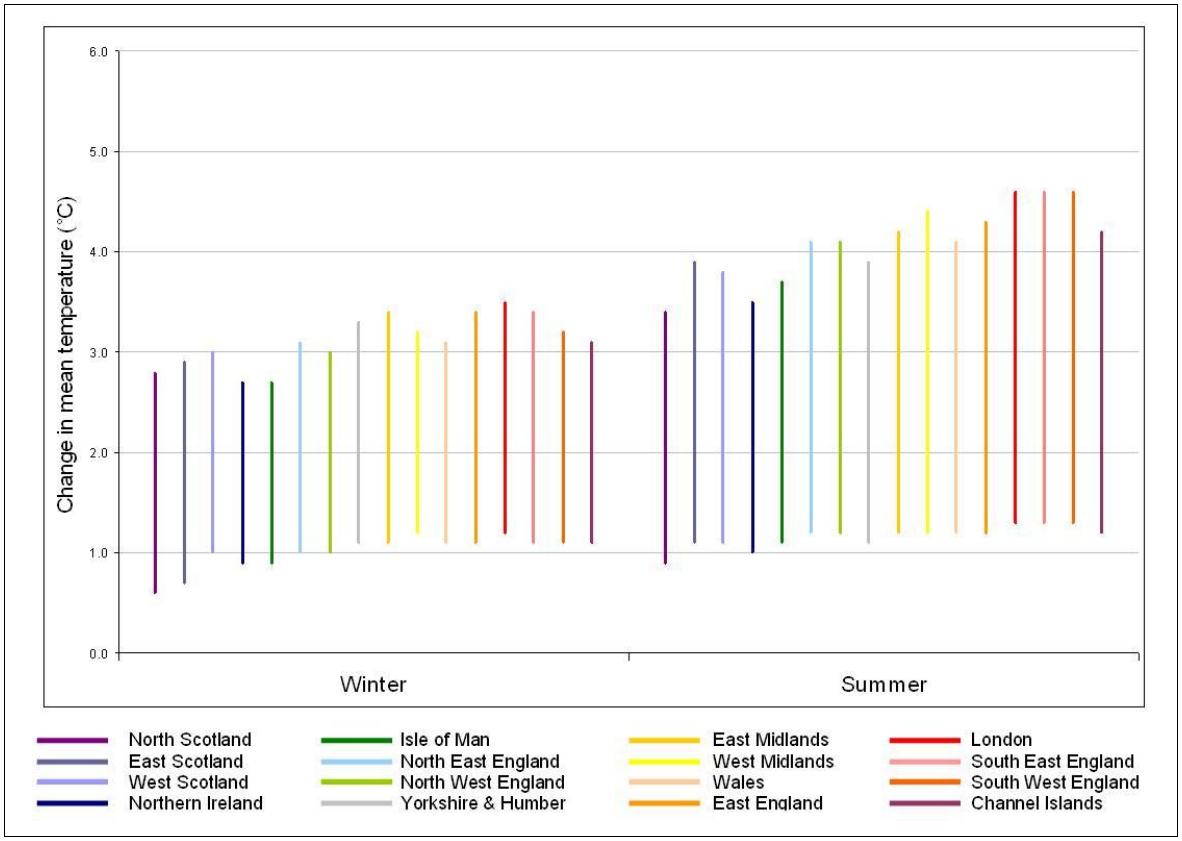
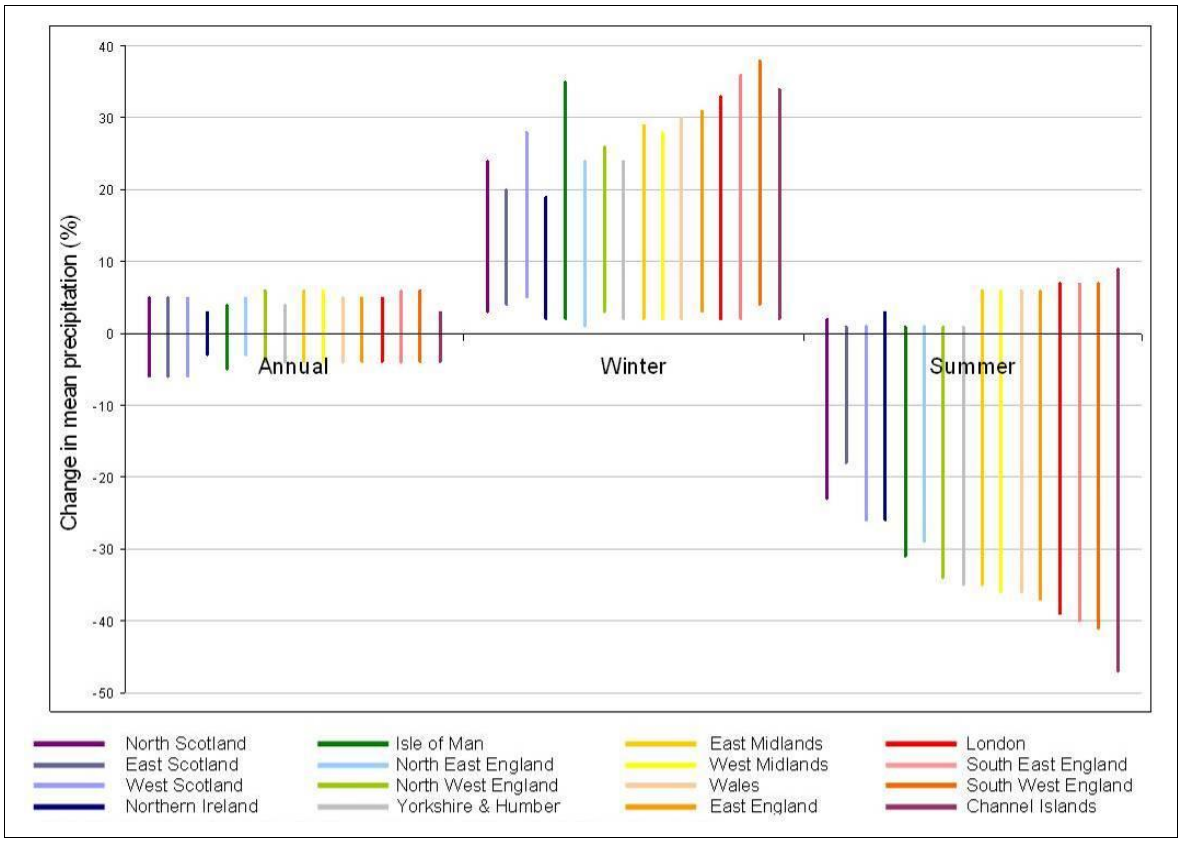


Figure 1.5 Range of changes in 30-year mean annual, winter and summer mean precipitation considered in the CCRA, averaged over administrative regions, by the 2050s under the Medium emissions scenario
(Source: Met Office)

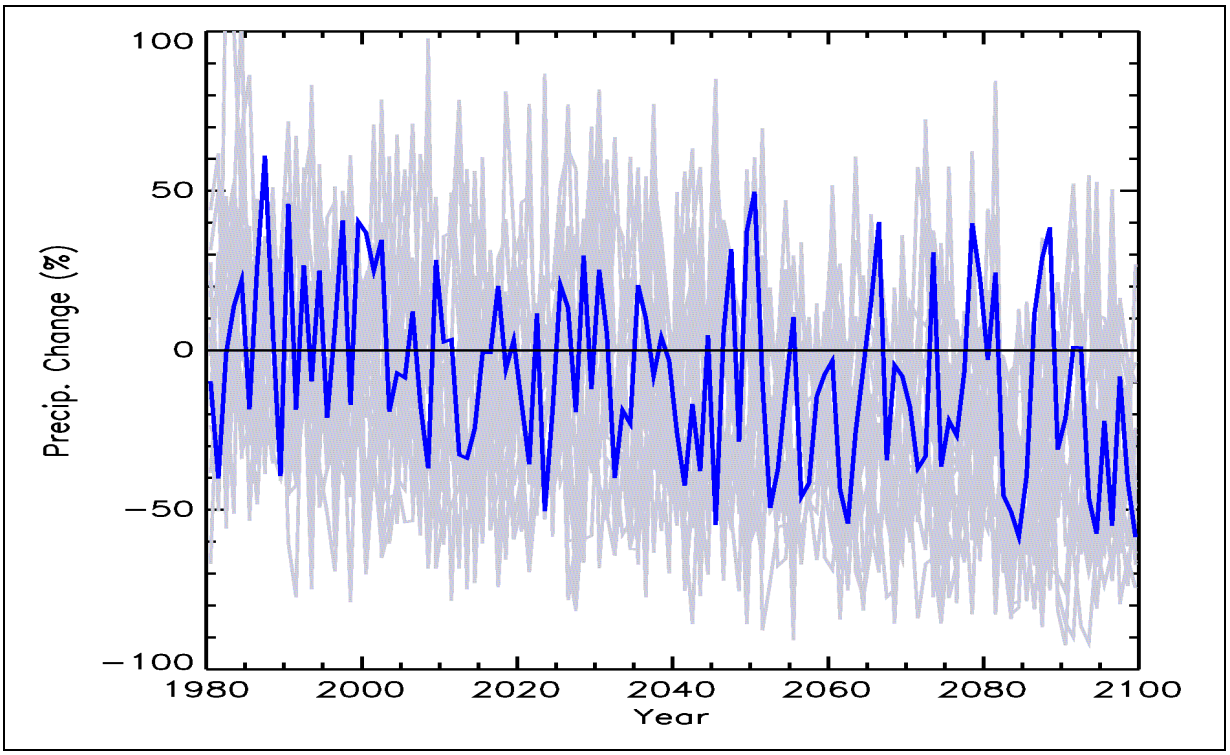


1.2.5 Potential for climate changes not reflected in UKCP09

While the above changes refer to 30-year averages, variability for individual years may be much larger in either direction. So even in a model which shows more of a tendency toward drier rather than wetter summers in the long-term average, individual very wet years are still possible (Figure 1.6). Similarly, despite the projected long-term warming trend, cold winters may still occur, especially in the near to medium term. In Figure 1.6, sixteen climate model variants are shown with overlapping grey lines, and an additional one is highlighted in blue in order to illustrate the year-to-year variability in a single projection. Note that while the set of models generally show more of a tendency towards decreasing rather than increasing summer precipitation, some model variants still show amounts of precipitation in a given year as being wetter than normal near the end of the century.

It should also be noted that while the UKCP09 projections were based on a state-of-the-art methodology at the time of preparing the CCRA, they are still only simulations and will change as a result of more recent climate observations and further advances in science. Further details of known strengths, assumptions and limitations of UKCP09 and ongoing developments in climate projections are provided in Annex A.

Figure 1.6 Percentage change in summer rainfall over South East England from 17 variants of the regional climate model
(Source: Met Office)



1.2.6 Future changes in extreme climate variables

UKCP09 provides projections of some aspects of weather extremes, specifically the temperature of the hottest day and coldest day and night of each season, and the precipitation rate for the wettest day of each season.

However, estimating future changes in extreme events is particularly challenging and is subject to even greater uncertainty than changes in average temperature conditions. The estimates provided in UKCP09 are discussed in Annex A. In the CCRA the estimates of changes in future flooding were based on a detailed application of the Regional Climate Model (RCM) data (Kay *et al.*, 2010), rather than direct use of the probabilistic data in UKCP09. This provided estimates of regional average changes in peak river flow of between no change and plus 60% by the end of the century (Chapter 3).

1.3 The Government response to climate change

1.3.1 The Climate Change Act 2008

The Climate Change Act 2008 made the UK the first nation in the world to have a legally binding, long-term framework to cut carbon emissions. It also requires a series of assessments of the risks of climate change for the UK, under both current conditions and over the long term, to 2100. The Act requires:

- A report on the risks of climate change to the United Kingdom, which should be laid before parliament in January 2012. The risk assessment report will then be updated every 5 years (Section 56). The 2012 CCRA provides the first of these assessments, which will support further appraisal of adaptation options for the UK and Devolved Administrations.
- The development of adaptation programmes that set out Government objectives in relation to adaptation to climate change, proposals and policies for meeting those objectives, and the time-scales for introducing those proposals and policies. These are expected to address the risks identified in the CCRA reports as well as contribute to sustainable development (Section 58).
- Regular assessments of the progress made towards implementing the adaptation programmes (Section 59) through reports prepared by the Committee on Climate Change, which was also established under the Act (Section 32).

1.3.2 The Adaptation Sub-Committee

The Adaptation Sub-Committee (ASC) is a sub-committee of the Committee on Climate Change (CCC), established under the Act. The committee's role is to provide expert advice and scrutiny to ensure that the Government's programme for adaptation enables the UK to prepare effectively for the impacts of climate change. This includes a scrutiny role on the preparation of the UK Climate Change Risk Assessment; the ASC provided advice on the CCRA at key points including its inception, method development and scientific peer review stages.

The ASC has published several independent reports on adaptation as well its specific advice to the Secretary of State regarding the development of the CCRA.

http://www.theccc.org.uk/reports/adaptation

1.3.3 Adaptation Reporting Powers

The Climate Change Act 2008 introduced a new power for the Secretary of State to direct "reporting authorities" (companies with functions of a public nature such as water and energy utilities) to prepare reports on how they are assessing and acting on the risks and opportunities from a changing climate.

Reports from a number of utilities, regulators and Government agencies have been published and are available online[23]. These are focused on risks to specific organisations and in many cases specific areas of the UK. The earliest ARP reports were considered in the CCRA but the short timescales available meant that the two evidence streams were not fully integrated.

Therefore, the ARP reports can be regarded as providing complementary evidence, which will be considered as part of the National Adaptation Programme and in future updates of the CCRA.

1.3.4 Departmental Adaptation Plans

This assessment made use of Government Departmental Adaptation Plans (DAPs) to review climate risks highlighted in these documents and to understand the policy context for individual sectors. These reports are available from the Defra website:

[23] http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/reporting-authorities-reports/

http://www.defra.gov.uk/environment/climate/government/departmental-adaptation-plans/

The project also involved consultation with Government departments to ensure that sector reports were up to date.

1.3.5 The Economics of Climate Resilience

This assessment considered the risks of climate change but did not explore their combined economic effects on different sectors, or adaptation responses to deal with those effects.

The Economics of Climate Resilience study will assess the economic impact of climate change across the UK economy. Information from the CCRA will be used to assess the climate risks to around 20 key policy questions. For each policy question, the scale of the risk will be assessed against planned policies and autonomous adaptation[24], in order to estimate the 'adaptation deficit' – the gap between the anticipated level of adaptation and the desirable level of adaptation. In addition, a number of policy options will be assessed in greater detail and the project's recommendations will become part of the National Adaptation Programme.

[24] Autonomous adaptation may reduce or, in the case of maladaptation, increase future risks. It will be important for the ECR study to identify the possible effects of maladaptation and consider policy options for addressing this.

2 Assessing Potential Climate Change Risks

This chapter provides more information on the main sources of evidence (Section 2.1), how we completed the CCRA (Section 2.2), including dealing with uncertainties in the climate and risk assessment models (Section 2.3), and the structure of the rest of this report and supporting documents (Sections 2.4 and 2.5).

2.1 The main sources of evidence

This first CCRA builds on a large amount of evidence gathered since the last national review of climate impacts in 1996 (CCIRG, 1996). This includes:

- Outputs from the UK Climate Impacts Programme (UKCIP) (West and Gawith *et al.*, 2005).
- A decade of stakeholder-led regional scoping studies (see Watkiss *et al.*, 2009) and similar activities led by Devolved Administrations.
- A concerted effort to improve our understanding of risks in the marine environment through the Marine Climate Change Impacts Partnership (MCCIP).[25]
- Significant research studies in some UK sectors, for example on future flood risks (e.g. Evans *et al.*, 2004; Kay *et al.*, 2010), overheating of buildings (e.g. Hamilton *et al.*, 2010), the impacts of heatwaves on health (e.g. Armstrong, 2010) that have provided stronger evidence of future risks and uncertainties.
- The Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) have reviewed literature on climate change risks, but have not provided a systematic, internally-consistent assessment of multiple risks and have also been limited in their focus on individual countries.
- Research on 'avoiding dangerous climate change' (AVOID programme, New *et al.*, 2010) as well as the 2010 and 2011 floods in Pakistan, Brazil, China and Australia have heightened concerns related to international impacts and how these may disrupt the UK economy through trade, aid, supply chains and international relations (Foresight, 2011a).

The CCRA assessment also involved extensive consultation to bring in expertise from the wider research community, policy makers, industry experts and regional partnerships. This included talking to more than five hundred people in sector workshops, forums, through e-consultation and targeted interviews. Early on in the project this was particularly valuable in sectors where research is less well developed, where systems are complex or where climate change risks are not well understood. Later in the project this was essential to identify how the study's findings aligned with Government policy.

[25] http://www.mccip.org.uk/

Both literature review and stakeholder evidence was gathered from eleven 'sectors' (or research areas) and in this report the main findings were grouped into five main themes:

Sectors

- Biodiversity & Ecosystem Services
- Agriculture
- Forestry
- Water
- Floods & Coastal Erosion
- Built Environment
- Energy
- Transport
- Marine & Fisheries
- Health
- Business, Industry & Services.

Themes

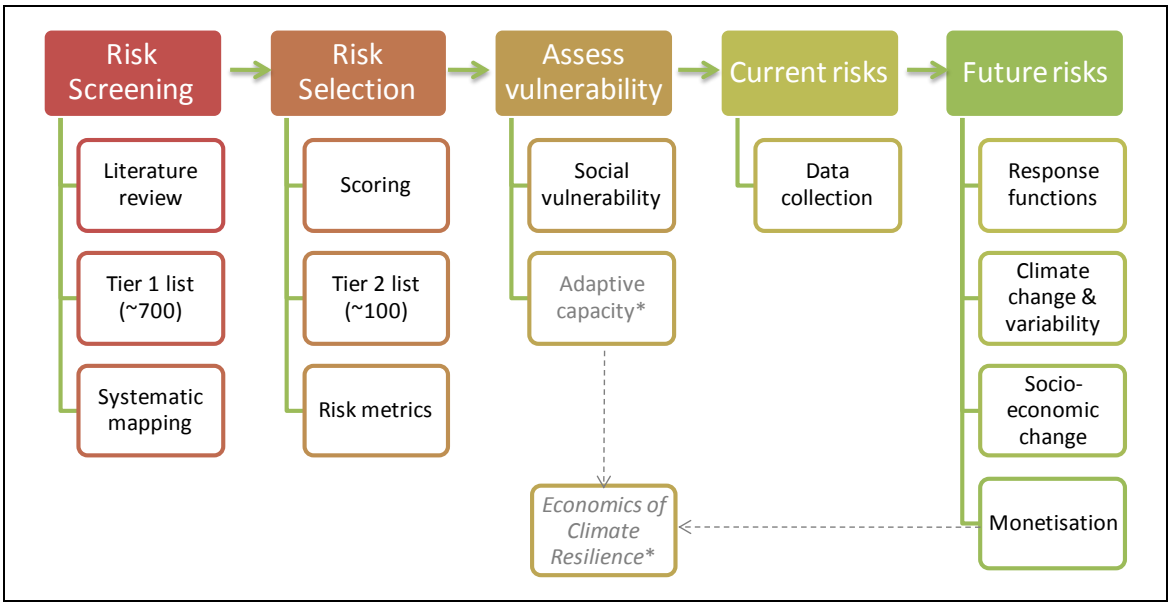
- Agriculture and Forestry
- Business
- Health and Wellbeing
- Buildings and Infrastructure
- Natural Environment.

2.2 A simple overview of the methodology

The methodology was developed in early 2010 to meet the specific requirements of the CCRA, within the timescales available for the first assessment. The proposed methodology was reviewed by the Adaptation Sub-Committee and was published on Defra's website in July 2010 (Defra, 2010b). Further details can be found in Appendix 1.

A simplified overview of the approach is shown in Figure 2.1 and further details are provided in this chapter on key aspects of the method, such as the assessment of social vulnerability and how the climate change and socio-economic drivers were combined to estimate future risks.

Figure 2.1 Simplified summary of the CCRA methodology and links with the Economics of Climate resilience project



* Ongoing studies to inform the National Adaptation Plan

- **Risk screening** involved literature reviews and consultation in each of the eleven research areas, which collectively developed a list of more than 700 potential climate change risks (Tier 1 list). A systematic mapping methodology provided a simple form of systems analysis to describe links between potential risks within sectors and between sectors. This helped to identify some additional risks across sectors and provides a starting point for more detailed research, including systems modelling to support future risk assessments.
- **Risk selection** involved a simple scoring exercise that considered the perceived magnitude and likelihood of risks and also the perceived urgency of adaptation action. This process, which involved gathering feedback from stakeholders, selected a more manageable list of approximately 100 risks to study in greater detail. For each potential risk a 'risk metric' was defined to describe risk magnitude under a range of future scenarios.
- **Assessment of vulnerability** was related to collecting further evidence on other non-climate factors that influence future risks, such as the social vulnerability of different groups of people in the UK, the capacity of organisations to respond to information about future climate change and information about existing Government policy on adaptation.
- **An understanding of current risks** was the starting point for the assessment in each sector. This involved collecting the best information available on current risks from Government departments and the regulated industries. In some sectors, such as floods and coastal erosion risk management, extensive national data sets were available for England and Wales, whereas in other sectors, such as Business, Industry & Services very limited information was available. The main gaps in evidence were recorded in each Sector Report.
- **Future risks** were assessed using a staged approach that involved understanding the sensitivity to climate variables using 'response functions', considering the effect of future climate change and variability on the current population, and then considering population changes to estimate the total climate risk for future time periods. The difficulty of assessing long term socio-economic changes was recognised and the project included a qualitative assessment of the main drivers of potential risks. Finally, some potential risks were monetised to aid comparison across sectors and themes. In addition, some further broad categorisation of potential risks as 'high', 'medium' and 'low' was completed to inform the conclusions (Chapter 9).
- **The Economics of Climate Resilience (ECR)** is a separate and ongoing research study to inform the National Adaptation Programme (NAP). Our work on adaptive capacity (Ballard, Black and Lonsdale, forthcoming) and some of the monetisation findings will be used in this study to estimate the most cost effective adaptation policies.

Some of the key components of the method are discussed in further detail in the following section and in greater detail in Appendix 1.

2.2.1 Key components of the risk assessment methodology

Involvement of stakeholders in risk screening and selection

An extensive programme of stakeholder engagement was an essential component of the CCRA method. This was in order to develop a broad appreciation of the key issues, maintain an appropriate focus and track down relevant information. Stakeholders were involved at different points in the process and in different ways, depending on their interests and the type of input they could provide.

- Sector groups provided information for risk screening, assisted in the development of scores for risk selection and provided feedback to moderate the results of the scoring exercise.

There was ongoing engagement with:

- The project steering group, comprising representatives from government departments and the Devolved Administrations;
- A group of in-house experts, including representatives from a number of government agencies; and
- The Adaptation Sub-Committee, with a number of in-depth discussions with members of the committee and the secretariat.

In addition, a wide range of stakeholders were able to engage with the CCRA through:

Information provision – Stakeholders were invited to register to receive information about developments in the CCRA and were also provided with information as part of meetings, workshops and online feedback opportunities.

Information gathering – Stakeholder meetings and workshops were used to identify and access information that would be useful for developing the risk assessment.

Consultation – Stakeholders were invited to share information about their own approaches, priorities and needs.

Feedback – Where possible, stakeholders were invited to comment on reports and findings.

Vulnerability

Key Term

Vulnerability – Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (UKCIP definition).

Vulnerability is a term used in the CCRA to describe how sensitive a system is to an impact. The system can either be a social system or a bio-physical system. The greater the sensitivity of the system; the greater the effect of the impact. For example, people with poor health are more sensitive to the impacts of flooding, because their immune systems are already low and exposure to cold, damp conditions can increase the likelihood of illness. Whilst this report also refers to vulnerability in relation to bio-physical systems (see Chapter 8), the term is used most frequently to refer to the vulnerability of social systems, and in particular individuals and communities (Box 2.1). In places “social” appears before the term vulnerability to highlight the focus on social

systems. Social vulnerability was examined as part of the sector based risk assessment work and also via an evidence review (Annex B).

Adaptive capacity

Key Term

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.[26] Adaptive capacity has a different meaning in ecology, which is outlined in Chapter 8.

Potential risks can be reduced, or heightened, by how well we recognise and prepare for them, i.e. by our 'adaptive capacity'. High capacity is needed to make actions that we take today, or may take in the future, effective in coping with future climate impacts. Considering adaptive capacity is essential for adaptation planning and the CCRA has included work in this area that will contribute to the ongoing Economics of Climate Resilience study.

Monetisation

The purpose of this step was to monetise risks as far as possible. This provided one element to help assess the relative importance of different climate change risks for the UK. The aim was to express the risk in terms of its effects on social welfare, as measured by individuals' preferences using a monetary metric. However, depending on the availability of data, it was sometimes necessary to use alternative approaches (e.g. repair or adaptation costs) to provide indicative estimates. Where quantitative risk data did not exist, it was necessary to use expert judgement within the CCRA team to achieve this aim.

The generic methodology for monetary valuation of climate change risks and adaptation in the CCRA is primarily based on that developed in the HM Treasury Green Book[27] and its Supplements[28] and for UKCIP by Metroeconomica (2004).

The CCRA 'top down' approach on its own would provide quite a narrow appreciation of the risk landscape. However, this was balanced by detailed work on social vulnerability (Annex B), systematic mapping and extensive stakeholder engagement (Box 2.2).

[26] Modified from IPCC to support project focus on management of future risks (Ballard *et al.*, 2011)
[27] 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.
[28] http://www.hm-treasury.gov.uk/data_greenbook_supguidance.htm

Box 2.1 Understanding social vulnerability

There is evidence that particular places or people are particularly vulnerable to floods, heatwaves and, to a lesser extent, drought. The following factors may increase the vulnerability of people to climate risks (CAG, 2009):

i. Location and place
ii. Poor mental and physical health
iii. Fewer financial resources
iv. Living and working in poor quality homes or workplaces
v. Limited access to public transport
vi. Limited or lack of awareness of potential risks
vii. Lack of social networks
viii. Little access to systems and support services (e.g. health services)

Whilst factor i. is about living in places at risk, such as the floodplain, factors ii to v relate to people who are socially deprived and factors vi to viii focus on people who are disempowered. The CCRA made use of this framework[29], extending it to cover droughts. It also found additional factors, which were important, such as gender and social class for flood risks (Walker and Burningham, 2011, Jonkman, 2003, Burningham *et al*., 2008) and gender and age for heatwaves (Vassello *et al*., 1995).

Measuring and mapping social vulnerability is an ongoing research question in the UK (see e.g. Lindley *et al.*, 2011) and across Europe[30]. One approach has been to use the Index of Multiple Deprivation (IMD) as a "good enough" indicator of a broad range of factors contributing to deprivation (e.g. Walker *et al.*, 2006). The CCRA flood sector analyses used the IMD to identify the number of vulnerable people at significant risk from flooding in England and Wales.

Figure 2.2 shows a map of this indicator for the UK and shows areas of higher deprivation in urban centres, coastal areas and areas that have experienced economic decline in the past.

The CCRA explored existing evidence on current social vulnerability and came up with a number of conclusions on social vulnerability to climate change, which are presented in Annex B and discussed in Chapter 9.

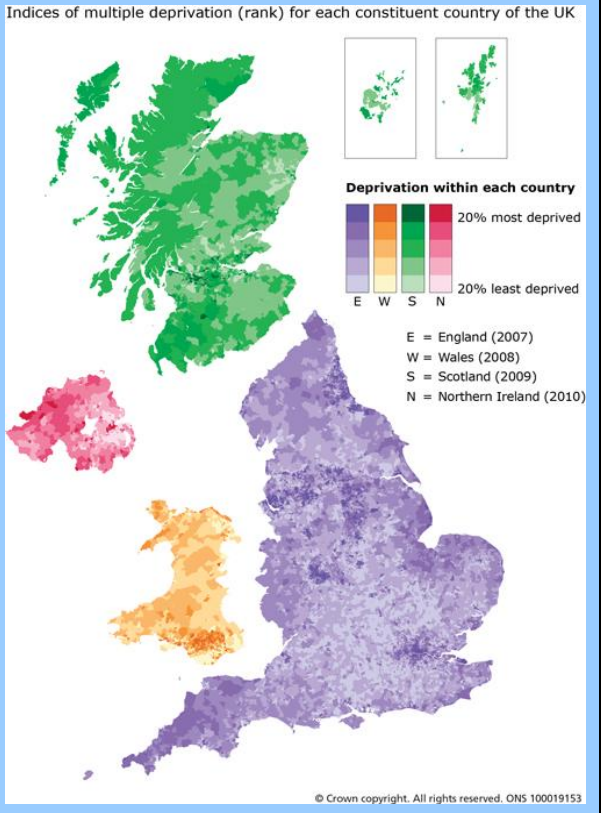


Figure 2.2 Indices of multiple deprivation in the UK with the most deprived areas in darker colours
(Source: ONS)

[29] Annex B provides a detailed review of the evidence of social vulnerability in relation to these three areas. The research reviewed is almost wholly that which has been carried out before, during or after examples of these extreme events. There are few studies looking prospectively at who might be impacted as a result of climate change, but within the review the recent Joseph Rowntree Foundation "Social justice and climate change" projects are included, which do have that perspective.

[30] For example, ongoing research on the EC Mediation project - http://mediation-project.eu/case-studies/northern-europe-vulnerability-of-the-elderly-to-climate-change-in-the-nordic-region

Assessment of future risks

Box 2.2 Key Components of the CCRA for assessing future risks

There were essentially three key components to the risk assessment, namely:

- The development of functions to describe the climate sensitivity of individual consequences (referred to as response functions);
- The use of these functions in conjunction with climate projections to estimate the change in risk relative to the present day baseline; and
- The scaling of these 'response' projections to take account of how they may be influenced by future changes in socio-economic conditions and any autonomous or planned adaptation.

These components of the assessment were considered individually and collectively, so that the relative contribution of each of the following could be clearly identified:

- The underlying sensitivity of the risk,
- The projected change in the relevant climate variable; and
- The socio-economic influence.

The CCRA method has focused on understanding the sensitivity of selected risks to current and future climate and which, collectively, make up the 'risk landscape'. In both the process of identifying the risks and developing response functions, consideration was given to identifying aspects of the risk landscape that were particularly vulnerable and so likely to be susceptible to, or unable to cope with, adverse effects of climate change. In many instances, this depends not only on the sensitivity of the particular risk (i.e. how quickly the consequence changes in response to a change in some climate variable) but also whether the consequence is likely to be pushed beyond some critical threshold, or whether the relevant system has some inherent capacity to adapt.

The advantages of the CCRA method are that:

- It is relatively simple to understand;
- The analysis can be done with the data and knowledge currently available; and
- It allows a clear presentation of relative risk that may arise as a result of climate change.

However, the 'reductionist' nature of the method also carries some disadvantages:

- There is limited analysis of the interaction with other non-climate drivers of change; and
- The approach has a limited ability to capture complexity, non-linearity and systemic risks.

Where relevant these issues are highlighted in the text. Overall this approach means that the influence of climate is explored in detail but the influence of social, political and economic changes is less well developed. Future CCRA cycles are expected to improve this aspect of the risk assessment.

2.3 Working with future projections and uncertainty

One of the most significant challenges for climate change risk assessments is dealing with the considerable uncertainty in climate change projections, future social and economic changes and the models used to estimate the potential risks to people, the economy and the environment. This section provides some further background on these issues and how they were dealt with as part of the assessment.

2.3.1 Climate and socio-economic scenarios

Key Terms

Emissions scenarios - A plausible representation of the future development of emissions of substances (e.g. greenhouse gases and aerosols that can influence global climate). These representations are based on a coherent and internally consistent set of assumptions about determining factors (such as demographic and socio-economic development, technological change) and their key relationships. The emissions scenarios used in UKCP09 do not include the effects of planned mitigation policies, but do assume different pathways of technological and economic growth which include a switch from fossil fuels to renewable sources of energy (Murphy *et al.*, 2009).

Climate scenario – A coherent and internally-consistent description of the change in climate by a certain time in the future, using a specific modelling technique and under specific assumptions about the growth of greenhouse gas and other emissions and about other factors that may influence climate in the future (UKCIP, 2003).

Socio-economic scenario – Scenarios concerning future conditions in terms of population, Gross Domestic Product and other socio-economic factors relevant to understanding the implications of climate change (IPCC 2007a).

Climate projections – UKCP09 provides probabilistic projections of climate change based on quantification of the known sources of uncertainty (Murphy *et al.*, 2009). In this report the term 'projections' is used to refer to a range of outcomes according to UKCP09 for a specific emissions scenario (Box 2.3). If specific values are extracted from UKCP09 for an emissions scenario, time period and probability level, then these may also be referred to as scenarios, using the above definition. It should be noted that the CCRA did not assign probabilities to any outcomes – the probabilistic projections of UKCP09 were used to provide a range of scenarios but without likelihoods being attached.

Lower, central and upper estimates – are used in scorecards to show the variability of the potential risks. These represent the range of climate scenarios considered.

The *central estimate* is always based on the p50 probability level for Medium emissions scenario.

The *upper and lower estimates* depend on the emissions scenarios considered for the particular time period. Typically, the *lower estimate* is based on the p10 estimate for Low emissions scenario and the *upper estimate* is based on the p90 probability level for the High emissions scenario. This is explained in more detail in Box 2.4.

Box 2.3 Climate scenarios used in the CCRA method

The CCRA made use of UKCP09, including the underlying RCMs[31], the probabilistic projections[32] and, in a small number of cases, the Weather Generator[33]. Further details describing UKCP09 are included in Annex A and can be found on the UKCP09 projections web site, which provides an updated Science Report and further guidance. The following climate scenarios were used when the probabilistic projections were considered in the assessment:

- 2020s: **p10 Medium, p50 Medium, p90 Medium**;
- 2050s: **p10 Low**, p50 Low, **p50 Medium**, p50 High, **p90 High**; and
- 2080s: **p10 Low**, p50 Low, **p50 Medium**, p50 High, **p90 High**.

These changes in climate were used to define a plausible range of outcomes for each time period **and were not used as probabilities** (Box 2.4). Instead, the scenarios in **bold** were used to define the 'UKCP09 range.' The naming convention above is used in Chapter 3 on the biophysical impacts of climate change but thereafter they are referred to as Lower, Central and Upper estimates for describing the potential risks for UK society.

When the RCMs or Weather Generator outputs were considered a similar approach was taken that aimed to capture a reasonable range of possible changes in climate. Full details of the methods used are included in individual sector reports and some further information on UKCP09 is provided in Annex A. The choice of climate model was one factor that affected the level of confidence assigned to each individual risk metric (Box 2.5).

The UKCP09 range considered does not cover the full possible range of climate changes, but provides a consistent framework for this assessment. When these are combined with socio-economic changes the range of uncertainty increases significantly.

2.3.2 Uncertainty, confidence and likelihood

Key Terms

Uncertainty – The degree to which an outcome cannot be precisely known, for example due to natural variability, limitations of models and the fact that the future cannot be known.

Confidence – The degree to which the findings of the assessment are considered valid, based on the type, amount, quality, and consistency of evidence, as well as the degree of agreement on the evidence.

Likelihood – The chance of an event or outcome occurring, usually expressed as a probability. We cannot associate likelihood with specific changes in climate risks, therefore likelihood is not used in this assessment. Instead we consider potential risks for a wide range of plausible scenarios.

The assessment of risk from climate change is limited in two ways:

- There is a limit to our knowledge of important atmospheric and bio-physical processes and the potential consequences of climate change, and there are limits to the data available to undertake any analysis.
- Even when the data and knowledge are available the results are not certain as we can not predict future emissions or natural variations in climate (however, understanding the level and nature of uncertainty attached to the results can provide useful information for decision makers (Ranger *et al.*, 2010)).

[31] http://ukclimateprojections.defra.gov.uk/content/view/999/500/
[32] http://ukclimateprojections.defra.gov.uk/content/view/857/500/
[33] http://ukclimateprojections.defra.gov.uk/content/view/858/500/

An additional complication is that uncertainty means different things in different contexts. In everyday language it implies doubt and ambiguity. However, in climate change research it has a very specific meaning. For example, there are three sources of uncertainty that are considered in the UK Climate Projections Report: UKCP09:

- Natural climate variability
- Uncertainty in the climate models
- Uncertainty in rates of future emissions.

There are a number of additional uncertainties which then relate to assessment of risk from climate change and its impacts, including:

- Uncertainty related to current risks – particularly for extreme events, the estimation of which is already subject to considerable uncertainty;
- Uncertainty in impacts models – including deductive models, statistical relationships and our use of 'response functions' to scale previous study outputs; this is particularly the case where statistical relationships or even conceptual models are extrapolated beyond the range of historic climate;
- Uncertainty in social and economic changes – population growth, sector GDP etc. as captured in project population forecasts and other futures work; particularly land use change for which there are no long-term forecasts or scenarios;
- Uncertainty related to planned and autonomous adaptation - i.e. what assumptions we make in our analysis;
- Uncertainty related to monetisation of consequences; and
- Uncertainty related to unidentified risks, or the collective impact of interacting risks.

Uncertainty within the context of this study is therefore a term used to reflect the fact that we are unsure whether certain states or outcomes will occur.

In previous Intergovernmental Panel of Climate Change (IPCC) assessments, the term *likelihood* was used to describe quantified uncertainty (e.g. *very unlikely:* <10% probability; *about as likely as not:* 33-66% probability; and *very likely:* >90% probability). However, in most cases within the assessment, such quantitative definitions were not possible, simply because the underlying probabilities could not be defined. The validity of the findings has, therefore, been assessed using an alternative approach, which is based on the type, amount, quality, and consistency of evidence, as well as the degree of agreement on the evidence, which is similar to updated methods, which are now being used by the IPCC (Mastrandea *et al.*, 2010)[34].

[34] Judgements on the level of agreement in the evidence were made by the project team, based on peer reviewed literature and other evidence, for example from workshops and Government reports. This project started before the IPCC work was published.

Box 2.4 Using The UKCP09 range to inform the development of plausible future scenarios

The UK Climate Projections (UKCP09) provided probabilistic projections of climate change over the land surface, for three emissions scenarios. By considering observed data and a range of different climate models, the outputs estimate the probabilities of changes in climate being more or less than specific thresholds. This approach provides useful information for detailed risk assessment studies. In the original UKCP09 report, key findings on climate change for each emission scenario were presented in terms of specific probability levels, namely the 10% 50% and 90% probability levels[35] (termed p10, p50 and p90 in this study). The CCRA has, however, only used the projections simply to define a plausible range of changes of climate, which we call the 'UKCP09 range'. It has not presented key findings in probabilistic terms in the same way as UKCP09. It also only considered the Medium Emission scenario for the 2020s as the rates of warming are very similar to the Low and High emissions scenarios for this time period. All three emissions scenarios were considered for the 2050s and 2080s. The lowest, central and highest changes for each time period were used to define a range of possible changes as outlined in Figure 2.3.

Figure 2.3 Use of UKCP09 to defined a range of possible changes in climate variables

	Low Emissions			Medium Emissions			High Emissions		
	p10	p50	p90	p10	p50	p90	p10	p50	p90
2020s				L	C & X	U			
Range				←Range→					
2050s	L x	X	x	X	C & X	x	x	X	x U
Range	←			Range				→	
2080s	L x	X	x	x	C & X	x	x	X	x U
Range	←			Range				→	

Key

L – Lower estimate of change for specific time period

U – Upper estimate of change

C – Central estimate (all scenarios)

X – Central estimate for specific emissions scenario to enable comparison of emissions

x – Other scenarios considered to understand spread of outputs for a specific emissions scenario

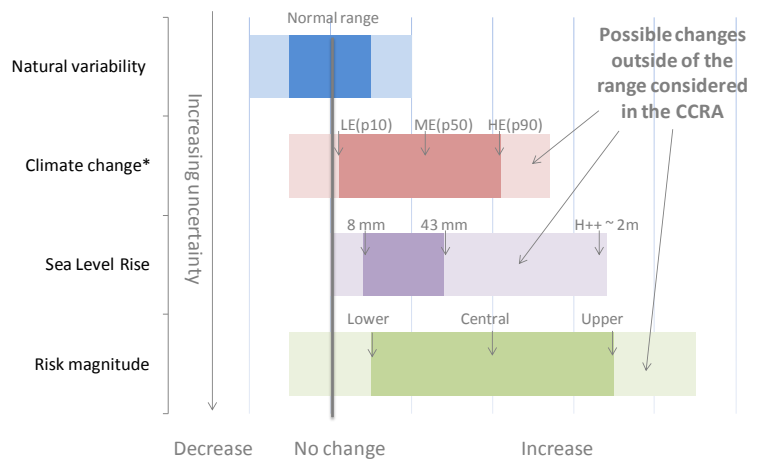
The probabilities presented in UKCP09 cannot be translated into the probability related to specific risks for a number of reasons, including:

- The probabilities of different emissions pathways and important social and economic changes that affect risk are unknown; and
- The probabilities related to different levels of adaptation are unknown and have not been fully explored in this assessment.

For risks that are affected directly by socio-economic factors, such as population growth, the lower rates of climate change were combined with lower population growth estimates and the higher rates of change with the highest population estimates to provide lower and upper estimates of risk magnitude. The uncertainty range increases at each stage of the assessment so that the final 'CCRA range' provides a wide spread of possible outcomes. It is still possible that changes may be outside of this range as illustrated in Figure 2.4.

[35] http://ukclimateprojections.defra.gov.uk/content/view/593/690/
For example, if a projected temperature change of +4.5°C is associated with the 90% at a particular location in the 2080s for the UKCP09 Medium Emission scenario, this should be interpreted as it is projected that there is a 90% likelihood that temperatures at that location will be equal to or less than 4.5°C warmer than temperatures in the 1961–1990 baseline period. Conversely, there is a 10% likelihood that those temperatures will be greater than 4.5°C warmer than the baseline period.

Figure 2.4 The range of outcomes presented in the CCRA and increase in uncertainty range (2080s)



* The UKCP09 changes in annual average temperature are generally positive but for some variables the UKCP09 range may cover negative to positive changes. Therefore the CCRA range of risks may also go from a decrease to an increase. For this reason it is important that the full range of outcomes is considered and not just the central results.

The CCRA completed some sensitivity testing for the H++ sea level rise scenario but the headline results were based on lower rates of sea level rise.

The CCRA used a scoring concept, which was developed to express both the strength and level of peer acceptance of the evidence. The purpose of scoring was to record and carry through information on the 'weight of evidence' associated with climate risks. Hence throughout this report, where there is credible evidence, confidence is expressed across a range from 'very low' to 'very high' as summarised in Box 2.5. However, no potential risks that were defined as 'very low' made it through the risk selection stage so these were effectively filtered out of the assessment as it moved from a Tier 1 list of 700 risks to the Tier 2 list of 100 risks. Similarly, the few potential risks that were regarded as 'very high', were downgraded to 'high' during the study as the limitations of the available data and methods became evident. In many such cases improvements to approaches aimed at increasing our confidence in risk assessments have been recorded as part of the project to inform future risk assessment and other research studies.

Box 2.5 Levels of confidence used in the CCRA method

The different levels of confidence used by the CCRA can be broadly summarised as follows:

0. Very low - Non-expert opinion, unsubstantiated workshop discussion with no supporting evidence.
1. Low - Expert view based on limited information, e.g. anecdotal evidence, or very simplistic estimation methods using single climate variables and based on historical data.
2. Medium - Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector. This typically includes risk analyses where the methods are strong but the UKCP09 science may be less reliable, for example on summer precipitation.
3. High - Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'. This includes analytical methods that have made full use of UKCP09 including RCM data, such as our estimates of changes in flood frequency, and analysis of potential risks that are very strongly linked with increases in temperature.
4. Very high - Comprehensive evidence using best practice and published in peer reviewed literature; accepted as the best approach for national assessment. While some risk assessment methods fall into this category, e.g. the National Flood Risk Assessment (NaFRA) in England and Wales, confidence is reduced when coupled with climate and socio-economic projections. As such no potential risks were assessed as ‘very high’ confidence but this may be achievable for future assessments.

The confidence scoring is associated with potential risks, the estimated direction of change and order of magnitude[36].

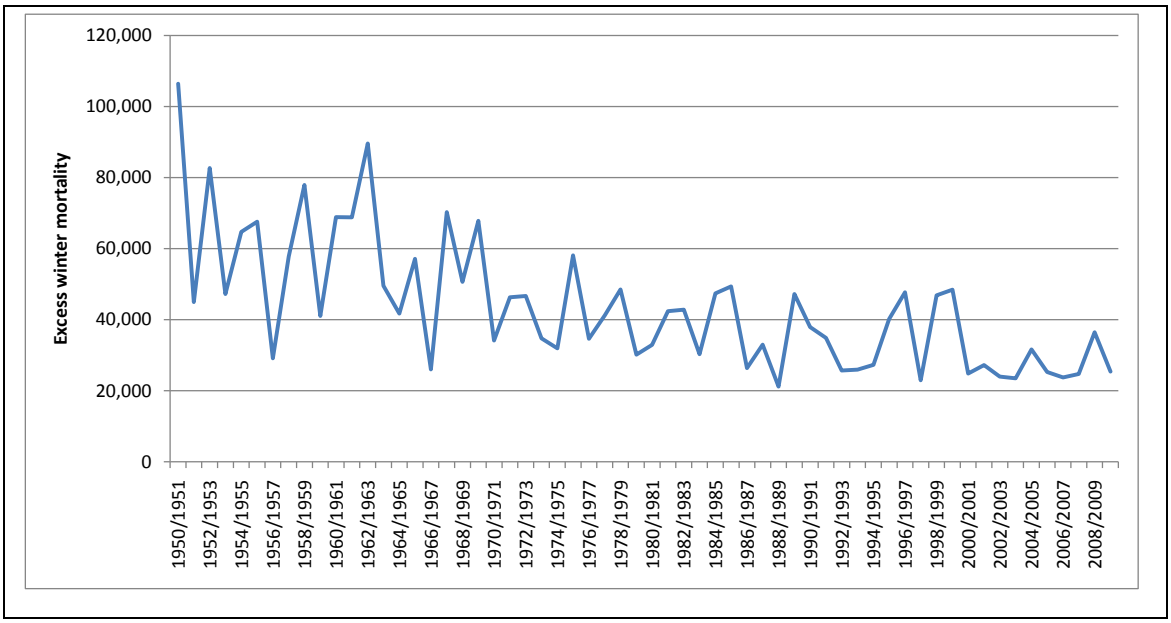
2.3.3 Including socio-economic changes in the CCRA

The nature of risks, vulnerability and adaptive capacity all change over time in response to both climate and socio-economic drivers. From an historical perspective it is clear that social and economic trends can have a far greater influence than natural climate variability on many risks. Improvements in services (health, water, energy, etc.), advances in technology and good regulation may reduce risks. Increased population size, uncontrolled development and social changes may mean greater exposure to hazards, increases in vulnerability and greater pressure on the natural environment. Increasing wealth will always inflate damage and disruption costs and it is essential to disaggregate these effects to understand the relative influence of climate and socio-economic change.

The CCRA did not include analysis of past trends for all risk metrics but socio-economic influences are clear in many cases. For example, excess winter mortality, which includes a range of illnesses as well as cold weather effects, has declined significantly over the last 50 years (Figure 2.5). UK agriculture has become more resilient to drought and also much better at managing crop pests and diseases, which has contributed to increasing yields (Chapter 4). Similarly, the reliability of public water supplies has improved considerably since privatisation in England and major investment has improved water quality in rivers and bathing beaches.

[36] By following our quantitative methodology, some estimates are reported using relatively precise values for lower, central and upper values. This should not be mistaken for accuracy or high confidence in the exact numbers reported.

Figure 2.5 Decline in excess winter mortality in England and Wales



Source: ONS, 2011 – available from ONS http://www.statistics.gov.uk/statbase/ssdataset.asp?vlnk=7090

Other risks appear to have increased over similar time periods, for example insured losses from weather disasters has risen in Europe over the last few decades (Munich Re, 2008). These headline figures include factors such as a greater population, higher GDP and increased development along vulnerable European coastlines, as well natural climate variability. There is some evidence that risks have increased even when these data are normalised for key socio-economic changes. It is also evident that absolute risks have increased due to social and economic factors, such as increased wealth in parts of Europe, in the same way that hurricane risks on the US eastern seaboard increased substantially as the coastline was developed.

Socio-economic drivers in the CCRA

The CCRA used a standard set of population projections across all sectors and these were particularly important for floods, water supply and demand, health, built environment and energy assessments where the number of people and properties has a significant influence on future risks. In order to capture the wide range of uncertainty in future population, three projection variants were used (Low Population, Principal and High Population) which were derived from the Office of National Statistics "*2008-based National Population Projections*" (Table 2.1). These variants combine high and low assumptions in the main demographic components of change. Three time horizons (2025, 2055 and 2085) were selected to correspond with the central year of key 30 year UKCP09 time periods (2010-2039, 2040-2069 and 2070-2099). A baseline year of 2008 was used in the regional calculations (Table 2.1).

The principal population projection provides the baseline for future growth and indicates a rise in UK population to 69 million in the 2020s, 78 million in the 2050s and 86 million in the 2080s. Population projections typically focus on the next 25 years and there is less confidence in the longer term projections. Recent mid year estimates show that the UK population is increasing with the population getting older (currently 16% of the UK population is over 65 years of age), broadly in line with the ONS Principal Projection. A larger population overall may place greater pressure on the environment, in terms of land use and consumption of natural resources, and greater pressure on health, water, energy, transport and waste services to meet higher demands.

The CCRA incorporated the affects of climate change and population change in a series of steps that enables an understanding of the relative importance of different drivers (Box 2.6). Full details of individual analyses are provided in the sector reports.

Table 2.1 Population projections based on ONS data aggregated for UKCP09 administrative regions and interpolated to years centred on UKCP09 2020s, 2050s, 2080s time periods

		Population in millions								
		Low population			Principal projection			High population		
UKCP09 Region	2008	2020s	2050s	2080s	**2020s**	**2050s**	**2080s**	2020s	2050s	2080s
East Midlands	4.4	4.8	5.0	4.8	**5.1**	**5.9**	**6.7**	5.3	6.9	8.9
East of England	5.7	6.3	6.6	6.3	**6.7**	**8.0**	**9.2**	7.1	9.6	12.6
London	7.7	8.3	8.6	8.3	**8.8**	**10.2**	**11.6**	9.2	12.0	15.3
North East	2.6	2.7	2.7	2.7	**2.8**	**3.0**	**3.2**	2.8	3.3	3.9
North West	6.9	7.1	7.2	7.1	**7.3**	**7.9**	**8.4**	7.5	8.5	9.8
South East	8.4	9.1	9.4	9.0	**9.5**	**11.1**	**12.5**	10.0	12.9	16.5
South West	5.2	5.7	5.9	5.7	**6.0**	**7.0**	**7.9**	6.3	8.2	10.6
West Midlands	5.4	5.7	5.8	5.7	**5.9**	**6.6**	**7.2**	6.1	7.3	8.8
Yorkshire & Humber	5.2	5.7	5.9	5.7	**6.0**	**7.0**	**7.9**	6.3	8.2	10.5
Wales	3.0	3.1	2.9	2.6	**3.2**	**3.5**	**3.7**	3.4	4.1	5.0
Eastern Scotland	2.4	2.4	1.8	1.1	**2.6**	**2.7**	**2.7**	2.9	3.6	4.4
Northern Scotland	0.3	0.3	0.2	0.1	**0.3**	**0.3**	**0.3**	0.3	0.4	0.5
Western Scotland	2.5	2.5	2.5	2.4	**2.5**	**2.6**	**2.5**	2.6	2.7	2.8
Northern Ireland	1.8	1.8	1.6	1.1	**2.0**	**2.1**	**2.0**	2.1	2.6	3.1
Total	*61.4*	*65.6*	*66.1*	*62.5*	***68.6***	***77.9***	***86.0***	*71.8*	*90.4*	*112.7*

Data Sources: Office of National Statistics. 2009. 2008-based National Population Projections. Published online at http://www.statistics.gov.uk/downloads/theme_population/NPP2008/NatPopProj2008.pdf
Office of National Statistics. 2010. Sub national Population Projections (SNPP) for England. Published online at http://www.statistics.gov.uk/statbase/product.asp?vlnk=997
General Register Office for Scotland. 2010. 2008-based Population Projections for Scottish Areas. Published online at http://www.gro-scotland.gov.uk/statistics/publications-and-data/popproj/2008-based-pop-proj-scottish-areas/index.html

Box 2.6 Combining climate change effects with socio-economic changes

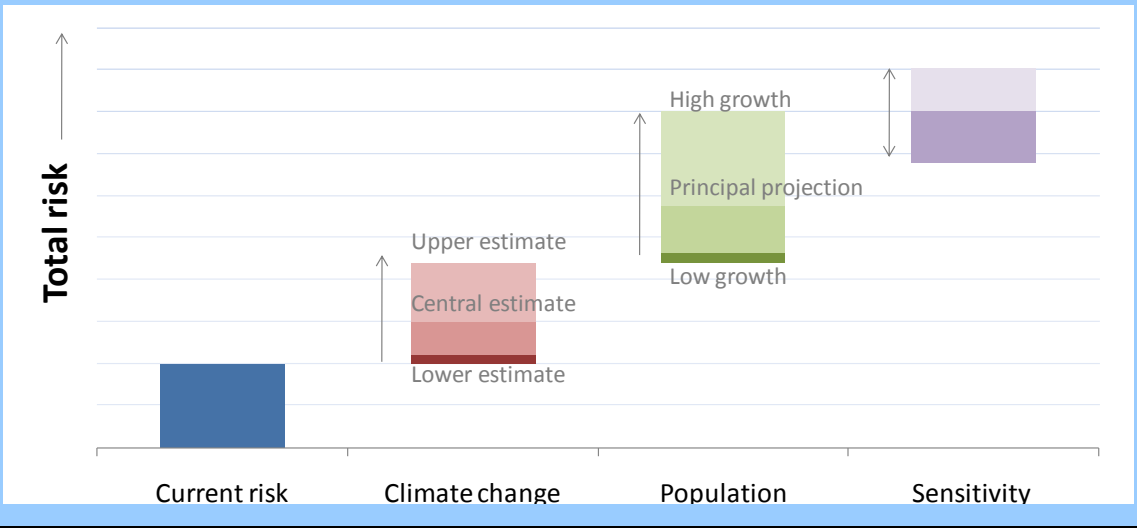
Some of the potential risks considered in this assessment have been linked solely to changes in climate but most develop due to the combined effects of climate change and socio-economic changes. For potential risks that are quantified in this assessment the results were built up in stages by:

1. Considering the current risks, due to the natural variability of climate, social vulnerability and existing risk management measures;
2. Adding the effect of climate change, typically based on UKCP09, to estimate a lower, central and upper estimate of the potential risk;
3. Adding the influence of population growth as this may increase the numbers of people exposed to hazards, such as flooding, or increase the demands for goods and services, such as water and energy; and
4. Completing sensitivity analysis on any important assumptions made or particularly sensitive parameters in any impacts modelling.

When comparing risks in 'scorecards' and 'onset plots' we show the climate sensitivity of potential risks because these results are available for all risks considered in this assessment. However, we also report the total climate risks with population within each of the themed chapters (Chapters 3 to 8). This is similar to the concept of 'total climate risk' used in the insurance industry (ECA, 2009). The more detailed sensitivity analyses are included in the relevant sector reports.

An example of the build up of results in shown in Figure 2.6 below. In this example climate change (combined with natural variability) increases risk but in some cases potential risks may be reduced or go up or down depending on the scenarios considered. Population growth typically increases risk and in some cases the growth in population may be an equal or even greater contributor to risk than climate change. Sensitivity analysis generally increases and decreases risk estimates and in a few cases assumptions made have a significant affect on the findings. The ongoing Economics of Climate Resilience study will go further by considering how the total risks can be reduced by cost effective adaptation measures.

Figure 2.6 The build up of results starting with current risks, then adding climate and population changes



Longer term socio-economic futures

Projections of population and socio-economic trends are ideal for considering risks in the short and medium term (to 2050s) but are less helpful for longer term assessment. This is because the population is just one of many social and economic factors that

may influence risks in the long term and other drivers can not be quantified in the same way as population. As an alternative approach the sector assessments considered a number of other dimensions, providing some qualitative discussion on how these may affect future risks (Box 2.7).

Box 2.7 Dimensions of change affecting longer term climate change risks for the 2080s

Population needs/demands (high/low) - This dimension is intended to encapsulate drivers of population size and distribution (geographically and demographically) and the pressure the population forces onto the country in terms of housing, education etc. One extreme is that there is a high degree of demand on natural, economic and social resources (demand exceeds supply and more people are exposed to risk); the other is that demand is very low (supply exceeds demand and people are less exposed to risk).

Global stability (high/low) - This dimension describes drivers based on world events that would increase or decrease global stability (e.g. war, natural disasters, economic instability). The extremes are higher global stability (with little pressure on Governments and people) compared to today, and lower global stability (with a high degree of pressure on Governments and people that outweigh other priorities) compared to today.

Distribution of wealth (even/uneven) - This dimension considers the distribution of wealth amongst the British population; the extremes being whether it is more even compared to today, or more uneven (with a strong gradient between the rich and poor) compared to today.

Consumer driven values and wealth (sustainable/unsustainable) - Globalisation and consumerism are the primary drivers here, specifically movement towards or away from consumerism values. The extremes are that consumers prioritise their time for working and the generation of wealth, with a focus on the consumption of material market goods and services compared to today; and consumers reduce the importance of work and wealth generation in favour of leisure and less materialism, with a focus on the consumption of non-market goods and services such as conservation and recreational activities in green spaces.

Level of Government decision making (local/national) - This relates to how centralised policy- making is on adaptation; the extremes being whether there is a completely centralised policy compared to today; or whether there is a very small central Government input and high degree of localism in decision making compared to today.

Land use change/management (high/low Government input) - These dimensions relate to aspects of urbanisation versus rural development. The extremes are that looser planning restrictions might increase development in rural areas (building on the green belt, power stations, etc.) compared to today, versus tighter planning which might increase urban development (more brown field sites) compared to today.

For each detailed risk, the relevance of each socio-economic dimension and the effects of the extremes of each dimension were briefly discussed in each sector report.

2.4 Purpose and structure of this report

This report draws together and interprets the evidence gathered by the CCRA regarding current and future threats (and opportunities) for the UK posed by the impacts of climate up to the year 2100. The report is intended to help policy-makers and others understand the nature of the risks, their relative magnitude and timing, the strength of evidence related to potential risks and other issues that influence the overall risk landscape for the UK. Government will then use this report, along with other studies, to produce an overview that will form part of the CCRA Act Report.

Further details of each chapter are given overleaf.

Chapter 3 Biophysical impacts

This chapter describes the main biophysical impacts of projected climate change, such as changes to flooding, erosion, drying and nutrient cycling and also the impacts of higher levels of atmospheric CO_2, such as stimulation of photosynthesis, increased plant water use efficiency and ocean acidification. These direct impacts influence many different sectors and are presented collectively to highlight their importance and to avoid repetition in later chapters of the report.

Chapter 4 Agriculture and forestry

This chapter discusses current and projected climate risks (and opportunities) for UK agriculture and forestry, including crop and livestock production and yield, damage (pests and diseases, fires, flooding, etc.), water demand and availability, heat stress.

Chapter 5 Business

This chapter discusses current and projected climate risks (and opportunities) for UK businesses, including financial and insurance markets, disruption to utilities and infrastructure required by businesses, supply chains (including international trade) and productivity losses (due to overheating, flooding, etc.).

Chapter 6 Health and wellbeing

This chapter discusses current and projected climate risks (and opportunities) for the health and wellbeing of the UK's population, including mortality and morbidity due to heat and cold, flooding, ozone, UV exposure, outdoor recreation, travel and working comfort and overseas aid.

Chapter 7 Buildings and infrastructure

This chapter discusses current and projected climate risks (and opportunities) for UK buildings and infrastructure (namely energy, transport, water and information and communications technology (ICT)), including damage from flooding, subsidence and landslides, overheating and the urban heat island effect, effectiveness of green space and cultural heritage.

Chapter 8 Natural environment

This chapter discusses current and projected climate risks (and opportunities) for the natural environment of the UK, including terrestrial, freshwater and marine environments. This includes issues such as species migration, pests, diseases, invasive non-native species, soil organic carbon, habitat damage (from erosion, fires, flooding, etc.) and river and sea water quality.

Chapter 9 Evaluation and conclusions

This chapter discusses the main risks (and opportunities) to the UK as a result of current climate and projected climate change and gives some consideration to the multiple dimensions of risk. This leads on to the conclusions for the study as a whole; key findings for each of the themes having been provided in the previous Summary of Findings.

Appendices

Appendix 1 provides a summary of the method used for the assessment;

Appendix 2 provides tables to explain the attribution of magnitude and urgency;

Appendix 3 provides some further background on systematic mapping;

Appendix 4 tabulates the full list of approximately 700 risks identified (Tier 1 list);

Appendix 5 tabulates the risks that have been analysed in more detail as part of this first CCRA (Tier 2 list) and provides links to the relevant sections in this report; and

Appendix 6 provides a glossary of standard terms used in the CCRA.

Annexes

Annex A is a Met Office paper on UKCP09 and its use in the CCRA; and

Annex B provides a review of the current evidence on social vulnerability to climate change impacts (Twigger-Ross and Orr, 2011).

Summary plots and tables

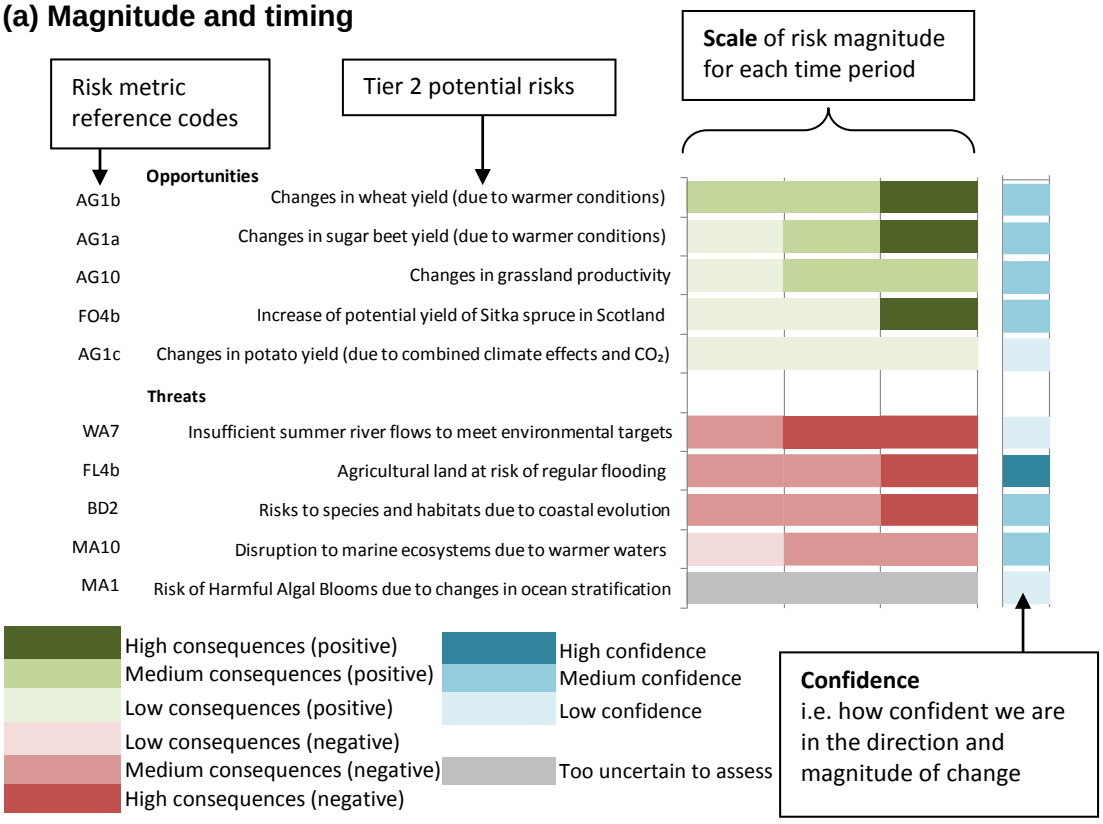
At the beginning of chapters 4 to 8 there is a figure that summarises the potential risks that are relevant to the theme. A more detailed summary is provided at the end of each of these chapters in the form of a scorecard. Examples of these summaries are provided in Figure 2.7.

- In the timing figure (a) the risks are ordered into opportunities and threats, ranked from high to low magnitude. The shading of the bar denotes how the magnitude of the central estimate for medium emissions varies over time. Confidence scores for each risk are also given, indicating the level of confidence in whether the consequence will occur.
- The scorecard (b) lists the risks in order of confidence and presents the lower, central and upper risk estimates for all three time periods in terms of three magnitude classes 1: Low; 2: Medium and 3: High. The lower, central and upper estimates summarise the full range of results based on the UKCP09 projections (see Box 2.3). The basis for this classification is explained in more detail in Chapter 9 and Appendix 2.

The scoring used in these figures and tables is based on climate change alone to allow comparison between all potential risks. Within each themed chapter, the effects of climate and socio-economic changes are considered in more detail.

Figure 2.7 Examples of the plots and scorecards used to summarise risks

(a) Magnitude and timing



(b) Scorecards

Risk metric reference codes

Confidence i.e. how confident we are in the direction and magnitude of change

Time interval and risk estimate (lower, central and upper)

Metric code	Potential risks for the natural environment	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
AG10	Changes in grassland productivity	M	1	1	1	1	2	2	1	2	2
FO4b	Increase of potential yield of Sitka spruce in Scotland	M	1	1	1	1	1	1	3	3	3
AG1c	Changes in potato yield (due to combined climate effects and CO_2)	L	1	1	2	1	1	2	1	1	2
WA7	Insufficient summer river flows to meet environmental targets	L	1	2	3	2	3	3	3	3	3
FL4b	Agricultural land at risk of regular flooding	H	2	2	2	2	2	3	2	3	3
BD2	Risks to species and habitats due to coastal evolution	M	1	2	2	2	2	2	2	3	3
MA10	Disruption to marine ecosystems due to warmer waters	M	~	1	~	~	2	~	~	2	~
MA1	Risk of Harmful Algal Blooms due to changes in ocean stratification	L	Too uncertain								

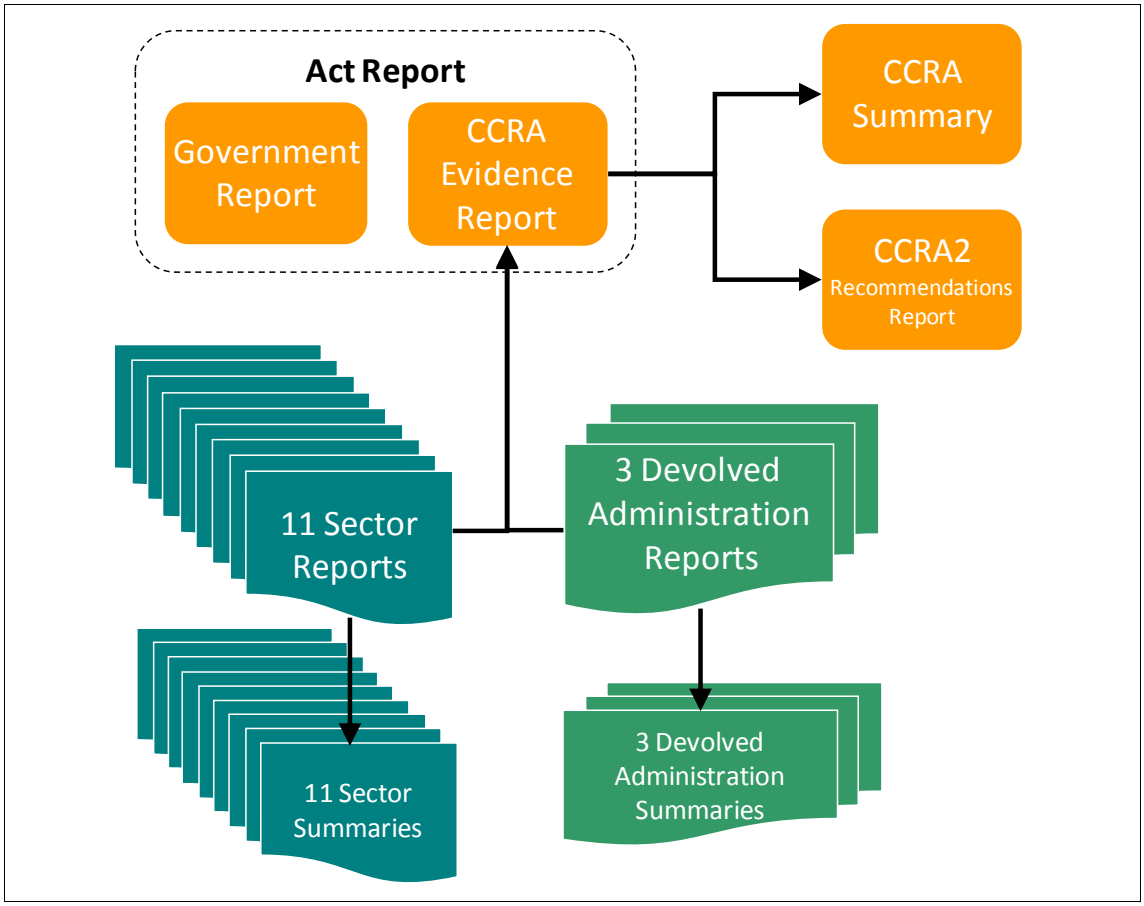
M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

Magnitude using the three classes (3 – high, 2 – medium, 1 – low). Economic, environmental or social thresholds can be used depending on the nature of the metric

2.5 Other CCRA related reports

This report presents the evidence of current and future climate change risks for the UK as a whole to 2100. This is supported by detailed assessments in each of the eleven sectors and a number of additional components that summarise findings for different audiences (Figure 2.8).

Figure 2.8 CCRA reporting structure



Sector Reports –The sector reports document the assessment of risks for each of 11 sectors, and these are cited throughout this report. Their purpose is to provide the more detailed data and information that underpins this assessment.

Sector Summaries – Key findings from each Sector Report are summarised for senior UK Government and international policy-makers.

Devolved Administration Reports – Following on from the UK-wide assessment, assessments were undertaken for Northern Ireland, Scotland and Wales in consultation with stakeholders. These reports present the outputs from the UK-wide assessment from the perspective of each country, supplemented with local case studies.

Devolved Administration Summaries – Key findings for each Devolved Administration are summarised for policy-makers.

CCRA Summary – Key findings from the CCRA are summarised for policy-makers.

CCRA2 Recommendations Report – A report describing the gaps in knowledge and lessons learned during the first CCRA.

Government Report – Using the CCRA Evidence Report as the underpinning evidence, along with the output from other ongoing studies, this report presents the main CCRA findings in the context of current policies and future plans for the development of the National Adaptation Programme.

CCRA Act Report – The CCRA Evidence Report and the Government Report together form the report to be laid before parliament as required by the Climate Change Act 2008.

3 Biophysical Impacts

Changes in climate are expected to have a range of direct impacts on biological and physical processes in the natural and human environment. This chapter describes these impacts on the UK, focusing on processes in the natural environment, such as changes in river flows, which have consequences for the full range of themes and sectors covered in this assessment. Understanding these potential impacts is an important step for the assessment of climate change risks. Impacts such as changes in heating and cooling, the timing of seasons, river flooding, the drying of soils and the magnitude of erosion and cycling of nutrients are relevant to a wide range of consequences described in Chapter 4.

3.1 Background

Changes in climate are expected to have a range of direct impacts on biological and physical processes in the natural and human environment. Many of these processes involve interactions between the atmosphere and land or oceans and are captured at a broad scale in Global Climate Models (GCMs) and RCMs (Murphy *et al.*, 2009). However, it is not yet possible to represent all the details needed to describe a range of impacts so most assessments have used climate models, often with further downscaling methods (Jones *et al.*, 2009; Wilby & Fowler, 2011) to provide finer resolution inputs to national, regional, river basin or site and sector specific studies. This assessment was primarily based on evidence from models that represent specific processes (e.g. hydrological, coastal erosion, nutrient cycles), empirical analyses that have explored the sensitivity of specific consequences to climate and expert elicitation based on available climate change, impacts assessment and vulnerability research. Fully integrated impacts assessment models may be available for use in future UK risk assessments.

This chapter describes the major biophysical impacts of climate change on the UK. It focuses on processes in the natural environment that have consequences for the full range of themes and sectors covered in this assessment. Specifically, it considers the following two key areas that form the main sections of this chapter:

- Section 3.2 - Biophysical impacts on land and the freshwater environment. This section looks at the impacts of changing temperatures as well as changes in the seasonal balance of precipitation. Biophysical impacts in the human environment are touched upon, e.g. heating and cooling processes, but are covered more comprehensively in the Buildings and Infrastructure theme (Chapter 7).
- Section 3.4 – Biophysical impacts on the coastal and marine environment. This section looks specifically at sea level rise, coastal evolution, changes in ocean climate e.g. temperature, primary productivity and Arctic sea ice.

The evidence presented in this chapter is drawn from the UKCP09 Climate change projections report (Murphy *et al.*, 2009) and the UKCP09 Marine and coastal projections report (Lowe *et al.,* 2009), CCRA sector reports and other research projects. It provides the building blocks for evidence presented in Chapters 4 to 8 and

may also be relevant for ‘users’ of the CCRA that wish to consider the biophysical impacts for their own studies.

Further detail on the biophysical risks, with more information on how the magnitude of the risks vary under different scenarios is provided in the scorecard at the end of the section, Table 3.11.

3.2 Biophysical impacts on land and the freshwater environment

3.2.1 Measuring direct impacts of rising temperatures

Warmer conditions will have a direct impact on a wide range of biological and physical processes on land and the freshwater environment. In addition, the direct heating and cooling of land surfaces, buildings and roads has a wide range of consequences for the built environment and transport sectors, including urban heat island effects, overheating of buildings and damage to transport infrastructure.

There are several derived climate indices that provide a means of quantifying these impacts based on observed data and the outputs of climate models including:

- **Air frost days (AFD)** – the total number of days per year when the minimum daily surface air temperature is below 0°C. This can be used to assess climate suitability, and can also affect the spread and prevalence of pests and diseases.
- **Cooling degree days (CDD)** – a measure of the frequency and extent to which days have a mean temperature above 22°C and so will require some form of cooling (e.g. air conditioning) to be used (Jenkins *et al.,* 2009a). The number of degrees Celsius that the mean temperature is above 22°C is calculated for every day of the year and summed. This indicator can be used to estimate the energy required to cool buildings (Chapter 7).
- **Heating degree days (HDD)** – a measure of the frequency and extent to which days have a mean temperature below 15.5°C and so will require some form of heating to be used (Jenkins *et al.,* 2009a). The number of degrees Celsius that the mean temperature is below 15.5°C is calculated for every day of the year and summed. This indicator can be used to estimate the energy required to heat buildings (Chapter 7).
- **Growing degree days (GDD)** – a measure of heat accumulation which is calculated as the day-by-day sum of the mean number of degrees by which the air temperature is more than 5.5°C. It can be used to assess climate suitability, estimate growth stages in crops and predict crop maturity and so is of relevance to agriculture and forestry (Chapter 4), while it can also provide an indication of the timing of biological processes such as bud burst, and is therefore of relevance to the natural environment (Chapter 8).
- **Growing season length** – period bounded by daily mean temperature exceeding 5°C for more than five consecutive days, and daily mean temperature being less than 5°C for more than five consecutive days (after 1 July). This measure of growing season can also be impacted by other climate factors, e.g. water availability. It is of relevance to agriculture and forestry (Chapter 4), as well as the natural environment (Chapter 8).

- **Thermal humidity index (THI)** – this represents thermal discomfort and is calculated as a function of both air temperature and relative humidity. The index is of relevance to biodiversity and ecosystems (Chapter 8), as well as agriculture, where it has been used to assess consequences for livestock, including potential impacts on fertility and milk production in dairy herds (Chapter 4).

3.2.2 Impacts of future rises in temperature on selected climate indicators

Climate indicator	Relevance	Confidence
Heating and cooling degree days	Built environment, health	High

The heating degree days (HDD) for the baseline period (1961-1990), and the mean changes in HDD for the three future periods (2020s, 2050s and 2080s) are shown in Figure 3.1. The top row shows the absolute HDD for the baseline period and changes in HDD for the three future periods, and the bottom row illustrates the uncertainties i.e. the variation in the ensemble[37] mean. The figure shows that HDD for 1961-1990 range from 2,000 in southern England to 4,000 in Scotland. The climate projections suggest that the HDD will decrease during the 21st century as the climate warms. By the 2080s (right-hand column of Figure 3.1) the HDD over southern England are roughly 50% of the values for 1961-1990, and over Scotland they are about 30% smaller. Should this occur then energy demands for heating buildings could decrease (see Chapter 7). The uncertainty in the HDD decreases into the future, because the HDD values become smaller.

The cooling degree days (CDD) for the baseline period (1961-1990), and the mean changes in CDD for the three future periods (2020s, 2050s and 2080s) are shown in Figure 3.2 (top row), together with the variation in the ensemble mean (bottom row). These results show that CDD are projected to increase significantly during the twenty-first century, especially over southern England. For 1961-1990, the average CDD over southern England are simulated to be about 25 to 50, whereas by the 2080s they have increased by 125 to 175. The projected increase in CDD is reduced with increasing latitude, such that the increases over northern England and Scotland are much smaller (25 to 50). Should any increases in CDD occur then energy demands for cooling buildings could increase (see Chapter 7).

The ensemble mean variation in projected changes in CDD also increases during the 21st century, with the largest variations located where there are the largest increases in CDD. These results show that there is a greater spread (indicating higher uncertainty) in modelled CDD than HDD. Analyses of surface daily maximum and minimum temperatures over the UK (Jenkins *et al.*, 2009a) indicate that minimum temperatures are rising at a faster rate than maximum temperatures. There is also a greater spread in projected minimum temperatures from the 11-RCM data than in maximum temperatures. The CDD are more sensitive than the HDD to changes in minimum temperatures; hence the relative uncertainty in future CDD may be greater than the uncertainty in HDD.

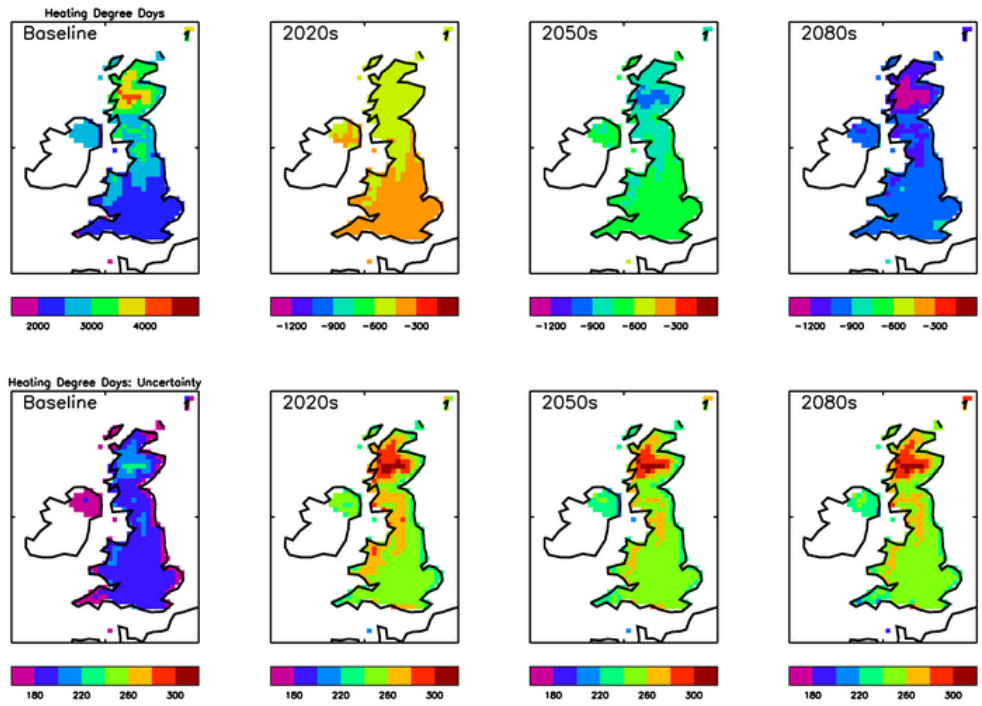
Both HDD and CDD can be estimated using the UKCP09 Weather Generator as well as data directly from the Met Office's RCM[38].

[37] A set of simulations: http://ukclimateprojections.defra.gov.uk/content/view/553/690/
[38] Refer to the UKCP09 projections web pages: http://ukclimateprojections.defra.gov.uk/content/view/730/500/

Climate indicator	Relevance	Confidence
Growing degree days	Ecosystems, agriculture	High

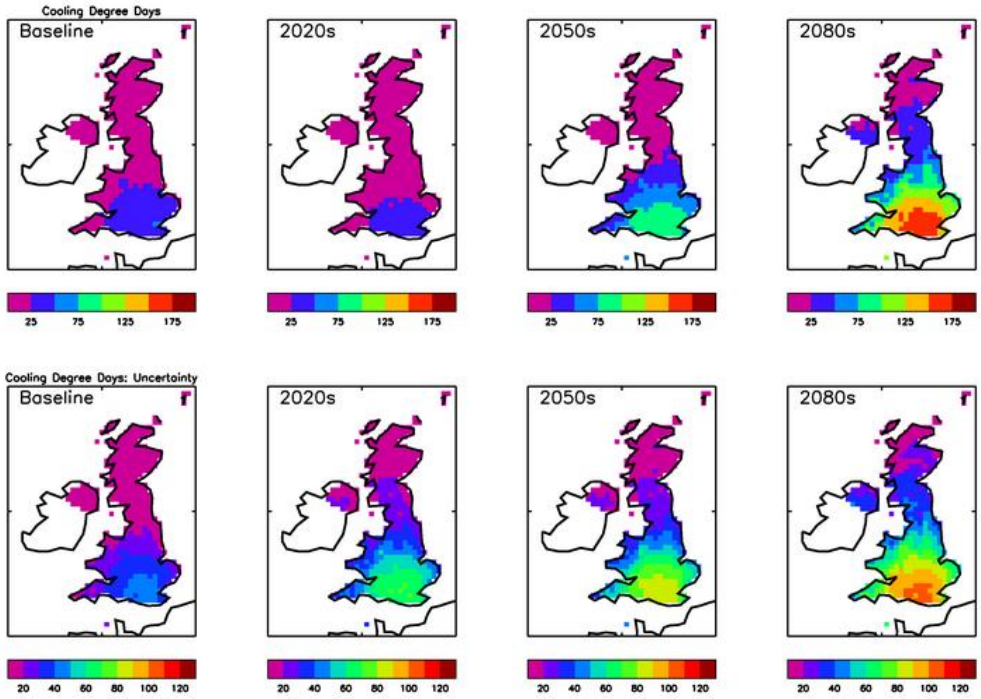
The modelled number of growing degree days (GDD) and projected changes are shown in Figure 3.3. For the baseline period (1961-1990), GDD range from a maximum of 900 in the south-eastern corner of England to less than 200 in Scotland and the patterns of GDD are similar to those of CDD (Figure 3.2). During the twenty-first century, GDD are projected to increase over the UK, mostly in southern England, and particularly over the coastal areas where the largest temperature increases are projected to occur. By the 2080s, GDD have increased by around 900 over southern England and by 400 over Scotland. An increase in GDD could provide opportunities for agriculture and forestry, e.g. the potential to grow new crops within the UK (see Chapter 4).

Figure 3.1 Heating Degree Days (HDD) from 11 member RCM climate projections
(Source: Met Office)



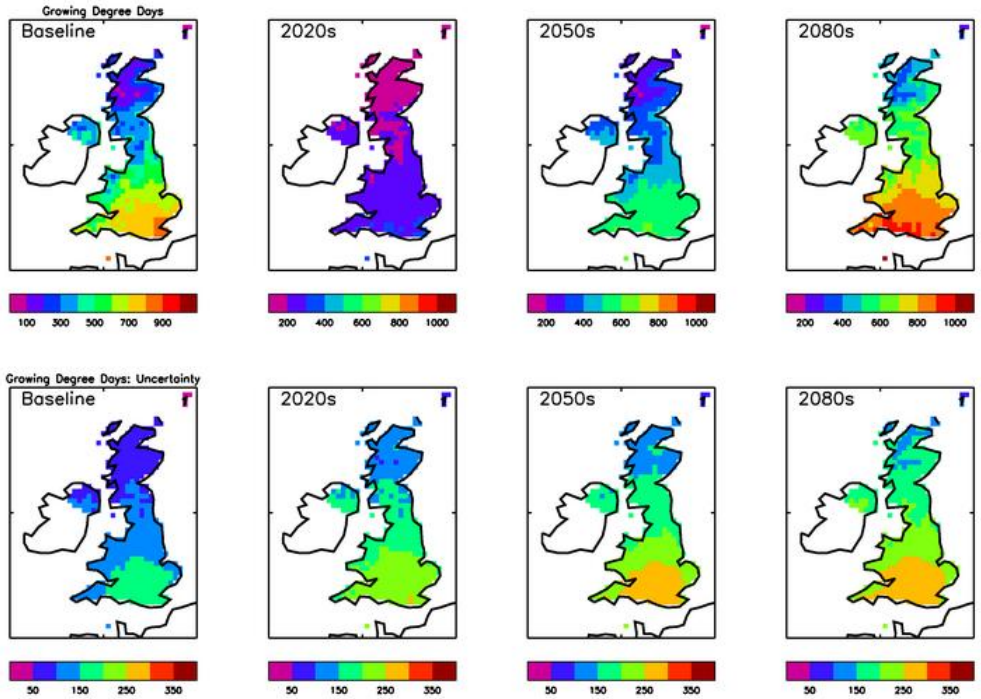
The baseline data (left-hand column) are the multi-model mean heating degree days over the period 1961 – 1990 (top row) and the variation between the models (bottom row). The next three columns show the projected changes in the plotted parameter from the multi-model mean (top row) and the uncertainty in those changes (bottom row) for the 2020s, 2050s and 2080s. The indicator is calculated over every year within a 30-year period and averaged over those 30 years.

Figure 3.2 Cooling degree days (CDD) from 11 member RCM climate projections
(Source: Met Office)



The baseline data (left-hand column) are the multi-model mean cooling degree days over the period 1961 – 1990 (top row) and the variation between the models (bottom row). The next three columns show the projected changes in the plotted parameter from the multi-model mean (top row) and the uncertainty in those changes (bottom row) for the 2020s, 2050s and 2080s. The indicator is calculated over every year within a 30-year period and averaged over those 30 years.

Figure 3.3 Growing degree days (GDD) from 11 member RCM climate projections
(Source: Met Office)



The baseline data (left-hand column) are the multi-model mean growing degree days over the period 1961 – 1990 (top row) and the variation between the models (bottom row). The next three columns show the projected changes in the plotted parameter from the multi-model mean (top row) and the uncertainty in those changes (bottom row) for the 2020s, 2050s and 2080s. The indicator is calculated over every year within a 30-year period and averaged over those 30 years.

Climate indicator	Relevance	Confidence
Thermal humidity index	Ecosystems, agriculture (livestock)	Medium

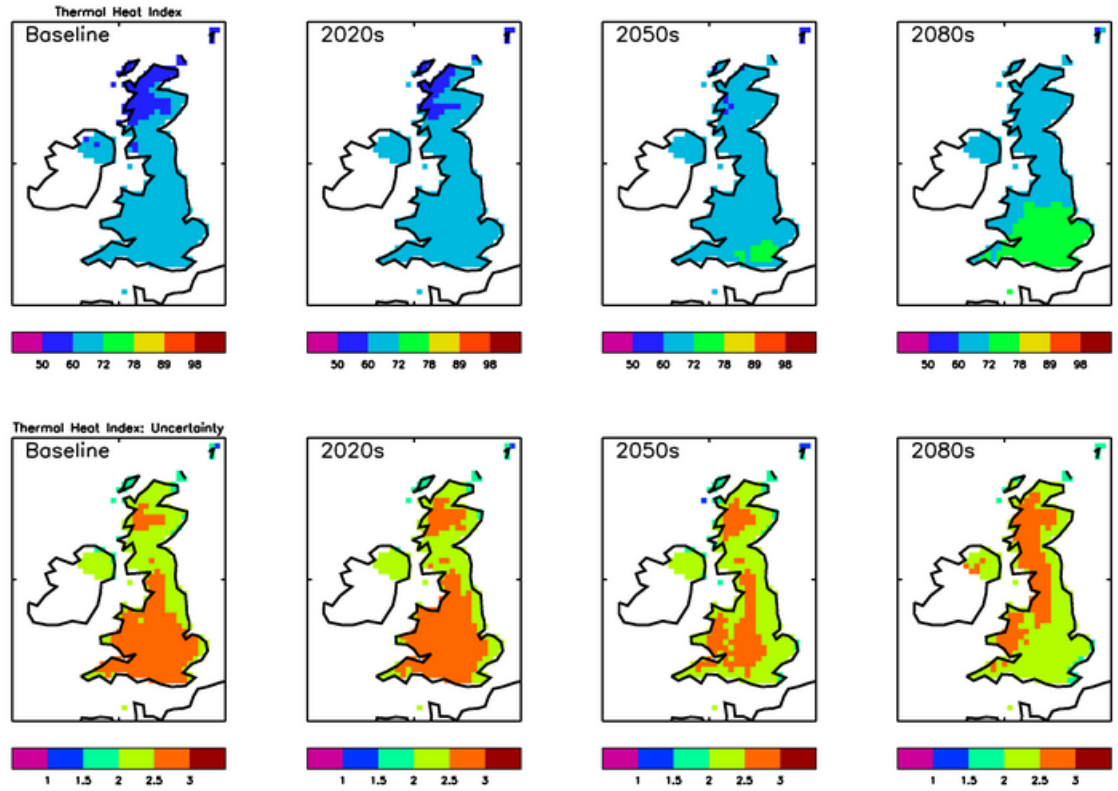
The thermal humidity index (THI) combines temperature with relative humidity in an index that describes thermal discomfort. The THI values associated with varying degrees of stress in cattle are shown in Table 3.1.

Table 3.1 THI ranges and impacts on cattle

THI range	Impact
< 72	No stress
72 - 78	Mild stress
78 - 89	Severe stress
89 - 98	Very severe stress
> 98	Death likely

The maximum monthly average THI values are shown in Figure 3.4. For the baseline period, the THI values lie between 60 and 72 over most of the UK, except for parts of northern Scotland where lower values between 50 and 60 are calculated. These values indicate that, on average, cattle should not experience any stress.

Figure 3.4 Monthly maximum thermal humidity index (THI) values
(Source: Met Office)



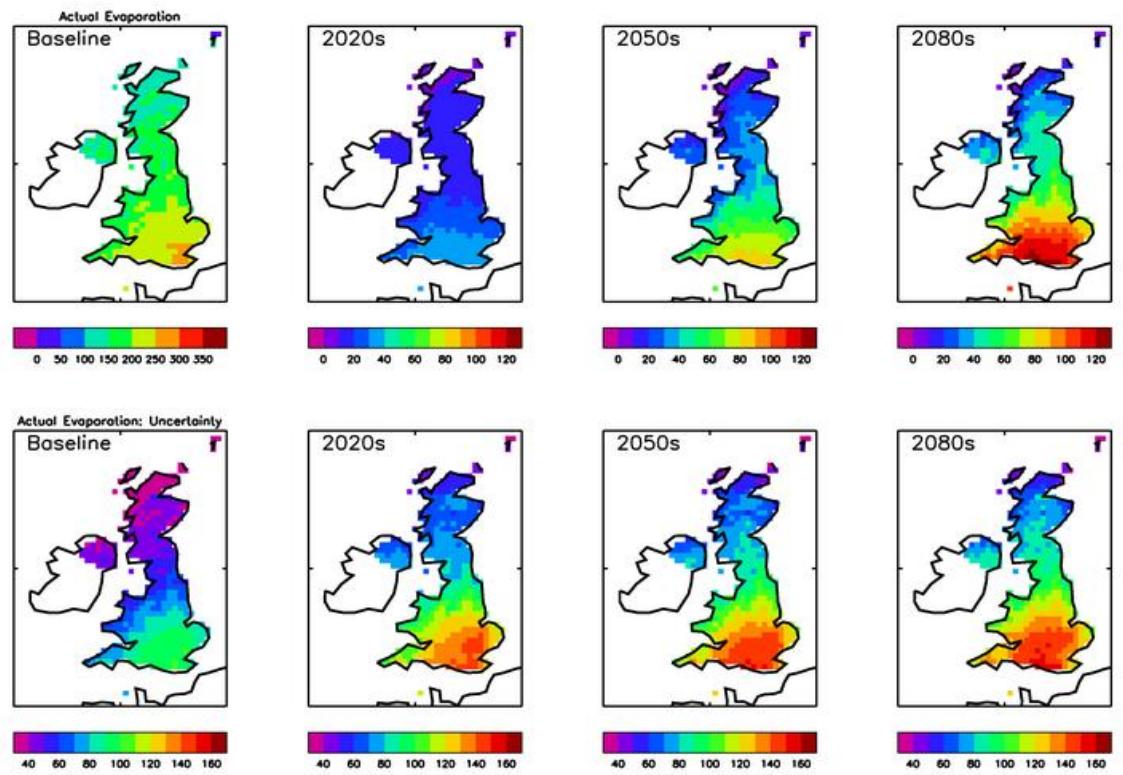
The baseline data (left-hand column) are the multi-model mean THI values (top) and the variation between the models (bottom). The next three columns show the projected values of the THI for the 2020s, 2050s and 2080s (top row) together with the variation between the models (bottom row). The indicator is calculated over every year within a 30-year period and averaged over those 30 years.

For the three future periods (2020s, 2050s and 2080s), the simulated THI values in the ensemble mean increase to between 60 and 72 over Scotland, Wales and the northern half of England, indicating no stress in cattle. Over southern England the THI values lie between 72 and 78 by the 2080s, indicating that cattle could experience mild stress during the summer period.

Climate indicator	Relevance	Confidence
Actual evaporation	Ecosystems, agriculture, water, floods, built environment	Medium

Figure 3.5 shows the model evaporation amounts for the baseline period (1961-1990) and the changes in evaporation in each of the three future periods (2020s, 2050s and 2080s) together with the uncertainties. These data show that the uncertainties in projections of evaporation are large. The multi-model mean changes indicate that the monthly maximum evaporation will increase, especially in southern England. However, the uncertainty in these changes is much larger than the change itself. Only the increase in evaporation over central southern England in the 2080s is significant.

Figure 3.5 Monthly maximum evaporation (mm per month)
(Source: Met Office)



The baseline data (left-hand column) are the multi-model mean monthly maximum evaporation in the period 1961 – 1990 (top) and the uncertainty (bottom). The next three columns show the projected changes in evaporation from the multi-model mean changes (top row) and the uncertainty in those changes (bottom row) for the 2020s, 2050s and 2080s.

3.2.3 Overview of biophysical impacts on ecosystem function

Warming conditions would affect biological processes, impacting on plants and animals and changing ecological community structure and composition. Such changes in the functioning of ecosystems would in turn affect the ecosystem services that can be

supported (see Chapter 8 for details). Direct impacts caused by changes in the physical environment are likely to include:

- **Physiological processes -** in plants, animals and other organisms, such as photosynthesis, respiration, metabolic rate and decomposition. In general terms, an increase in average temperatures increases the rate of these processes.
- **Phenology of flora and fauna -** i.e. the timing of periodic natural phenomena such as migration of birds, bud bursting, or flowering of plants. There is some evidence to suggest that 'phenological mismatches' are already occurring in Europe. Phenological mismatches can lead to declines in species abundance.
- **Geographical distribution of a given species -** the range of environmental conditions within which a species can survive may be considered to constitute that species' 'climate space'. The ability for a species to follow their climate space depends on whether there are barriers to its movement, if it is a 'good disperser' and if suitable habitat is available. If species are unable to move to a new location they may undergo *in situ* changes such as:
    - **Acclimation** - the process by which a species adjusts to slowly changing environmental conditions (e.g. evolving a thinner fur coat to increasing temperature).
    - **Behavioural change** - the alternative use of micro-habitats (e.g. burrowing deeper to cope with increasing temperatures).
    - **Phenotypic plasticity** - the ability of an organism to change its phenotype (i.e. its observable characteristics) in response to changes in the environment. An example of phenotypic plasticity in plants is the alteration of leaf size and thickness.
    - **Genetic adaptation** – certain individuals within a species may be more suited to survival and reproduction under the new conditions than others. Successful reproduction by these individuals will help aid the continued survival of their species as a whole. This is much more likely to occur in species that have large populations, short generation times and high genetic variability.

The evidence for changes in ecosystem function is summarised in Chapter 8 and discussed in detailed in the Biodiversity & Ecosystem Services Sector Report. Further consequences of changes in ecosystems for other sectors are described in the respective sector reports.

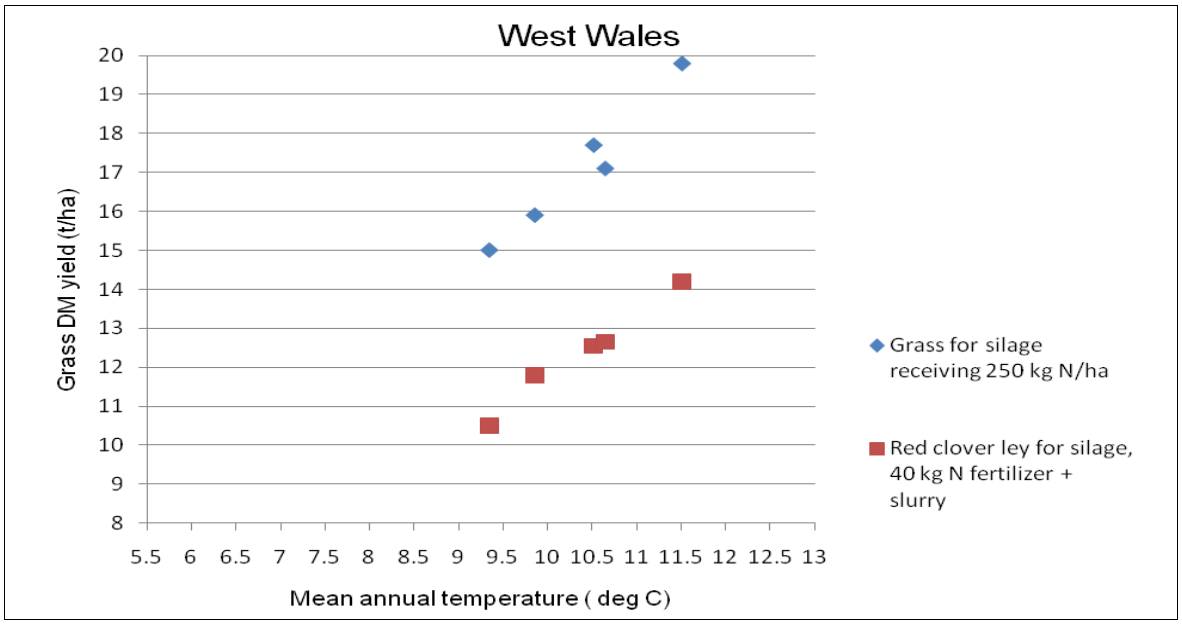
3.2.4 Primary production

Primary production is the production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis. In plants primary productivity is influenced by a number of climatic factors (e.g. levels of CO_2 in the atmosphere and changes in temperature, precipitation and solar radiation).

Optimum rates of primary production are expected to increase in temperate ecosystems with higher temperatures and increasing levels of atmospheric CO_2. However, water availability and soil nutrient supplies may limit production, even offsetting favourable conditions. Models of plant growth need to consider a complex mix of factors to estimate changes in production due to climate variability and change.

The influence of individual climate variables is evident in the results of experimental and modelling studies. Outputs based mainly on modelled outcomes used in Defra Project CC0359 (described by Topp and Doyle (2004)) were used to examine the impacts of higher temperatures and elevated carbon dioxide levels in four sites across the UK. Figure 3.6 shows the response for one site in lowland west Wales, an area which is representative of some of the most productive grassland in the UK. The grass and red clover yield increase linearly with an increase in mean annual temperature. This analysis is covered in more detail in Chapter 4.

Figure 3.6 Relationship between herbage yield metric based on observed and modelled projections, for high-N grass and low-input red clover swards under silage cutting, for lowland west Wales

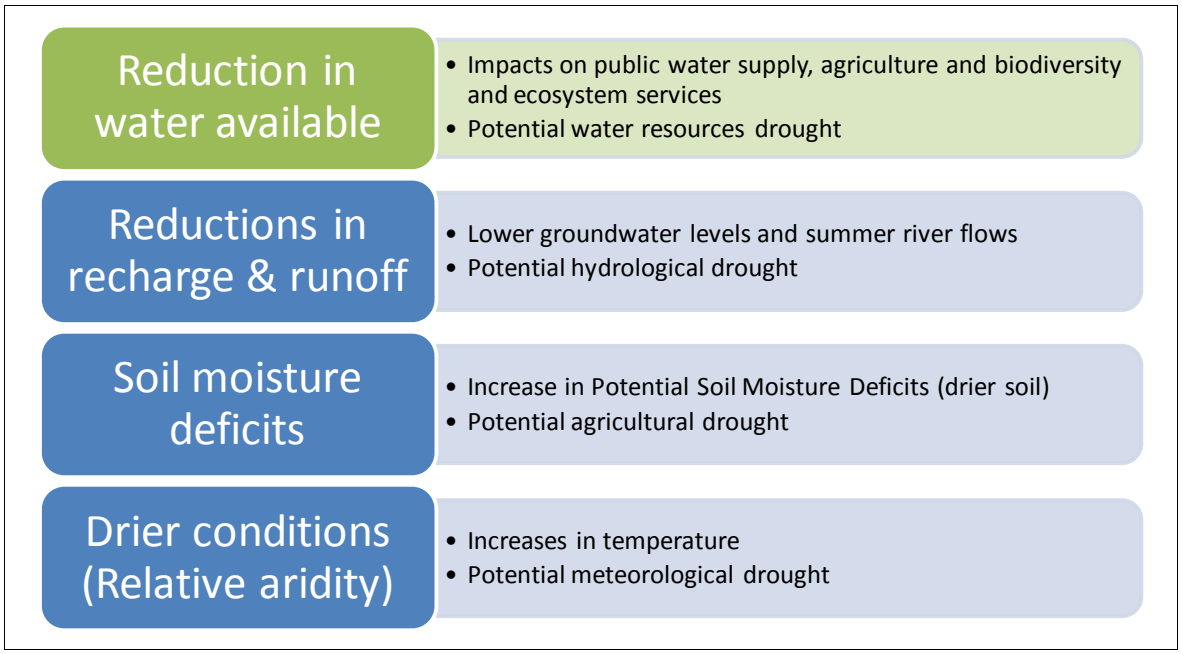


While the findings of studies show that generally grass growth benefits from an increase in spring and autumn temperatures together with higher CO_2 concentrations, in other studies, it is suggested that the benefits of increases in mean temperatures and lengthening of the growing season in Europe are likely to be counteracted by more frequent extreme drought events (Ciais *et al.*, 2005). The consequences of these biophysical impacts on the soil and plant growth are discussed in the context of agriculture and forestry in Chapter 4.

3.2.5 Relative aridity

Aridity describes how dry a climate is. Aridity indices typically combine annual precipitation and average temperature to classify climates according to their aridity. In a changing climate, warmer conditions combined with reductions in annual precipitation may shift parts of the UK towards more arid conditions. These changes would still see the UK classified as temperate, rather than a true semi-arid climate, but drier conditions are likely to have impacts on soils, groundwater recharge and river flows. Figure 3.7 shows the biophysical impacts and example potential consequences of drier (i.e. more arid) annual average climate conditions.

Figure 3.7 Related biophysical impacts (blue) and example potential consequences (green) of drier annual average climate conditions



As part of this assessment, a Relative Aridity Score (RAS) was developed as a measure of how warm and dry the climate is based on annual precipitation and temperature relative to the 1961-1990 climate. Previous research has shown that annual aridity indices corresponded well with major UK droughts (Marsh, 2004; Cole and Marsh, 2005).

As the RAS is a simple annual index it can be calculated based on UKCP09 (using the full set of sampled data for each emission scenario and time period) and also based on other modelling studies that use different climate scenarios. For climate change assessment, RASs provide information on future long-term (30-year periods) climate conditions rather than how variable the climate is from year to year. However, there are limitations associated with its use. For example, it does not consider the effects of changing seasonal patterns of rainfall that may have equal significance to the change in annual average conditions. Further details on the RAS and the assumptions and limitations associated with its use can be found in the Water Sector Report.

RASs were calculated using the UKCP09 changes in temperature and percentage changes in precipitation, for the 2020s, 2050s, and 2080s and for the Low, Medium and High emissions scenarios[39]. The results based on UKCP09 indicate that there may be more arid conditions in the future.

For the 2020s Medium emissions scenario, central estimate, most of the river basin regions have a relative aridity score indicating that conditions are 'more arid' than normal with respect to the 1961-1990 climate. In the 2050s this is the case for all the river basin regions and this is the time period where we may start to observe very different hydrological conditions to the 1961-1990 climate. In the 2080s, the majority of the river basin regions have a score indicating that conditions are 'extremely' warm and dry compared to the 1961-1990 climate[40].	Medium confidence

[39] For each UKCP09 river basin, each period and each emission scenario, 10,000 aridity scores were calculated.
[40] All calculations are **relative** to the river basin baseline climate – a higher RAS in the north than the south means the **relative** changes are higher and NOT that the north has become more arid than the south of the UK. Overall the results indicate generally warmer and drier conditions across the whole of the UK. While this is the case for the annual average

The changes are smaller, both in relative and absolute terms, in northern parts of Scotland. In the Anglian and Thames river basin regions, which are already two of the driest in the UK, the relative changes are not the largest but the absolute changes in aridity are most significant and flag potentially considerable changes to soil moisture balances and the basin scale water balance.

3.2.6 Potential soil moisture deficits

Changes in the hydrological cycle, including increasing aridity for average annual conditions, would affect the amount of moisture stored in soils. Soil moisture is directly influenced by two main climate variables, rainfall and 'reference evapotranspiration'. In the UK, soil moisture deficits tend to build up when potential evapotranspiration exceeds rainfall in early spring before peaking in summer and then declining once precipitation begins to exceed evapotranspiration during autumn and winter.

Plants need a supply of water from the soil in order to grow and sufficient moisture at key development stages to flourish, or reach optimum yields in the case of crops. For a range of different crops and climates, a strong relationship has been shown to exist between the need for irrigation and the potential soil moisture deficit (PSMD) (de Silva *et al.*, 2007; Rodríguez Díaz *et al.*, 2007; Knox *et al.*, 2010b) and has been widely used to quantify the irrigation needs in a number of countries.

As part of this assessment PSMD was calculated using a simple monthly water balance model which used UKCP09 data as an input. According to the long term average PSMD between 1961 and 1990, parts of Suffolk, Kent, the West Midlands, Nottinghamshire, and the south coast are where PSMDs, and subsequently irrigation needs, are greatest. For future UKCP09 projections it was found that:

In the 2020s soil moisture deficits are likely to increase by approximately 40 to 60mm (roughly 40% nationally) (Medium emissions scenario, p50) but the spread of results is very wide and this may decrease under the 'wet' (p10) scenario and increase significantly under the 'dry' (p90) scenario. In the 2050s soil moisture deficits increase in almost all scenarios and locations; the central estimates of change are significantly different from baseline conditions and while there is still a large spread of results the overall picture is of drier soil conditions. In the 2080s soil moisture deficits increase two to three times for the central estimates and present a picture of much drier soil conditions in almost all scenarios.	Medium confidence

The mapped outputs for the 2050s and 2080s, shown in Figure 3.8, suggest that generally areas of high maximum soil moisture deficit increase in size and magnitude, spreading across England from the south and east towards the north and west. Further details on how PSMD was calculated are given in the Agriculture Sector Report.

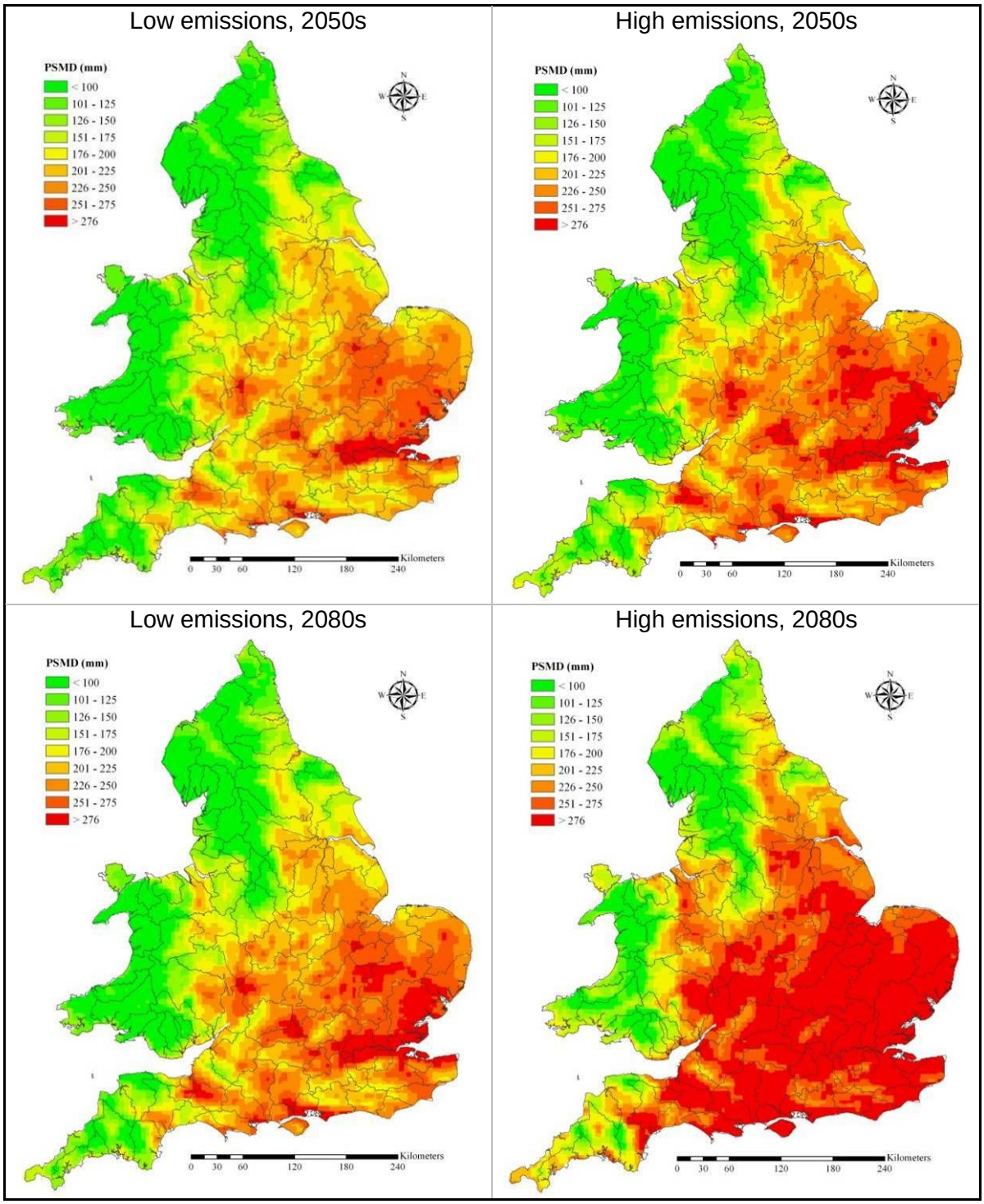
The consequences of high moisture deficits (i.e. drier soils) include:

- Lower levels of groundwater recharge and river flows at the basin scale;
- The potential drying out of valued habitats (e.g. wetlands and peatlands) (see Chapter 8);
- An increase in irrigation requirements of horticultural crops (Chapter 4);
- Changes to land suitability for both trees and crops (Chapter 4); and
- Subsidence of buildings in areas with clay soils (Chapter 7).

climate, seasonal changes mean that winters are likely to be warmer and wetter with the drier conditions in other seasons centred on the summer months.

Figure 3.8 Changes in agroclimate ($PSMD_{max}$) in England and Wales for selected UKCP09 emissions scenarios

(Source: Knox *et al.*, 2010b)



3.2.7 Fire

Both temperature and precipitation have a significant influence on the incidence of wildfires in areas of natural habitat. Hotter, drier weather conditions can increase the probability of wildfires occurring. Strong correlations have been shown to occur between periods of low rainfall and a higher incidence of outdoor fires (UK Climate

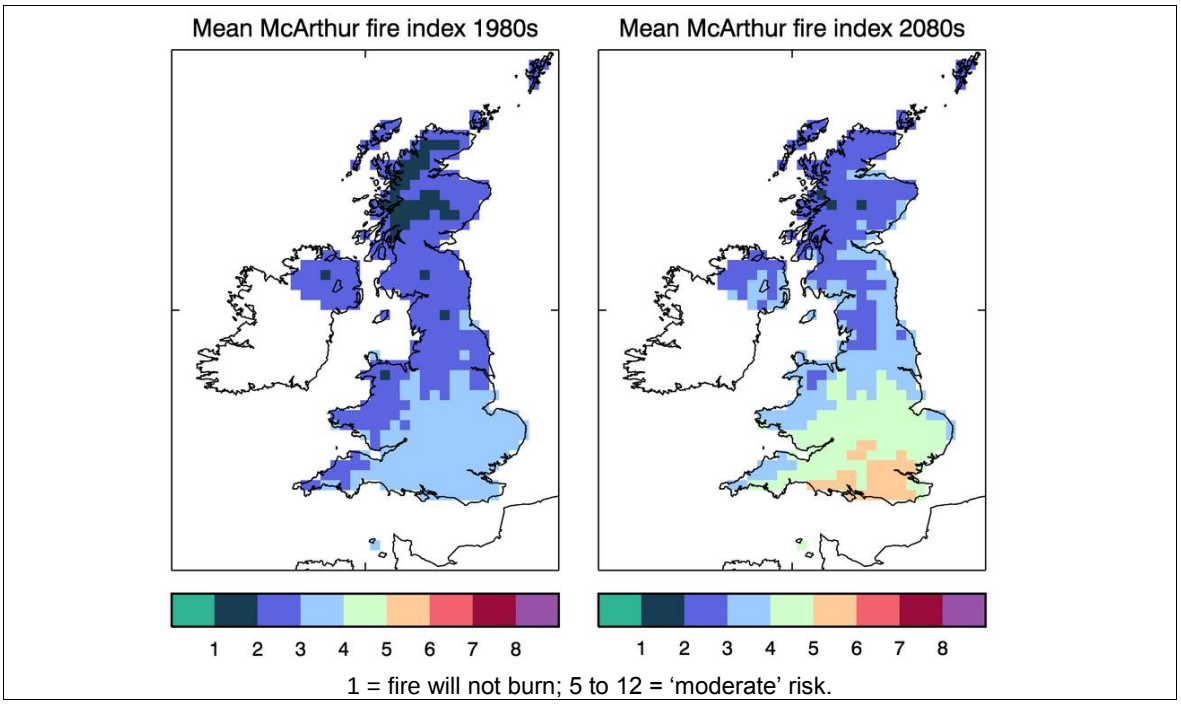
Change Indicator 16[41]) and between high summer temperatures and the frequency of fire (both wildfire and building fire) (Gazzard, 2010). These conditions are likely to occur more frequently with climate change.

Several established fire danger indices provide an opportunity for assessing the potential impact of climate change on the occurrence of wildfires. This assessment looked in more detail at the McArthur Forest Fire Danger Index (FFDI), which shows how the conditions that have the potential to lead to wildfire might change. It uses a number of variables including daily maximum temperature, daily mean wind speed and the number of days since last rainfall to consider a variety of characteristics within one index. The FFDI has recently been used to undertake preliminary modelling of the effects of climate change on fire danger in the UK based on the 11-member ensemble of RCMs. Figure 3.9 shows the outputs of this modelling. A value of 1 means that fire will not burn, while a value of 5 to 12 is considered a 'moderate' risk. Further information on the use of this index can be found in the Biodiversity and Ecosystem Services Sector Report.

Figure 3.9 shows that there is a suggested increase in the index across the whole of the UK by the 2080s. The increased risk of wildfires varies across the UK, with the largest increase (over 40 %) occurring in the south-east and extending into south Wales. The smallest increases in the index are along the north coast of Scotland.

Wildfire can have considerable consequences on biodiversity, affecting habitats and species, irreversibly damaging peat habitats and potentially resulting in the local extinction of species. Peat fires can also release substantial amounts of carbon into the atmosphere. Applying this index to UK national parks has provided an indication as to how fire might affect species and habitats under future climate projections (Chapter 4). Wildfires are also an issue for agriculture and forestry as well as the emergency services (Chapters 4 and 6). Additionally they can affect power lines and roads (as smoke can result in closures and heat intensity can damage road surfaces) and homes, businesses and tourism.

Figure 3.9 McArthur Forest Fire Danger Index for UK using UKCP09
(Source: Met Office)



[41] http://www.ecn.ac.uk/iccuk/indicators/16.htm

3.2.8 Low flows

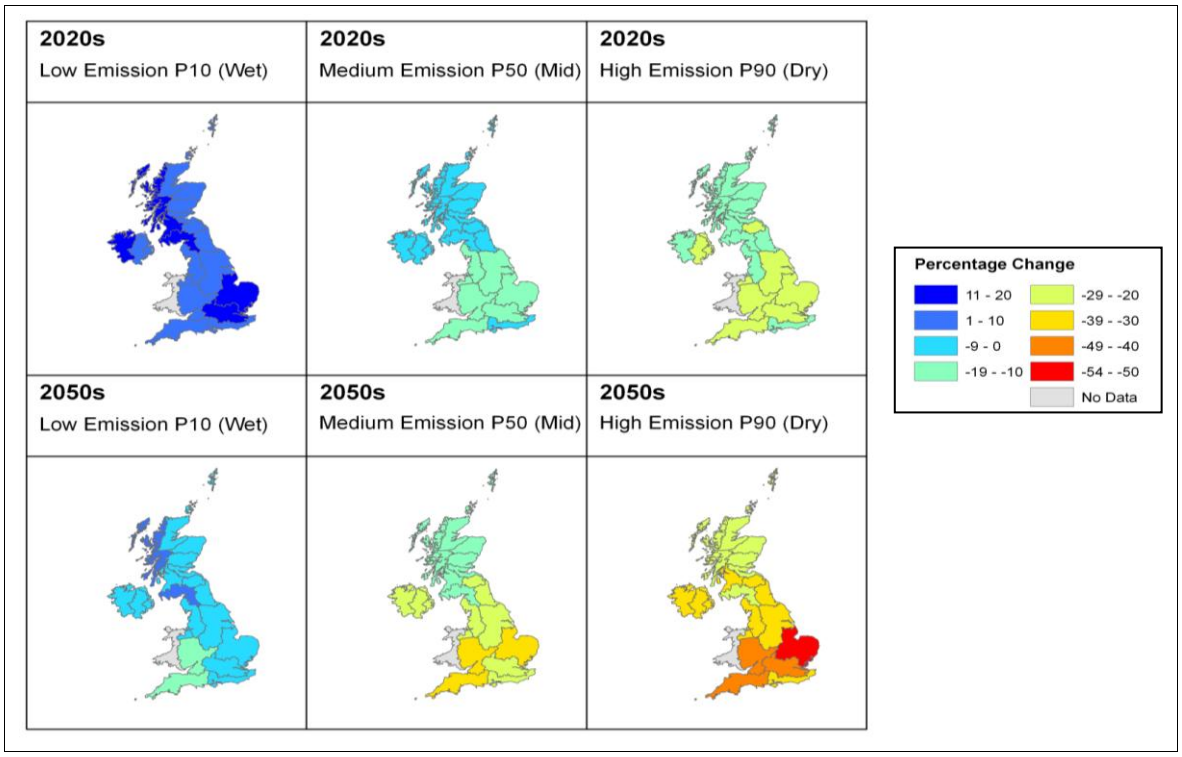
The effects of changing seasonal climate on river flows have been studied in detail over the last two decades (e.g. CCIRG, 1996; Arnell, 2004). These studies generally indicate higher winter flows and lower summer flows in the UK. As more climate models and downscaling approaches have developed, these studies have developed a much better understanding of uncertainties related to choice of climate model, downscaling approaches and hydrological modelling methods (Lopez *et al.*, 2009).

It is now clear that changes in seasonal precipitation and evapotranspiration are both important factors (Watts, 2010), along with river basin characteristics, such as the amount of river flow derived from baseflows or groundwater sources (Vidal and Wade, 2007). Recent work with UKCP09 indicates that statistically significant changes in summer flow may occur well before increases in average winter flow (Vidal *et al.,* 2011). Discussion of high flows can be found in Section 3.2.10.

Low flows, specifically the change in the low flow characteristic Q95, were assessed in this study. The Q95 is the flow that can be expected to be exceeded 95 out of every 100 days, and is the key flow within a watercourse's flow variation that is often recognised as being ecologically important. Existing evidence from work completed for the UK Water Industry was used to produce a 'response function' for percentage change in Q95 low flow in relation to relative aridity (UKWIR, 2009). The relationships are based on the average hydrological response of different catchments within each UKCP09 river basin region. The response function was then used to estimate Q95 low flow reductions for the full range of future periods and emissions scenarios. Further details can be found in the Water Sector Report.

Figure 3.10 shows the average percentage change in Q95 low flow by UKCP09 river basin region for the 2020s and the 2050s. It shows that all regions exhibit the same strong trend; from increases in Q95 low flow for the 2020s 'wetter' scenario to more extreme reductions for the 2050s 'more arid' scenario. These reductions are further exacerbated by the 2080s. The extent of the range of possible regional changes can be demonstrated by looking at the river basin regions with the highest (Anglian) and lowest (Orkney and Shetland) sensitivities, Tables 3.2 and 3.3.

Figure 3.10 Percentage change in Q95 low flow by UKCP09 river basin region with probability levels associated with UKCP09 average annual relative aridity



Overall, there is 'medium' confidence in this assessment for the 2020s but extrapolation of results to some of the more extreme scenarios is problematic and the confidence reduces to 'low' in the longer term. Further studies using outputs of the Met Office RCM are expected to report in late 2011.

Changing summer river flows may have a wide range of consequences including changing the water available for people, farming and the environment, the quality of river water (as there is less water to dilute any pollutants) and the ecological status of aquatic habitats (Chapters 4 to 8).

Table 3.2 Percentage change in Q95 low flow – Anglian UKCP09 river basin region

	Low emissions			Medium emissions			High emissions		
	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)
2020s	15	-12	-29	15	-13	-31	13	-13	-30
2050s	-7	-30	-46	-14	-35	-50	-19	-39	-54
2080s	-16	-38	-54	-29	-48	-63	-38	-56	-70

Table 3.3 Percentage change in Q95 low flow – Orkney and Shetland UKCP09 river basin region

	Low emissions			Medium emissions			High emissions		
	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)
2020s	7	-5	-14	7	-5	-14	7	-5	-14
2050s	-2	-13	-21	-4	-15	-22	-6	-17	-25
2080s	-5	-16	-24	-9	-20	-28	-13	-25	-33

3.2.9 Water temperatures and quality in rivers and lakes

It is expected that increases in air temperatures due to climate change would lead to a rise in water temperatures. The extent of warming, particularly of the entire water column, is highly dependent on a number of other factors too including flow velocity, evaporation rates and the depth of the water column. River water temperatures have been found to vary both with region and river type (catchment altitude, geology and size) with the former often having the stronger influence (Hammond and Pryce, 2007).

Water temperature influences a number of characteristics including the rate of bacteriological processes and chemical reactions that occur within rivers and lakes. Potential consequences of warmer water include:

- Exacerbation of existing problems such as eutrophication (see Box 3.1), for example through improving conditions for algal growth as well as reducing saturation levels for oxygen concentrations. The negative effects on water quality could affect ecosystem function.
- Changes in denitrification, which is highly dependent on temperature and can lead to increased rates of nitrate loss from rivers and lakes (Whitehead *et al.*, 2009). This could have positive consequences for water quality.
- Lake thermal stratification, with warmer surface layers of water potentially inducing stratification (Hammond and Pryce, 2007) and possibly affecting ecosystem function.
- Impacts on the growth rates of some species and certain behavioural aspects of aquatic organisms including the timing of emergence of insect populations and migration of fish, which are controlled or influenced by water temperatures (Whitehead *et al.*, 2009).
- Changes in the distribution of invasive non-native species where they are limited in their distribution by low temperatures, such as the zander, *Stizostedion lucroperca*; (Arnell, 1998).

Despite the links between air temperature and water temperature, this is a complex area of research that needs to consider hydrological and energy balance processes. In this assessment, there is high confidence that water temperatures will rise, but it is not possible to provide meaningful regional estimates of change without more detailed work. There are also many indirect impacts relating to changes in nutrient and hydrological cycles and changes in land and water management that may affect future water quality. The consequences due to the interactions of all these processes are discussed in Chapter 8.

Box 3.1 Eutrophication of Lough Neagh, Northern Ireland

Lough Neagh is the largest freshwater lake in the UK, covering an area of approximately 383 km² in the centre of Northern Ireland. It is extremely important for biodiversity, supporting and allowing a number of different rare or local species to flourish. For example, it is considered the most important non-estuarine site for wintering wildfowl in the UK (Allen and Mellon, 2006). Lough Neagh also supplies around 50% of NI Water's available treated water as well as supporting a number of recreational activities including fishing and water sports.

As the lough is shallow, it is sensitive to pollution and vulnerable to eutrophication. Eutrophication is defined by the EC Urban Waste Water Treatment (UWWT) Directive (91/271/EEC) as "the enrichment of water by nutrients, especially by compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable balance of organisms present in the water concerned". The resulting growth of plants such as algae can affect the transparency of water, as well as the levels of dissolved oxygen concentrations and pH, causing ecological disruption and potentially affecting habitats and species (EHS, 2008). This is not the only impact; a eutrophic watercourse can also have detrimental effects on the aesthetic appeal of water, and the increased growth of toxic blooms of blue-green algae can have serious implications for livestock and other animals as well as health and safety issues affecting recreational activities.

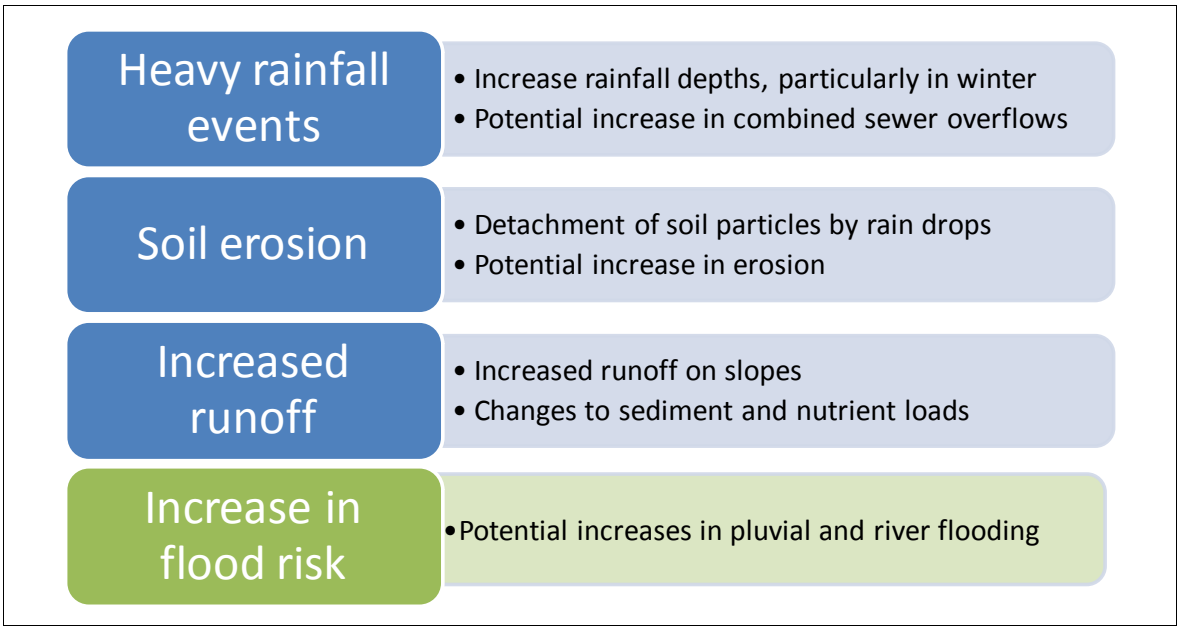
Eutrophication is considered to be the most widespread threat to good water quality in Northern Ireland (EHS, 2008). Lough Neagh is highly eutrophic (hyper-trophic) due to nutrients coming from both agricultural and urban sources. Efforts have been made to reduce the levels of nutrients in the lough, including the introduction of phosphate stripping at wastewater treatment works (WwTWs). However, the improvements to water quality have since been negated by the presence of agricultural runoff, and phosphorus concentrations have risen steadily since 1987. Over the last 150 years, the flora of the Lough has changed dramatically due to eutrophication. Algae growth has increased, leading to a reduction in light penetration to the depths of the lough which has contributed to a decline in once-abundant macrophytes (Allen and Mellon, 2006).

Being shallow, Lough Neagh may be particularly vulnerable to any changes in rainfall and temperature that might occur due to climate change. In loughs, a reduction in flushing due to low flows might increase residence times of pollutants, while increased temperatures can improve conditions for algal growth as well as reducing saturation levels for oxygen concentrations. This can particularly be an issue for shallow loughs. An increase in winter rainfall and the frequency of intense rainfall events may lead to an increase in nitrogen being leached from the surrounding agricultural land as well as discharges of effluent from point sources. All these changes could further contribute to eutrophication in the lough, with potential implications for local ecology, recreation and water supply including a possible requirement for more intense treatment processes.

3.2.10 Heavy rainfall

Warmer conditions are expected to lead to a more intense hydrological cycle with an increase in rainfall (depths and intensities), particularly in winter months (Chapter 2). Even with drier conditions on an annual average basis, rainfall depths may increase in winter months and the frequency of heavy rainfall may increase in several seasons. Heavy rainfall events are related to a number of biophysical impacts, such as an increase in soil erosion and diffuse pollution, and may increase the risks of flooding from excess runoff or from rivers as shown in Figure 3.11.

Figure 3.11 Related biophysical impacts (blue) and examples of potential consequences (green) of increase in heavy rainfall events



These impacts could in turn have implications for water quality in the following ways:

- An increase in the frequency of spills from Combined Sewer Overflows (CSOs) would increase pollution. This may be a particular issue during the summer months when receiving waters have inadequate capacity for dilution.
- Increased soil erosion could lead to greater loads of suspended solids within waters and a reduction in water clarity.
- More runoff could increase leaching of agricultural contaminants from surrounding land (diffuse pollution).
- Flooding could increase suspended solids and sediment yields as well as contaminants.

The UKCP09 projections provide changes in seasonal variables but further analysis of RCM time series or application of the UKCP09 Weather Generator (WG) are required to develop projections of heavy rainfall. Tables 3.4(a) and (b) reproduce outputs from the WG for the median annual maximum one day rainfall (Rmed1[42]) for sites in England (E), Scotland (S), Wales (W) and Northern Ireland (NI). The figures in Table 3.4(a) are taken directly from the updated UKCP09 Weather Generator report (Jones *et al.*, 2010) and show the observed data (1961-1990), WG outputs for the same period (control climate) and WG outputs for the 2080s Medium emissions scenario. Table 3.4(b) compares the WG control climate to the observed data and the future changes.

[42] Rmed is an index that can be easily derived from output from the UKCP09 WG (Jones *et al.*, 2009)

Table 3.4 Summary of changes in heavy rainfall for selected locations in the UK (E – England, W – Wales, NI – Northern Ireland, S – Scotland) based on the UKCP09 Weather Generator
(Source: Jones *et al.,* 2010)

(a) Observed data, WG outputs for the control climate and WG outputs for the 2080s Medium emissions scenario

	Observed	1961-1990 - control			2080s Medium		
	50%	10%	50%	90%	10%	50%	90%
Rmed 1 day (Median annual maximum rainfall, mm)							
Heathrow (E)	38	31	35	39	34	41	50
Yeovilton (E)	33	32	34	37	35	41	51
Coltishall (E)	35	31	34	37	32	38	46
Dale Fort (W)	33	33	36	39	38	43	51
Ringway (E)	38	31	34	36	33	39	46
Aldergrove (NI)	31	31	34	36	34	39	46
Eskdalemuir (S)	60	51	55	59	58	66	75
Wick (S)	29	29	30	32	32	37	42

For example, observed median annual maximum rainfall (Rmed) for Heathrow is 38mm; this compares with 35mm (31 to 39mm) simulated by the WG for the same period. For the 2080s Medium emissions scenario, WG outputs for Rmed are 41 mm (34 to 50 mm).

(b) Comparing the WG outputs for the control climate with the observed data and the WG outputs for the 2080s Medium emissions scenario

	Observed	1961-1990 - control/observed			2080s Medium/control		
	50%	10%	50%	90%	10%	50%	90%
Rmed 1 day factors (Control/observed and 2080s Medium/control)							
Heathrow (E)	38	0.82	0.92	1.03	1.10	1.17	1.28
Yeovilton (E)	33	0.97	1.03	1.12	1.09	1.21	1.38
Coltishall (E)	35	0.89	0.97	1.06	1.03	1.12	1.24
Dale Fort (W)	33	1.00	1.09	1.18	1.15	1.19	1.31
Ringway (E)	38	0.82	0.89	0.95	1.06	1.15	1.28
Aldergrove (NI)	31	1.00	1.10	1.16	1.10	1.15	1.28
Eskdalemuir (S)	60	0.85	0.92	0.98	1.14	1.20	1.27
Wick (S)	29	1.00	1.03	1.10	1.10	1.23	1.31

For example, for Heathrow, the p50 median annual maximum rainfall (Rmed) WG simulation for 1961 – 1990 is slightly lower than the observed values for the same period. Rmed WG simulations for the 2080s Medium emissions scenario are higher than the WG simulations for 1961 – 1990 for all locations.

Heavy rainfall is expected to increase in depth by between 15% and 23% by the 2080s and this appears to be a significant increase above the control climate figures for each site.

Some further analysis of WG outputs was completed to estimate the frequency of heavy rainfall events that may cause sewer flooding, pluvial flooding (surface water flooding) and soil erosion. For the first two impacts, a WG analysis was completed for London, Glasgow, Cardiff and Belfast. This analysis simply counted the number of storms of different rainfall depths up to a total flood depth of 60 mm. For the soil

erosion work, WG analysis was completed for four agricultural areas that are vulnerable to erosion and focused on the erosive power of heavy rainfall events (Chapter 3).

Overall evidence from UKCP09 and use of the WG suggests an increase in precipitation in winter months due to a combination of greater depths and more frequent heavy rainfall events. This suggests larger volumes of runoff with potential negative impacts on flood risk and sewer overflows in urban environments. Flash-flooding associated releases from combined sewer overflows (CSO) could in turn increase associated illnesses at the coast due to the varying occurrence of microbial pathogens in the marine environment. This is discussed in Chapter 6 and in detail in the Marine and Fisheries Sector Report, while the frequency of CSO spills is considered in Chapter 7 and in detail in the Water Sector Report. Increased runoff in urban areas may offer opportunities too, for buildings and business, with potential requirements for better guttering and downpipes and possibly the collection of water in greywater recycling.

3.2.11 Rainfall erosivity

Soils are an important and irreplaceable resource that provide a range of functions or 'ecosystem services' that are essential for growing food, supporting biodiversity and providing an essential part of carbon and nutrient cycles. Soils may be eroded by wind or heavy precipitation and therefore potential increases in rainfall intensities, as a result of climate change, are a potential threat that may increase erosion rates. Previous reviews have also raised concerns related to increases in summer drought, which may damage soil structure and subsequently influence erosion (CCIRG, 1996). The interaction of many climate, soil, hydrological, landscape and land use factors have the potential to cause greater rates of soil erosion and long term soil degradation. Current erosion rates are low, compared to other parts of the world, but there are problems in parts of the UK related to specific uses of land, e.g. high grazing densities of livestock or deer in Scotland (Lilly *et al.*, 2009) or arable and horticultural production on steep slopes or on highly erodible soils in the east and south-east of England.

The concept of 'rainfall erosivity' describes the energy in rain drops and its potential for soil erosion. It is highly correlated with rainfall intensity and any increase in intensity or the number of intense storms per year is likely to increase erosion rates. Severe erosion episodes may cause significant damage to soils, agricultural production and water quality, potentially contribute to loss of carbon and increase sediment loads in rivers that may affect river ecology and sedimentation of water intakes and reservoirs. Some of these consequences are discussed further in Chapter 8 on the natural environment and biodiversity. This section summarises the potential biophysical impact of changes in rainfall erosivity and potential erosion rates.

Evidence on current rates of erosion come from field scale studies, monitoring of suspended sediment in rivers and detailed modelling studies. Recent research in Northern Ireland and Scotland has modelled soil loss due to grazing and climate change. This is particularly important in these countries as their peaty soils account for approximately 40 % of the UK's soil carbon (Lilly *et al.*, 2009).

For the UK, changes in rainfall intensity can be estimated using data from RCMs, the UKCP09 Weather Generator or UKCP09 sampled data on 'rainfall depths' on the wettest day of the year. Some illustrative calculations are summarised below. Further research outputs for England and Wales are expected in 2011.

Calculations for four sites across the UK, using the UKCP09 Weather Generator and the Medium emissions scenario for the 2080s, indicate that it is likely that rainfall

erosivity would only increase in areas that receive greater annual precipitation at intensities above 10 mm/hour:

• In the east of England rainfall erosivity may decrease or increase; the mid estimate (p50) is just a 3% increase from the 1961-1990 baseline[43]. The estimated range is from minus 18% to 36%. • In Scotland rainfall erosivity may increase by 56% (23% to 58%). • In Wales rainfall erosivity may increase by 55% (21% to 69%). • In Northern Ireland rainfall erosivity may increase by 49% (8% to 71%).	Medium confidence

3.2.12 Solute and sediment transport

The changing balance of seasonal precipitation is likely to have a direct impact on solute and sediment transport, although understanding the relative impacts of climate versus land use change is difficult without detailed catchment scale monitoring and modelling. Examples of potential changes in processes owing to climate include:

- Increases in nitrate leaching in winter months because of an increase in precipitation, infiltration in soils and recharge of groundwater;
- Similarly, changes in phosphorus losses from soils through erosion or leaching processes, particularly following heavy rainfall events;
- Changes in pesticide leaching and breakthrough in soils and groundwater systems; and
- Potential for enhanced nutrient loss following drought periods, when plants have failed to make use of nutrients and fertiliser.

In each case, nutrient and pesticide transport will also depend on availability, and other factors such as changing land use, technology and regulatory changes may be more important than hydrological change in future time periods (UKWIR, 2011). The potential consequences of changing patterns of solute transport include changes in water quality at the catchment scale, ecological status and the requirements for water treatment.

3.2.13 Pluvial flooding

Pluvial flooding is typically defined as flooding that occurs before excess runoff enters drainage systems and water courses[44]. Pluvial flooding is likely at rainfall intensities of greater than 30 mm/hour. The values in Table 3.5 are used as part of the Flood Forecasting Centre's Extreme Rainfall Alert system in England and Wales. When these values are exceeded warnings are provided to emergency planning and response organisations such as Environment Agency, emergency services and local authorities.

[43] This is likely to be within the range of natural variability

[44] *"'Pluvial' flooding is defined as flooding that results from rainfall generated overland flow before the runoff enters any watercourse or sewer. It is usually associated with high intensity rainfall events (typically >30mm/h) but can also occur with lower intensity rainfall or melting snow where the ground is saturated, frozen, developed or otherwise has low permeability resulting in overland flow and ponding in depressions in the topography."* NERC Flood Risk from Extreme Events (FREE) Background information for proposals relating to pluvial events (2007); http://www.nerc.ac.uk/research/programmes/free/events/ao3.asp

Table 3.5 FEH[45] rainfall depths averaged and rounded for eight UK cities

Rounded UK rainfall depth values (mm)				
	Duration (hrs)			
	1	3	6	12
1 in 10 year return period (10% annual probability)	20	30	40	50
1 in 30 year return period (3.3% annual probability)	30	40	50	60

For the 2080s High emissions scenario the number of heavy rainfall events (>40 mm for any duration) increase in frequency for all sites. For example at sites in Wales, where the current frequency of rainfall alerts appears to be high, analyses for the 2080s Medium emissions scenario for major UK cities shows that:

- Annual maximum daily rainfall (Rmed-1day) is projected to increase by 19% (range 15-31%).
- Heavy rainfall events (>40 mm) are projected to increase in frequency by almost two times (range approximately 1.6 to 2.1 times).

Medium confidence

3.2.14 High flows

Background

Major UK studies have highlighted the potential impacts of climate change on flooding from rivers and the sea[46]. Potential changes from a more intense hydrological cycle such as more frequent and intense rainfall may increase the average frequency of flooding from rivers, the magnitude of individual floods, the spatial extent of flooding across the country and even the clustering of flood events in time. There is considerable evidence for increases in peak river flow in response to higher precipitation. The more complex aspects related to spatial and temporal variation of major floods in the UK are still active research areas that are currently being addressed by the UK Research Councils as part of programmes under the umbrella of Living with Environmental Change (LWEC). In the context of climate change modelling, projections of extreme rainfall and future flooding are one of the most challenging areas of climate change science and the spread of possible outcomes is large.

Flood frequency and magnitude

River flooding is a natural process that occurs when rivers exceed their capacity and water flows across the floodplain. Flood processes are affected by factors related to:

- The ‘sources’ of flooding, e.g. storm duration, direction and extent, rainfall volumes and soil wetness; and
- The characteristics of flood ‘pathways’, such as land use, drainage systems, river channels and flood defences.

[45] The Flood Estimation Handbook, which offers guidance on rainfall and river flood frequency estimation in the UK http://www.ceh.ac.uk/Feh2/fehintro.html

[46] For example the Foresight Future Flooding Study http://www.bis.gov.uk/assets/bispartners/foresight/docs/flood-and-coastal-defence/executive_summary.pdf

This section is only concerned with the 'sources' of flooding and specifically with potential increases in runoff due to climate change. Changes in flood risk are discussed in Chapter 7.

Flood frequency or probability describes the average occurrence of flooding of a particular magnitude at a specific location. That means that it is possible to have several floods in succession at one location and then no flooding for many years, so called 'flood rich' and 'flood poor' periods (Robson, 2002). It is also possible to have major floods at different locations across the UK in the same year, for example the floods in 2007. There is considerable uncertainty in estimating the probability of flooding, particularly in a changing climate, but the collective UK evidence has been developed into a number of databases, models, analytical tools and mapping products that provide a strong basis for hazard and risk assessments.

Future changes in flooding from rivers

The Foresight Future Flooding study suggested that increased precipitation would increase flood risk by two to four times by the 2080s (Evans *et al*., 2004). More recent research by the Centre for Ecology and Hydrology has provided estimates of change in peak river flows on a regional basis in England and Wales based on UKCP09 (Reynard *et al.*, 2009; Kay *et al.*, 2010). This work has provided new insights into flood risks at the regional scale and the sensitivity of different types of river basin regions. The project provides plots of increases in peak flow for flood return periods of up to 1 in 50 years (2% flood). Similar research is underway in Scotland, but will not be completed until late 2011 (Kay, pers. comm.).

For this assessment, the peak flow results were used in a novel way by translating changes in the 1 in 50 year peak flow to changes in average flood frequency at the regional scale. This approach provides average figures for UKCP09 river basin regions for a number of key indicators:

- Average increase in peak river flow for the 1 in 50 (2%) flood event; and
- Average change in frequency of events of the magnitude of the historic 1 in 50 year (2%) flood.

To provide a similar approach to UKCP09, 10%, 5% and 90% probability levels of these indicators were estimated but they reflect more than just climate model uncertainty. In addition, it was assumed that the second indicator could be extrapolated to the 1 in 75 year flood, which is an important threshold to consider as above this threshold flood insurance may not be included as standard within household insurance policies in the UK. Kay *et al.* (2010) tested similar assumptions and concluded that as the flow increases models were reasonably stable when extrapolated to higher return periods, such as 1 in 100 years that is used for the Environment Agency's Flood Map in England and Wales. Finally, changes in individual catchments may be larger or smaller than the average regional figures and the figures presented here are only appropriate for broad scale national risk assessment.

The results indicate the following changes in peak flows based on UKCP09:

• In the near term, 2020s Medium emissions scenario, increases in peak flow varied from 'no change' to increases of 24%. • In the medium term, 2050s Medium emissions scenario, increases in peak flow varied from 'no change' to increases of 48%. • In the long term, 2080s and the full range of emissions scenarios, increases in peak flow varied from 7% to 60%.	High confidence

In addition:

- These changes in peak flow suggest an increase in frequency of river flooding for medium to large floods (50 to 100 year range); for example flood frequency would increase by approximately two times (from no change to four times) in the Thames, and by four times in Western Wales (two to ten times) for the 2080s Medium emissions scenario.
- Estimated changes in frequency vary across the country, with the greatest increases in Western Wales and the north-west of England and the lowest increases in the Anglian and Thames river basin regions.

The findings for the 2020s are typically within the precautionary allowance of 20%, which is in Defra guidance and is used by engineers and planners for decision making. The 2080s Medium emissions figures are similar to those presented in the Foresight study but the overall range considered in this study is greater; regional increases in frequency show up to a 13 fold increase in flood frequency (Northumbria, High emissions scenario, 2080s p90). This wide spread of possible outcomes still does not cover the full range of possible changes in peak flow (flood flows may actually decrease for the lower probability levels that are presented as 'no change' in this assessment and increases may be greater than those presented)[47].

Changes in Scotland and Northern Ireland have not been estimated as the research required has yet to be completed. Increases in flows are most likely to be similar to west Wales and north-west England, based solely on these regions being the most similar in terms of precipitation and catchment characteristics. However, it is not possible to confidently extrapolate the findings to new river basin regions.

The estimated changes in flow are shown for example river basin regions and scenarios in Tables 3.6 and 3.7. The overall confidence in the results for the impacts of climate change on peak flows is high because they are based on the results of a major research study with results published in the peer reviewed literature. There is a good understanding of the uncertainties and there is broad consensus that peak flows in rivers are likely to increase in the medium to long term due to climate change. These are key findings for this assessment, as flooding has consequences for all themes and sectors, discussed in this report (Chapters 4 to 8).

[47] The CEH risk plots were concerned with the risk of exceeding the 20% allowance and started at zero and plots were truncated at 60%, which was sometimes not quite at the p90 level. The CEH study was only available in draft at the beginning of the CCRA and small changes may have been made prior to publication. Also other climate models suggest larger increases or decreases in flood flows.

Table 3.6 Percentage increases in the 1 in 50 peak flow for three catchments
(Based on Kay *et al.*, 2010)

Thames				
	Emissions scenario	**p10**	**p50**	**p90**
2020s	Medium	0	7	23
2050s	Medium	0	14	35
2080s	Low	0	17	38
	Medium	0	22	50
	High	5	30	60*

Solway				
	Emissions scenario	**p10**	**p50**	**p90**
2020s	Medium	6	15	24
2050s	Medium	11	22	35
2080s	Low	11	23	40
	Medium	11	27	50
	High	19	38	60*

Western Wales				
	Emissions scenario	**p10**	**p50**	**p90**
2020s	Medium	5	15	24
2050s	Medium	10	23	38
2080s	Low	12	25	44
	Medium	14	30	55
	High	20	40	60*

Note: We chose to cap the results at a maximum of 60% increase in peak flows as the plots in Kay *et al.* (2010) were truncated at this value.

Table 3.7 Increases in flood frequency for UKCP09 river basin regions in England and Wales

UKCP09 river basin region	**Future return period (years) of current 1 in 100 year flow (1 in X years)**			**Approximate increase in flood frequency (X-times)**		
Changes in probability level →	p10	p50	p90	p10	p50	p90
Northumbria	63	27*	12	2	4*	8
Humber	73	26	12	1	4	8
Anglian	100	56	30	1	2	3
Thames	100	50	24	1	2	4
South East England	89	42	19	1	2	5
Severn	79	37	17	1	3	6
South West England	66	27	11	2	4	9
Western Wales	46	23	10	2	4	10
Dee	70	34	19	1	3	5
North West England	51	25	9	2	4	11
Solway	67	41	22	1	2	5
Tweed	72	47	29	1	2	3

*This would mean that the future return period of the current 1 in 100 year flow for Northumbria would be 1 in 27 years for p50, while flood frequency would increase by approximately 4 times.

3.3 Biophysical impacts on the coastal and marine environment

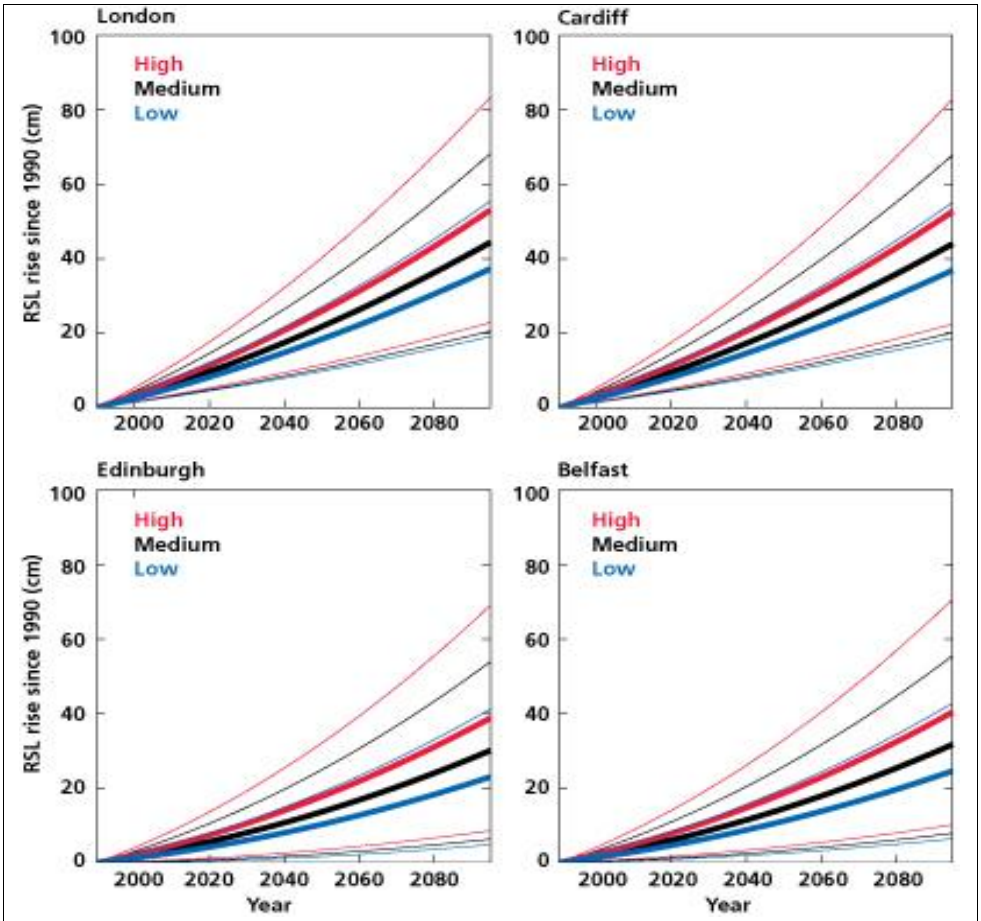
3.3.1 Sea level rise

There is clear evidence from the tide gauges and more recently satellite data that global sea levels have risen considerably since the mid 19th century and that the rate of rise has accelerated over the last 20 to 30 years (Jenkins *et al.*, 2009a,b). Global mean sea levels are currently increasing by approximately 3 mm per year. The main physical processes are the thermal expansion of the oceans and the addition of water, primarily from melting glaciers, ice sheets and caps.

The UKCP09 projections indicate absolute sea level rise (not including land movement) for 2095 range from approximately 13 to 76 cm. Local rates of sea level rise depend on a number of additional factors, including the movement of the Earth's crust. In the south of England land is subsiding at a rate of approximately 1 mm a year so relative rates of sea level rise (i.e. a combination of absolute sea level changes and vertical land movements) are greater in the south than in the north of the UK. UKCP09 projections for relative sea level rise are shown in Figure 3.12.

Figure 3.12 Relative sea level (RSL) rise for range of emissions scenarios over the 21st century

(Source: Lowe *et al.*, 2009)



Thick lines (central estimate values) and thin lines (range of uncertainty - 5th and 95th percentile limits) for four sample locations around the UK. Values are relative to 1990.

For example, Figure 3.12 shows that relative sea level increases for 1990–2095 are approximately 21 to 68 cm for London and 7 to 54 cm for Edinburgh (5th to 95th percentile for the Medium emissions scenario). These estimates are however thought to be conservative.

Some processes involved in the melting of large ice sheets are not well understood so the UKCP09 projections include an additional High-plus-plus (H++) scenario that represents a wider range of relative mean sea level rise and storm surge changes. The H++ scenario is not included in Figure 3.12 as it has been provided in addition to the main scenarios, with increases given from present day (1980–1999) to 2095 (no time series is presented). The H++ range is not intended to replace UKCP09's likely range of sea level rise and future surges, but rather it provides estimates of sea level rise and surge increase beyond the likely range but within physical plausibility (UKCP09) i.e. it provides a high impact, low likelihood scenario. For the UK this absolute sea level rise estimate for the H++ scenario is from 93 cm to 1.9m by 2100 (with the lower part of the range here taken from the maximum global mean sea level rise value given by the IPCC AR4, and the upper part derived from indirect observations of sea level rise in the last interglacial period (Lowe *et al.,* 2009).

Rising sea levels have direct impacts on the UK coastline but storm surges are the main process that leads to extreme sea levels. Reductions in atmospheric pressure combined with wind effects and local bathymetry cause higher sea levels along the coastline during surges. When these coincide with high astronomical tides there can be substantial consequences for natural environment (Chapter 8), coastal communities (Chapters 6 and 7) and coastal infrastructure (Chapter 7). Trends in model projections of storm surges have been found to be small everywhere around the UK, with the size of surge expected to occur on average about once in 50 years projected to increase by less than 0.9 mm a year (not including relative mean sea level change) over the 21st century (Lowe *et al.,* 2009). Moreover in most places it is not possible to clearly distinguish this trend from natural variability.

3.3.2 Coastal evolution

The evolution of the coast is dependent upon the interaction of:

- Rates of relative sea level change
- Sediment supply and demand
- Wave size and speed
- Rainfall and the frequency and intensity of storm events
- Anthropogenic interventions such as coastal defences and groynes.

The UK coastline comprises areas that are predominantly stable (e.g. those comprising hard rock formations) and those that are either eroding (where there is a permanent loss of land) or accreting (where coastal sediment builds up) (e.g. soft rock coast, beaches). Sea level rise will lead to an increase in the rate of erosion of some areas and may also lead to an increase in the rate of accretion in others, speeding up the long-term reconfiguration of some coastlines in the UK that is already occurring. This will result in the loss of some habitats and the creation of others.

A European-scale study of coastal erosion (Eurosion, 2004) found that over 17% of the UK coastline was experiencing erosion. Table 3.8 presents the breakdown of this for countries within the UK. The Eurosion (2004) figures indicate that England has the greatest proportion of coastline subject to erosion in the UK (30% of the total length) and that it is the most extensively defended (46% is protected by artificial structures

and beaches), with more limited erosion also experienced by Wales, Scotland and Northern Ireland.

Table 3.8 Coastal erosion and coastal defences in the UK

	Coast length (km)	Length of coast eroding (km)	Length of coast with defences and artificial beaches (km)
England	4,273	1,275 (30%)	1,947 (46%)
Wales	1,498	346 (23%)	415 (28%)
Scotland	11,154	1,298 (12%)	733 (7%)
Northern Ireland	456	89 (20%)	90 (20%)
UK Total	**17,381**	**3,008 (17%)**	**3,185 (18%)**

Source: Living with coastal erosion in Europe: Sediment and Space for Sustainability, PART II – Maps and statistics (2004), p. 21. Available from http://www.eurosion.org/index.html

NB. Figures in the last 2 columns show that some eroding coasts can also have artificial defences

Erosion has been examined as part of this assessment in terms of losses of agricultural land and a sub-set of BAP[48] habitats (for further details see the Floods & Coastal Erosion and Biodiversity & Ecosystem Services Sector Reports). In addition, the loss of beach and associated potential amenity value has been considered in the Business, Industry & Services Sector Report (and discussed further in Chapter 5). The projections for these different coastal interests are summarised in Table 3.9 in terms of area lost. Rates of erosion vary around the coast (see sector reports referred to for details) but the majority of values are in the range of 0.1 to 1.0 m per year. The rates are projected to increase by a factor of two for the Low emissions scenario and by a factor of five for the High emissions scenario, over a 100 year period (OST, 2003).

Table 3.9 Estimated area losses due to coastal erosion or sea level rise based on central estimates of the Medium emissions scenario (ha)

	Coverage	2020	2050	2080
Beaches	UK	**300 - 1600**	**700 - 3600**	**1200 - 6100**
Agricultural land	England & Wales	**1,360**	**4,690**	**7,720**
BAP habitats	England	**42**	**212**	**378**
BAP habitats considered:				
Grazing marsh		7	36	66
Deciduous woodland		24	135	239
Fen		2	6	7
Purple moor grass and rush pasture		1	2	3
Reedbed		2	11	22
Saline lagoon		6	22	41

Notes: Only a few of the priority BAP habitats, namely freshwater and open water BAP habitats behind the natural and defended coastlines of England were included in the analysis. Habitats such as saltmarsh and coastal vegetated shingle will be affected on the seaward side of the coastline, as will dry lowland habitats, such as coastal sand dunes, eutrophic standing waters (ponds and lakes) and lowland heathland on the landward side of the coastline, and hence the figures of habitat losses generated underestimate the habitats in England at risk from coastal erosion.

As sea level rises, the response on the coastline varies depending on the geomorphology, but in all cases will result in some form of marine transgression. Beaches, dunes and shingle ridges will tend to “roll” landwards whereas cliffs will slowly erode allowing the beach shore face to migrate landwards. Where this is

[48] Biodiversity Action Plans

constrained, either by slowly eroding cliffs or sea defences, the area of beach and other natural coastal assets will reduce (Taylor *et al.*, 2004). The combination of higher sea levels and greater loading from wave action would increase damage to natural and built assets (Townend, 1994). These issues are being addressed by the introduction of softer defences where possible and the development of habitat creation through managed realignment. Lee (2001) suggested that there could be a net gain of intertidal habitats (i.e. saltmarsh and mudflat/sandflat) although this was predicated on the implementation of large scale managed realignment around the country.

3.3.3 Sea temperature, salinity, stratification and circulation

Changes in water temperature, salinity, the stability of the water column and currents in the marine environment around the UK have been modelled using the Met Office Hadley Centre regional model ensemble (known as the PPE) to provide the meteorological forcing for the Proudman Oceanographic Laboratory Coastal Ocean Modelling System. A single scenario is available and this provides a physically plausible illustration of one future that might be realised under the Medium emissions scenario. The findings are summarised in the following sub-sections and a complete description of the UKCP09 marine projections is available from Lowe *et al.* (2009).

Sea surface temperature

Figure 3.13 shows that sea surface temperatures (SST) may rise to as much as 20 to 22°C in summer months. Additionally, seas around the UK are projected to become 1.5 to 4ºC warmer, depending on location.

Increased temperatures can cause shifts in the type of species and numbers, affecting ecosystem structure as well as fish and shellfish catches. Higher temperatures may also provide new habitats for invasive non-native species, diseases and pathogens. Some opportunities may also be presented however, for example in encouraging UK tourism. Further discussion around the consequences of increasing temperatures can be found in Chapter 8 and the Marine and Fisheries Sector Report.

Salinity

The seas around the UK are projected to be approximately 0.2 p.s.u. (practical salinity units) fresher by the end of the 21st century. The change in salinity is particularly dependent on the projected change in the storm tracks owing to the latter's effect on precipitation (Lowe *et al.,* 2009). Changes to salinity could affect ocean circulation, and because of the important role in which ocean circulation plays in the Earth's climate system, this may in turn potentially lead to dramatic changes in climate. There is, for example, some concern that changes in circulation could lead to a cooling in north-west Europe.

Stratification

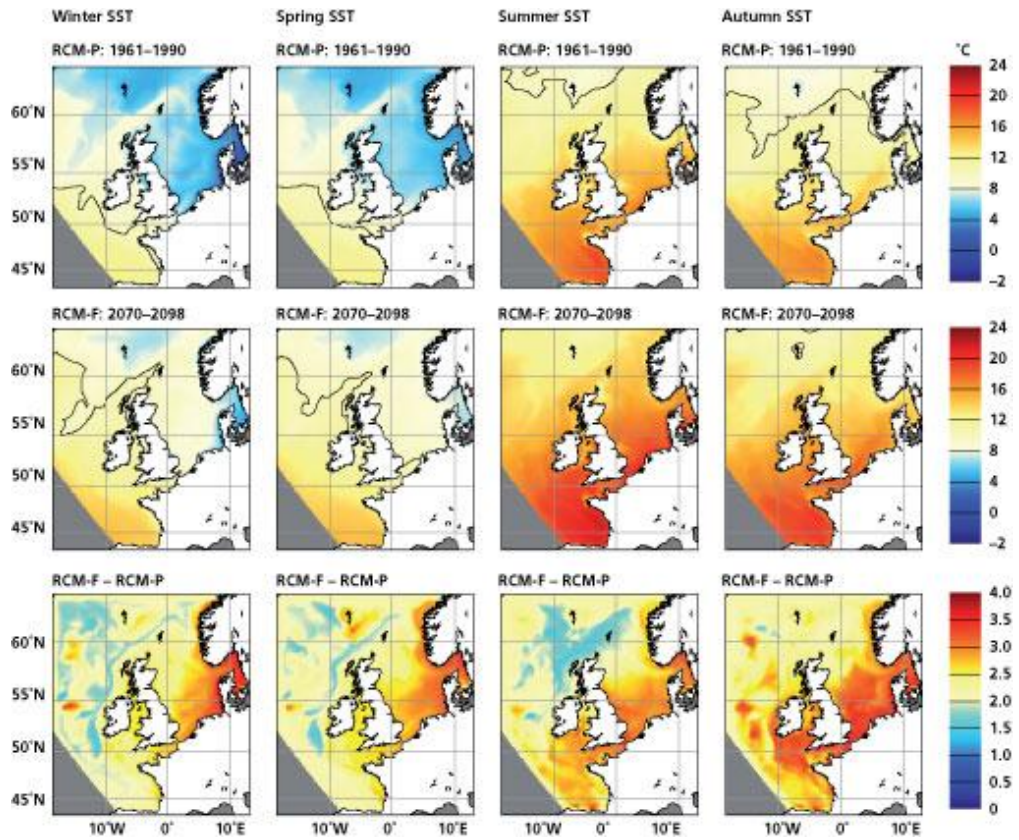
Seasonal stratification[49] strength is projected to increase but not by as much as in the open ocean. This stratification is projected to start approximately 5 days earlier and breakdown approximately 5 to 10 days later each year, hence extending the stratified period. As indicated in the Marine and Fisheries Sector Report, an increase in the duration of stratification of the water column in the future could encourage and enhance the development of harmful algal blooms (Chapters 6 and 8).

[49] The layering of warmer waters over colder waters

Circulation

Changes in the open ocean, especially the circulation, are particularly uncertain due to the proximity of the model boundary. Changes in circulation may have impacts on a range of physical and biological processes in the marine environment with consequences for marine species and water quality, including the frequency of harmful algal blooms or the incidence of marine pathogens (Chapters 6 and 8).

Figure 3.13 Seasonal mean sea surface temperature (SST) for the period 1961–1990 (upper panels), 2070–2098 (middle panels) and the differences between them (lower panels)
(Source: Lowe *et al.,* 2009)



Note: RCM is the Met Office Hadley Centre RCM, which covers the European region

3.3.4 Ocean acidification

The increasing amount of CO_2 in the atmosphere is acidifying the oceans as a result of its reactions with sea water. Approximately half of the CO_2 released by human activities since 1800 has been absorbed in the oceans (Sabine *et al.*, 2004). Between 1750 and 2009 atmospheric CO_2 has increased from around 280 to 387 parts per million (ppm), causing ocean pH to decline from 8.2 to 8.1 (Orr *et al*., 2005). There is strong evidence to suggest that the average surface ocean pH has not been much lower than about 8.2 for millions of years (Royal Society, 2005; Parliamentary Office, 2009). Future acidification can be estimated with high confidence for a known level of atmospheric CO_2. Based on the research of Blackford and Gilbert (2007) this assessment has estimated the pH of the North Sea for the 2020s, 2050s and 2080s and 2100, with oceans continuing to acidify with increasing CO_2 emissions. This is shown in Table 3.10.

Table 3.10 Projected oceanic pH for UKCP09 emission scenarios

	Low (B1)			Medium (A1B)			High (A1F1)		
Year	CO_2 ppm	pH	Change	CO_2 ppm	pH	Change	CO_2 ppm	pH	Change
2010	388	8.05	0.11	391	8.05	0.11	389	8.05	0.11
2020s	412	8.03	0.13	420	8.02	0.14	417	8.02	0.14
2050s	488	7.96	0.20	532	7.92	0.24	567	7.90	0.26
2080s	537	7.92	0.24	649	7.85	0.31	799	7.76	0.40
2100s	549	7.91	0.25	717	7.81	0.35	970	7.69	0.47

Whilst there is medium confidence that ocean acidification will continue, subsequent impacts on ecosystems are less well understood. Future increases in ocean acidity may have major negative impacts on some shell and skeleton-forming organisms by 2100 (see Chapters 5 and 8).

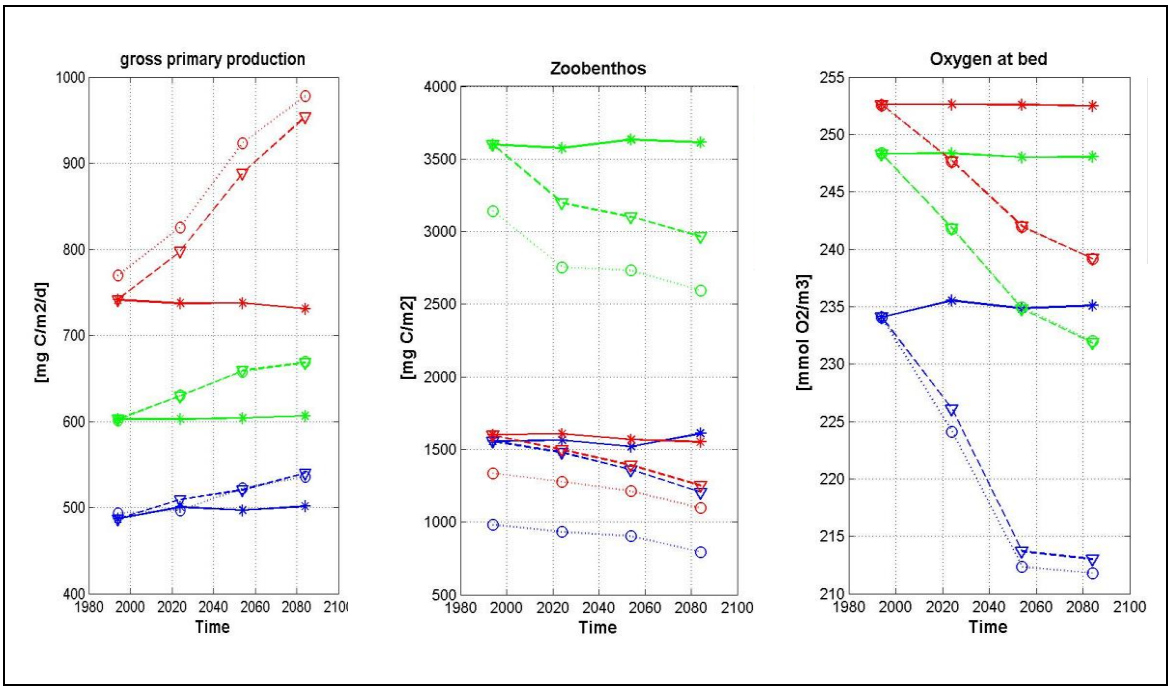
3.3.5 Marine primary productivity

In the marine environment, primary production is undertaken primarily by phytoplankton. In the North Sea, primary productivity ultimately drives benthic (sea bed) and pelagic (water column) food webs. Observational investigations carried out at three distinct sites in the North Sea during 2007 and 2008 indicate that climate warming will increase rates of carbon cycling in the pelagic system (by up to 20% by 2098), making fewer nutrients available to the benthic system. Connectivity between pelagic (water column) and benthic (sea bed) food webs is essential for ecosystem health and productivity.

The rate of primary production is also affected by the thermal stratification of the area, with better mixed sites projected to experience a larger increase in primary production than sites that are stratified seasonally. A potential impact of this finding is the suggestion that climate change may increase the risk of eutrophication given the same anthropogenic nutrient inputs. Three metrics of change from the model climate scenario runs are presented and shown in Figure 3.14, these parameters were those that were most sensitive to the changed climate (mainly increased water temperature).

Figure 3.14 Model climate scenario results for marine primary productivity

From left to right: A thirty year time slice of modelled gross primary productivity at the three sites in the North Sea. A thirty year time slice of modelled zoobenthos biomass at the three sites in the North Sea. A thirty year time slice of modelled oxygen concentration at the three sites in the North Sea.



Blue = North Dogger; Green = Oyster Grounds; Red = Southern Bight; .Asterix = Reference run; Triangles = Climate change scenario run; Circles = combined climate change and trawling run (see Marine & Fisheries Sector Report for further details)

The left-hand graph shows gross primary production as an index of planktonic production; the middle graph shows Zoobenthos (worms, crustaceans, molluscs etc.) as a measure of changes in benthic production; and the right-hand graph shows oxygen near the bottom as a measure of ecosystem health and possibly for eutrophication. The right-hand graph, for example, shows that annual average bottom oxygen concentrations could decrease by up to 5 -10% by the 2080s. The decrease is greatest for deep, stratified waters. This may have implications for fish and fisheries (see Chapter 8).

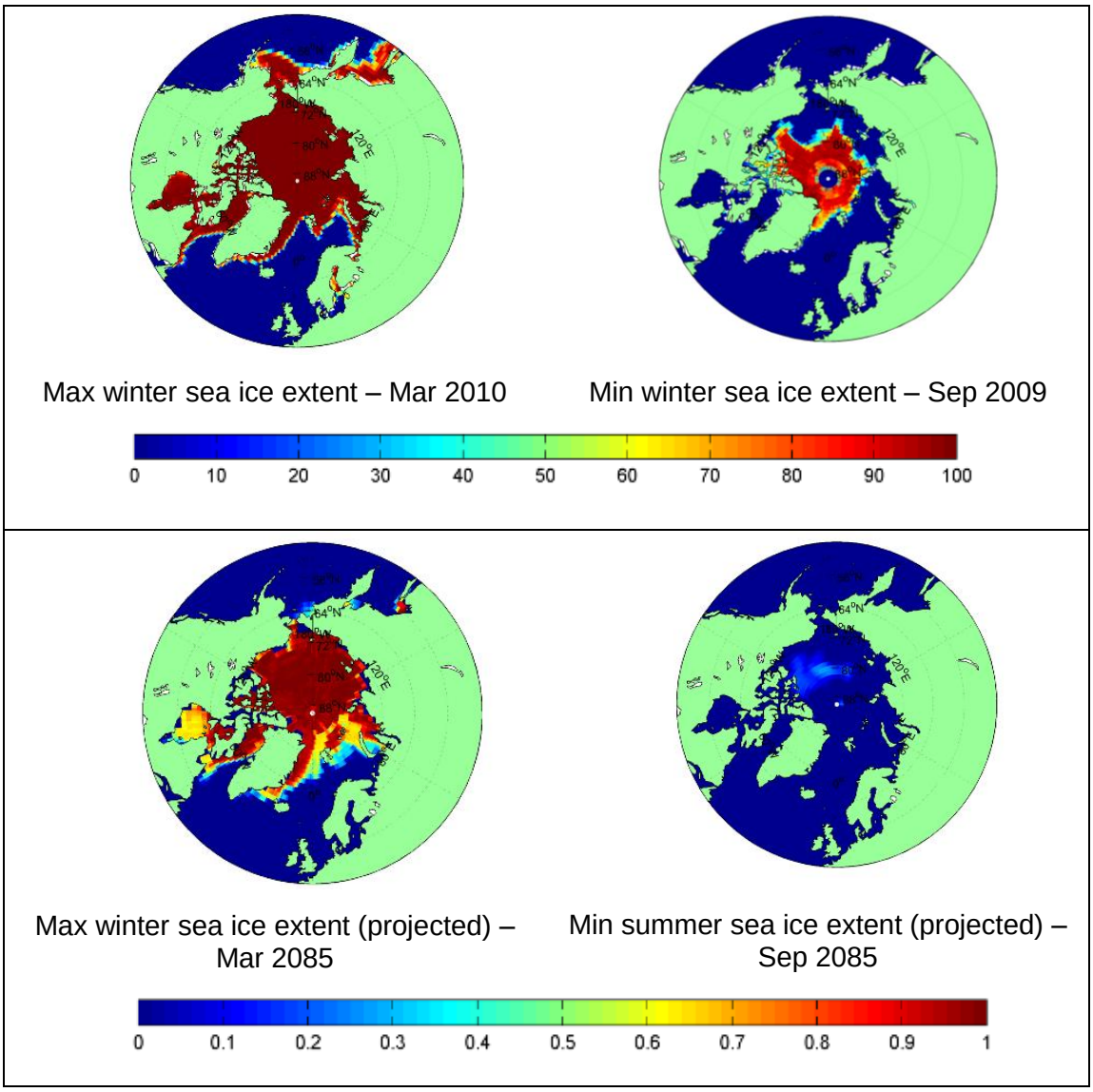
3.3.6 Arctic sea ice

Arctic sea ice is an important part of the global climate system. The natural variability of ice extent affects the reflection of radiation and heat exchange between the ocean and the atmosphere and modifies ocean stratification influencing thermohaline circulation systems, such as the North Atlantic Current (commonly but incorrectly known as the 'Gulf Stream').

Arctic sea ice naturally extends surface coverage each northern winter and recedes each northern summer but the rate of overall loss since 1979 when satellite records began has accelerated. Observed sea ice extent for the years 1979 - 2006 indicates a decrease or annual loss of around 45,000 km² of ice (3.7% per decade) (AMSA, 2009). The lowest five extents in the record have occurred in the last five years with the summer of 2007 seeing a record low when sea ice extent shrank to around 3 million km²; an extreme reduction in just one year. More recently in September 2011, sea ice extent reached its second lowest minimum since records began.

Some example projections of sea ice extent for present day and the 2080s, from the Met Office Hadley Centre observations datasets (HAdObs) and the Met Office climate model HadCM3, are provided in Figure 3.15. It should be noted that there is an anomaly in the minimum winter sea extent (September 2009), which was corrected for estimations of future changes to sea ice extent. Additionally, uncertainty with the HadCM3 plots is high, especially for the north-west passage. More recent models (HadGEM1) are more credible. Accurate quantification is, however, still elusive.

Figure 3.15 Examples of sea ice extent (fraction of area covered by ice) for both present day (2009/2010) and projected (2080s)



For example, looking at maximum winter sea ice extent, in some areas the fraction covered by ice (which had entire or almost entire coverage in March 2010) is projected to be approximately 0.7 to 0.4 in the 2080s.

Sea ice extent is also of importance to socioeconomic activities in the Arctic and its surroundings and any changes to sea ice will have large environmental and socioeconomic consequences (EEA, 2004). A detailed discussion of changes in Arctic sea ice extent is included in the Marine & Fisheries Sector Report, where it has been looked at purely as an opportunity for shipping. Further information on sea ice extent and shipping routes is provided in Foresight (2011a). Sea ice also affects salinity, with strong seasonal variations as sea ice forms in autumn (high salinity) and melts in

spring (low salinity). However, data sets are currently too short or incomplete to allow definitive statements to be made about many of the long-term trends in the salinity of the Arctic Ocean, meaning that accurate quantification of this effect is not yet possible (Rodger, 2009). Changes in Arctic sea ice may also have major consequences for climate in mid-latitudes, of which there is increasing evidence (e.g. Budikova, 2009; Petoukhov and Semenov, 2010; Overland and Wang, 2010).

3.4 Summary of biophysical impacts

This section summarises some of the main biophysical impacts of climate change. Understanding these potential impacts is an important step for the assessment of climate change risks. In general, there is higher confidence in impacts based on changes in temperature than precipitation and changes in ecosystem processes are highly dependent on other factors, such as land use change and management. Most impacts are expected to have negative consequences but some may have positive effects and these are discussed in the subsequent chapters.

Table 3.11 Scorecard of the main biophysical impacts of climate change for the UK

Changes in biophysical impacts	Confidence	Summary Class								
		2020s			2050s			2080s		
		l	c	u	l	c	u	l	c	u
Mean annual temperature rise (°C)	H	0.8	1.4	2.1	1.3	2.5	3.3	1.7	3.5	6.3
Changes in grassland yield (%)	M	6	18	14	10	25	32	14	32	32
Relative aridity (ratio)	M	0.9	1.7	2.6	0.5	1.9	2.8	1.2	2.1	3.1
Change in PSMDmax (mm)	M	-33	38	116	-7	86	183	4	118	277
Change in wildfires due to warmer and drier conditions (%)*	M	*10*	*19*	*28*	*17*	*32*	*42*	*22*	*45*	*81*
Change in low flows (Q95) - Anglian (%)	M	15	-13	-31	-7	-35	-54	-16	-48	-70
Change in low flows (Q95) - Orkney and Shetland (%)	M	7	-5	-14	-2	-15	-25	-5	-20	-33
Increase in winter rainfall (%)	H	-4	6	17	0	15	36	3	20	58
Change in rainfall erosivity - North Eastern Ireland (%)**	L	*-5*	*4*	*14*	*-3*	*9*	*25*	*-1*	*12*	*43*
Pluvial flooding (change in heavy rainfall events) - Glasgow	L	~	~	~	~	~	~	1.9	1.9	2.0
Increases in peak flows - Western Wales (%)	H	5	15	24	10	23	38	12	30	60
Sea level rise (mm)	M	8	10	12	18	22	26	31	36	43
Sea Level Rise H++ scenario (mm)	M/L	~	~	~	~	~	~	93	~	190
Ocean acidification - change in oceanic pH	M	0.13	0.14	0.14	0.2	0.24	0.26	0.24	0.31	0.4

** Scaled with changes in mean annual temperature*

*** Scaled with changes in winter rainfall*

M	Confidence assessment from low to high
~	No data

Relative changes

- Low
- Moderate
- High

4 Agriculture and Forestry

Overview	
• Agricultural systems are vulnerable to changes in climate and are among the first to feel the effects. Climate change presents both threats and opportunities. In the short term warmer temperatures and CO_2 fertilisation may present some opportunities to improve yields and introduce new crops, but these benefits may be limited by low water availability which is already being experienced in drier parts of the UK. • The geographical range of existing crops may increase and there could be opportunities to grow new crops, particularly in southern England. There may be large areas of land for which trees could be the most suitable crop. Large areas of forest could become suitable for different tree species from those that are currently grown and the suitability of the existing species could decline. • Agriculture and forestry are both highly influenced by international factors and face a wide range of social, economic and regulatory pressures, which may be more important in the near term than climate change risks. • For agriculture these include changes to Common Agricultural Policy, availability of finance and the need to reduce carbon emissions. For forestry these include fluctuating global markets for timber and timber processing and maintaining the skills base of the forestry workforce.	
Threats	**Opportunities**
• Crop losses and other impacts on high quality agricultural land due to flooding; • Higher summer soil moisture deficits, increasing demand for irrigation to maintain crop yields and quality; • Reduced timber yield and quality due to drier conditions and an increase in the frequency of drought; • Increased competition for water resources in the summer and pressures to reduce abstractions; • Potential for increased potency in existing, or introduction of new livestock diseases; • More intense rainfall with greater potential for soil erosion; and • Potential increase in forestry pests and diseases.	• Increased yields for current crops (e.g. wheat and sugar beet, potatoes) due to warmer conditions and/or CO_2 effects; • Increased grass yields benefiting livestock production; • New crops and tree species may be able to enter production, due to warmer conditions; • Opportunities to grow a wider range of non-food crops for energy and pharmaceuticals; • Increased yields of rain-fed potatoes due to greater CO_2 and climate effects; and • Increase in Sitka spruce yield in Scotland and where water availability is non-limiting.

Note: no prioritisation is implied in the order of these threats or opportunities.

Figure 4.1 Summary of agriculture and forestry impacts with an indication of direction, magnitude and confidence

* Note that magnitude of both opportunities and threats may be dependent on specific conditions, for example crop yields may only increase if water availability and nutrient supplies are not limiting factors.

High consequences (positive)	High confidence
Medium consequences (positive)	Medium confidence
Low consequences (positive)	Low confidence
Low consequences (negative)	
Medium consequences (negative)	Too uncertain to assess
High consequences (negative)	

4.1 Introduction

Agriculture and food production accounted for 7.1% of GDP in 2011 and employed some four million people[50]. UK agriculture provides approximately half of the food consumed in the UK (Defra, 2010e). Agricultural production is vulnerable to floods, heatwaves and droughts all of which are expected to increase in frequency as a result of climate change.

The UK's forests and woodlands are an important and unique asset. Commercial forestry is of economic importance in many parts of the UK and woods and forests provide a range of regulating, cultural and supporting services of considerable benefit to biodiversity, recreation, education and tourism. Forestry is vulnerable to drought, storms and gales and outbreaks of pests and diseases.

Agriculture and forestry are sensitive to atmospheric and climate conditions, including CO_2 concentrations, temperature and seasonal precipitation, many of which combine to influence yields and quality. Improved land management, greater irrigation of horticultural crops and technological developments have increased the yields of many UK crops over the last two decades and increased resilience to drought, pests and diseases. However, production is still affected by more extreme climate conditions, including floods, drought, frost and storms. Climate remains one of the main factors that influence land suitability for crops and tree species. The warmer conditions experienced in the UK since the 1970s (Jenkins *et al.,* 2009a) have already contributed to larger areas of vine production and present some opportunities for growing new and novel species (Section 4.4).

Agriculture and forestry face many similar issues, although the potential risks can develop quite differently in each sector due to different crop growth periods, which are seasonal or annual for crops and much longer term in forestry, and different management frameworks. For example:

- Overall productivity is important in both sectors.
- Pests and diseases pose similar threats, although the potential risks may be greater for forestry due to the inability to spray forests for practical, economic and health and safety reasons.
- For crops and trees, water availability and nutrient supply are essential for plant growth, as are sufficiently warm (or cold) temperatures during different growth stages.
- Forestry requires effective long term planning; future climate changes may impact on tree plantations currently being managed, potentially affecting the yield and quality of the end product and therefore the returns on forestry investment.
- In agriculture, a shorter crop-growth time means that farmers and land managers can be more responsive and adaptive to a changing climate.

[50] http://www.kpmg.co.uk/email/12Dec10/243584/RRD_243584_v2.html

- There is a need for effective planning for both sectors, e.g. the identification of potential longer term climatic changes can influence forest planning now and may also influence research and development into new crops for agriculture, which take time to develop.

This chapter considers the consequences of climate change for agriculture and forestry as sources of primary production in the economy. Both of these sectors are affected by direct biophysical impacts of climate, for example on plant growth and development and by similar indirect impacts, related to changing ecosystem services. Relevant biophysical impacts of climate change, such as growing degree days, are discussed in Section 3.2. Both sectors are also affected by global factors such as demand from a growing population, the desire for a more varied, high-quality diet requiring additional resources to produce and competition for key resources for production and food security (Foresight, 2011b). For example in the agriculture sector, population demographics will strongly influence crop production and food security, while in the forestry sector, the impact of pests and pathogens is very likely to be influenced by the demand for trade and timber imports (as this is a strong vector for their introduction into the country). New pests and diseases might also emerge due to globalisation of agriculture.

This assessment identified four key considerations that form the main sections of this chapter:

- Section 4.2 - Climate sensitivity to changing ‘baseline’ conditions, including elevated levels of CO_2, warming and changes to the seasonal balance of precipitation;
- Section 4.3 - Damage and disruption caused by floods, droughts, wildfire, wind-throw and potential changes to pests and diseases;
- Section 4.4 - Opportunities for new tree species and crops under warmer conditions, increasing sustainable production and the development of new markets; and
- Section 4.5 - Competition for resources, such as water for irrigated crops, industry and public water supply that may lead to changes in regulatory regime affecting agriculture. Competition for land may also increase with a change in climate.

In addition:

- Section 4.6 considers others aspects of risks, including the international dimension and the spatial variation of risk within the UK;
- Section 4.7 highlights the evidence gaps that exist in agriculture and forestry that may require more research in time for future CCRA cycles;
- Section 4.8 provides a summary and scorecard of the consequences of climate change for agriculture and forestry; and
- Other risks relevant to the broader food supply chain such as transport, energy and water supply are covered in Chapters 5 to 8. In particular, tourism and recreation are discussed in Chapter 5 and broader ecosystem and landscape issues are discussed in Chapter 8.

Figure 4.1 provides a summary of the risks considered with an indication of how the magnitude of the Medium emissions central estimate changes over time. Further detail of the risks of relevance to this theme, with more information on how the magnitude of the risks varies under different scenarios, is provided in the scorecard at the end of this chapter (Table 4.7).

4.1.1 Vulnerability and adaptive capacity

Some rural agricultural communities may be more vulnerable to climate change simply due to living in more remote locations with greater exposure to climate hazards. In general, remote areas have poorer access to services, poor transport links and higher than average costs for utilities, which are all relevant factors in the context of social vulnerability (Annex B). However, this assessment found limited evidence on specific social vulnerability issues for the climate change risks analysed in detail as these focused on agricultural and forestry production rather than the broader issue of the rural economy.

Adaptation in the agricultural sector is likely to require investment in longer term planning and technology (Foresight, 2011b). Larger agribusinesses are more likely to invest in 'no regret' adaptations such as on farm storage reservoirs, which can solve existing water resource issues as well as contribute to future adaptation. Smaller businesses may need more support to respond to opportunities and manage potential risks related to climate change.

A key issue within the forestry sector is its long-term nature. There are limited options to intervene within forest planning as only 0.2% of forests in England are currently felled and re-planted each year. The sector cannot adapt or change quickly; there is a limit on the ability to change species and practices in response to a change in climate.

4.2 Changing 'baselines'

Crop, forestry and livestock production are clearly linked to the biophysical characteristics of the natural environment. The key sensitivities in relation to climate change are illustrated in this section, considering both direct impacts such as those resulting from increases in mean temperature and indirect impacts such as the benefits of increased grass production for livestock systems.

Plant growth and developmental processes have optimum temperature conditions (Gornall *et al.*, 2010) and there are also clear relationships between growth and the radiation balance, water availability and nutrient supply. Increasing atmospheric CO_2 concentrations affects photosynthesis with benefits for most plant species. These relationships can be quantified at experimental sites at the plot scale but can not always be 'scaled up' to farm, regional and national scales due to greater complexity and differences between real farm conditions compared to carefully controlled experimental sites.

This assessment has considered experimental evidence and national production data to illustrate key sensitivities to changing baseline conditions and potential consequences for important UK crops and forest production. Livestock (beef, dairying, sheep, pigs, poultry) are also affected by climate directly, as production rates may be reduced in warmer and more humid conditions due to heat stress (Chapter 3), and indirectly as most systems depend on grassland production. This assessment has considered grassland productivity and the potential risks of thermal heat stress on UK dairy and meat production, including indoor reared animals.

4.2.1 The response of grassland

Grassland is the largest agricultural land-use category in the UK (7 million hectares (ha), plus a further 5 million ha of rough grazing). Beef and sheep production is generally more reliant on grass (typically supplying >70% feed requirements) than dairy production. Yields are important for livestock production throughout the UK and of national economic importance for Northern Ireland due to the relative value of meat exports.

The principal risk metric for grassland-based livestock production is herbage dry matter (DM) yield[51], which is measured in tonnes per hectare (t/ha). Grassland yield is strongly influenced by temperature and soil moisture availability (which is influenced by rainfall amount and distribution). These determine the number of grass-growing days (GGD) per year. The number of GGD is greatest in oceanic western areas on soils with good soil moisture conditions, and least in the upland areas and in areas with a more 'continental' climate (with low temperatures in spring plus dry periods in summer, as in eastern Britain). Average 'baseline' values of DM yields from grassland exist for a range of sites and growing conditions, based on reliable results of field experiments from the 1970s-1990s.

Improvements in grassland productivity have been made in recent decades largely through (1) a better understanding of the rates and timing of fertiliser applications and (2) improved plant genetics.

Agricultural productivity of UK grasslands is generally below its potential, partly due to the need to farm within environmental constraints and to promote sustainable production. For example:

- Greater fertiliser applications are not applied in order to avoid contributing to increased nitrate and phosphorus pollution of surface and ground waters.
- Many grassland areas, particularly in upland and marginal areas and in situations such as lowland meadows and wetlands, are of high conservation value and are managed under agri-environmental management agreements.

In the context of climate change there are several key features of UK grassland production that should be considered:

- Grassland has greater management flexibility compared with the main arable crops that have critical annual production cycles involving cultivation, sowing and harvesting dates. In response to seasonal and inter-annual variability in weather and growing conditions, farmers can (to varying extents) change:
    - The start and end of the grazing season
    - Stock numbers per hectare
    - The relative areas mown or grazed
    - Cutting dates for silage or hay.
- Forage yields per hectare vary considerably between sites and between years:
    - In general, production is greatest in the areas that have the highest mean temperatures;
    - Low temperatures in the spring reduce early season production and therefore the total annual production;

[51] The term herbage refers principally to grasses, of sown and unsown species, together with non-grass forage species of grassland, such as clovers and other legumes as well as any other non-grass species in the sward.

- Yields vary from 2-5 t/ha in poor grass growing regions, to 15-20 t/ha in the best areas of the UK, such as lowland western Britain;
- Average UK forage yields under moderate total nitrogen inputs (100-150 kg N/ha/year) are typically 6-8 t/ha under grazing, and 8-10 t/ha under management with less-frequent defoliation, with cutting for silage and some subsequent grazing; and
- The quality of grassland and feedstock is important but this has not been assessed for the CCRA. However, it is possible that an increase in quality may be as beneficial as an increase in yield.

- Grassland production follows an uneven seasonal distribution:
  - Cutting and conservation (mostly as silage) are necessary to meet feed demands in winter (or other times of feed deficit);
  - Most grassland farms have a year-round feed requirement, so the area available for silage and its potential production is a key determinant of farm output; and
  - Any climate-change implications for silage production from grassland require particular consideration.
- Based on a 'workable days' approach, a recent Defra (2010c) research project found that at a national level, soils are projected to be slightly less vulnerable to compaction due to climate change. However, in some regions, higher soil moisture contents would persist so that the localised threat of soil compaction would remain.

Similar grassland systems exhibit similar sensitivity to rises in temperature; for example, for grass-clover swards, yields increase by approximately 15% per degree warming. Projecting this relationship forward using UKCP09 suggests increases in yield of between approximately 20% for the 2020s medium emission scenario (range 11% to 31% for p10 to p90) rising to 35% (range 18%to 53% for low p10 to high p90) for the 2050s and 49% (range 24% to 54% for low p10 to high p90) for the 2080s[52], although in some parts of the UK this increase may be limited by drier conditions associated with higher temperatures. Table 4.1 summarises the potential increases in yield for the 2020s and 2050s.	Medium confidence

Table 4.1 Effects of changes in mean annual temperature on dry matter yield (%) for grass clover swards assuming that growth is not limited by lack of water or nutrients (Medium emissions scenario, lower, central and upper estimates)

	2020s			2050s		
Selected UKCP09 Admin Regions	**l**	**c**	**u**	**l**	**c**	**u**
North West England	11	21	31	21	*35*	*51*
Northern Ireland	10	19	28	20	*32*	*46*
Scotland North	9	18	27	17	29	*44*
South West England	12	22	33	24	*38*	*54*
Wales	11	20	31	22	*36*	*54*

Notes: These estimates are based on impacts modelling using older climate change models. Changes up to an increase in yield of 30% are within the range of modelled values (high confidence) but numbers in

[52] The 2080s data should be treated with caution as, due to there being no modelled outputs from UKCIP98 data, the projections have been extrapolated based on temperature, CO_2 and precipitation, from the 2050 figures.

brown italic font are based on extrapolation of existing data (low confidence). Full details of this analysis are included in the Agriculture Sector Report.

4.2.2 Livestock production

The effect of changing baseline conditions on livestock systems was based on modelling the entire production system, including the impacts of thermal humidity and heat stress on dairy production. Overall, the average climate conditions do not result in major losses from dairy system production or pose a major risk to dairy production and there are only problems in years with extreme heat. This is likely to continue to be the case in the near term (2020s). Recently there have been occurrences of zero-grazing schemes, with cows being kept indoors year-round. Whilst the effects of outdoor heat-stress may be reduced, there will be a need for effective ventilation to prevent high internal temperatures reducing productivity. Animal welfare considerations aside, this could increase milk-days and prevent reduced fertility.

- Increases in thermal humidity only begin to become relevant by the 2050s. For example, for the 2050s (Medium emissions) central estimate, the percentage loss of national milk production due to heat stress is projected to be 3 million kg/annum, less than 0.03% of UK current milk production. However, there may be additional costs related to declines in herd fertility due to farm profit and imbalanced milk supply country wide. This may impact on transport and delivery costs and subsequently affect the price of milk nationally.
- Consequences in the 2020s and 2050s become more significant under some scenarios with more humid and hotter conditions to the extent that they would impact on farmers operating on low margins and regional economies that rely on export of dairy products.
- Increases in grassland yield and quality should benefit livestock production, particularly meat production. However, the overall impacts on farming systems depends upon how farmers adapt and whether they increase production or achieve similar levels of production with less intensive inputs.
- Heat stress is unlikely to directly impact on housed livestock and poultry as long as the climate of their housing is actively managed. There could be an impact on farm energy costs however, to maintain suitable housed temperature conditions during periods of extreme outdoor temperatures. Furthermore, shelter and housing must be robust enough to withstand an increase in extreme events to ensure animals are properly protected. Transportation of livestock and poultry is another area where temperature management may become increasingly important.
- Any increase in the severity of extreme events could result in disruption to the transport infrastructure or supply chains (Transport Sector Report) on which producers rely on. This could affect animals in transport or cause costly delays in getting fresh produce to markets, impacting on quality and price.

To determine at what point an animal becomes heat-stressed the category of animal (e.g. milking dairy cow, growing calf) was assigned a Thermal Humidity Index (THI) value above which it was assumed they began to feel discomfort/heat stress. The THI combines temperature and humidity and is a measure of the degree of discomfort experienced by an individual animal in warm weather, and is calculated using daily weather data (Chapter 3). Further research (project code AW0513) is being undertaken by Defra on animal welfare issues[53] and will provide a more detailed analysis.

[53] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17724&FromSearch=Y&Publisher=1&SearchText=AW0513&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

4.2.3 The response of crops

Yield variability with climate has been assessed for sugar beet (reference arable crop), wheat (reference arable crop) and potatoes (reference field vegetable crop)[54]. Reasonable historical relationships exist between UK crop production and climate variability from which response functions have been developed. Application of these response functions to future climate provides an initial indication of the potential risks.

However, other climate related factors (including CO_2 fertilisation and climate extremes) and changes to farm practices regarding crop, water and nitrogen management need to be integrated into biophysical (crop) modelling approaches to provide robust estimates of future change. Overall, changing baseline conditions of warmer temperatures and CO_2 fertilisation could push yields upwards whereas more extreme climate conditions (floods, droughts, heat and cold periods) may disrupt production more frequently by the 2050s.

Positive impacts on yield:	**Disruptions to production:**
Warmer temperatures	Increased frequency of floods
Increasing atmospheric CO_2 concentration	Increased frequency of droughts
Fertilisation	Pests and diseases
Extremes of temperature	Storms (lodging of crops)
Breeding / Genetics	*Further potential risks are discussed in the sector reports and are included in the Tier 1 list in Appendix 4.*

New analysis completed for the CCRA used historical national yield data for representative crops of wheat, sugar beet and rain-fed potato to develop yield response functions for changes in climate. As these were based on national data rather than experimental sites they provide an indication of average national changes under a range of different farm conditions.

Most crops will be sensitive to a changing climate with impacts on both land suitability (for existing and new crops) and productivity (yield and crop quality). This assessment considered wheat, sugar beet and potatoes. Of the total 2009 UK agricultural output in terms of market prices, wheat represented over 10%, potatoes a little over 4% and sugar beet around 1.5%. In addition the suitability of a range of more unusual and new crops was considered in detail in the Agriculture Sector Report.

Combined projected changes in rainfall and evapotranspiration (ET) would increase aridity levels and demand for supplemental irrigation, particularly on high-value crops where quality assurance is a key market requirement. Many crops that are currently irrigated would require more frequent and larger applications of irrigation. Whilst yields for arable and horticultural crops have been assessed, the impact of climate change on quality has not been. Although in some scenarios the yield may decrease, an increase in crop quality may have a positive impact.

Over the past decade, some crop yields have increased significantly due to technological or management improvements. Sugar beet yields have increased steadily since 1990 and current average yields are approximately 7 t/ha (processed white sugar). However, average wheat yields have shown little increase and at around 8 t/ha they have failed to increase in line with genetic improvement, suggesting that plant breeding benefits are being given away elsewhere in the production cycle. This

[54] These crops were chosen because they are important crops with national production data available as well as further data from UK research farms, such as Brooms Barn. Rain-fed potato yields have been used as a climate change indicator in previous Defra studies.

might be related to soil degradation, poorer crop nutrition, failure to control weeds, pests and diseases or a combination of these factors.

By combining national data on historical yields with corresponding climate data, several simple yield response functions were developed and used to project future changes in yield due to climate change:

- Sugar beet yields were linked to mean growing season (March to November) temperature;
- Wheat yields were also linked to mean growing season (March to November) temperature; and
- Rain-fed potato yields were linked with variability in mean summer rainfall. This relationship has been used previously as an indicator of climate change (DETR, 1999).

Although these response functions are used to project future changes the quality and yield of crops may be influenced by a range of climatic variables and these should be considered together for a holistic understanding.

Linear relationships are found between temperature and sugar beet and wheat yields, with wheat yield having a greater response and sensitivity. Rain-fed potato yields were greater in wetter summers as adequate water was available to increase tuber mass (Agriculture Sector Report).

These relationships were used to provide an initial estimate of projected yields for future UKCP09 climate projections. The projections indicated large changes with respect to the 1961-1990 baseline period. For example, for the Medium emissions scenario there are projected to be:

Potential increases of wheat yields of 47% by the 2020s for the Medium emissions scenario, central estimate (range 22% to 76%), increasing to 79% by the 2050s for the Medium emissions scenario, central estimate (range 36% to 137%) and 111% by the 2080s for the Medium emissions scenario, central estimate (range 46% to 212%).	Medium confidence
Potential increases in sugar beet yield 23% by the 2020s for the Medium emissions scenario, central estimate (range 11% to 37%), rising to 39% by the 2050s for the Medium emissions scenario, central estimate (range 18% to 68%) and 55% by 2080s for the Medium emissions scenario, central estimate (range 23% to 105%).	Medium confidence
Potential change in potato yields of -2% (i.e. a reduction) by the 2020s for the Medium emissions scenario, central estimate (range -7% to +3%), -5% by the 2050s for the Medium emissions scenario, central estimate (range -12% to +3%), and -6% by the 2080s for the Medium emissions scenario, central estimate (range -18% to +2%). Larger impacts in important potato production regions were projected: -5% (-14% to +4%) in the East of England by the 2050s due to lower summer rainfall; however, more detailed biophysical models project an increase in yield due to CO_2 fertilisation effects.	Low confidence

Note: these projections assume nitrogen availability is non-limiting

Technological advances are likely to offset some of the production losses in some crop sectors - but extreme events will be the exception. Better mechanisation, new technologies, and improved management are all likely to help growers manage future climate uncertainty and risks (Knox *et al.,* 2010a). Benefits may be limited in some areas by availability of water and nitrogen. Future pest control developments including sterilization, plant genetics, vaccination and selective breeding may all act to offset the increased threat from pests and diseases (Foresight, 2011c) and may well lead to future actual potato and sugar beet yields exceeding those projected.

Wheat production - available soil moisture is an important factor both in the early and later parts of the growing season, hence the ability of the crop to exploit the available water resource may become a major determinant of final yield in drier parts of England.

Sugar beet - the increase in yield attributable to climate change is significant but the effect of better exploitation due to technological changes may take yield improvement way above this figure. However, the recent 2010 harvest was affected by extreme cold and wet conditions and illustrates that while the production system is extremely well adapted to average climate, it is less resilient to extreme conditions.

Potatoes - lower summer rainfall would indicate a lower main crop potato yield but these findings were not consistent with recent biophysical modelling studies that considered the impacts of CO_2, fertilisation and climate on potato yield.

- Daccache *et al.* (2011) showed that future potential yields without restrictions in water or fertiliser availability might increase by 13-16%, but that farm yields might only increase by 3-6% due to limitations in water and nitrogen availability. The potential increases are principally due to increased radiation and temperature levels and elevated CO_2 concentration effects.
- Wolf and van Oijen (2003) reported that irrigated tuber yields could increase by between 2-4 t/ha dry matter for most regions of Europe in the 2050s, largely due to the positive response to increased levels of CO_2 concentration.
- However, in Ireland, Holden *et al.* (2003) showed that an increase in future drought potential would threaten the viability of non-irrigated potato production. So while yields may increase in future, benefits may be limited by lower water availability in the longer term prompting movement of growers to suitable locations with water available for abstraction.

The response of potato yields to projected changes in climate is uncertain. Whilst there may be negative impacts due to reduced summer rainfall, detailed modelling of individual potato varieties shows that this could be offset by the positive effects of CO_2 fertilisation (Agriculture Sector Report). Although this assessment considers the detailed modelling as well as the simplistic response to lower summer rainfall we have assigned 'low' confidence to the results. Further work and modelling is needed to provide a robust national assessment.

CO_2 fertilisation may bring greater productivity to a wide range of crops, although there is considerable uncertainty regarding to what extent, if any. For many species greater CO_2 results in more efficient use of water and a larger root density. This potentially acts to partially alleviate projected drought pressures and benefits will only occur if plant growth is not limited by water and nitrogen availability. Europe may see increased yield due to CO_2 fertilisation in the short-term, but longer term projections are even more uncertain (Foresight, 2011b). For other species greater CO_2 concentrations may alter leaf/sheath ratios, reduce nitrogen uptake and increase fibre content lowering the quality of the plant.

4.2.4 Forest production

Similar findings are evident for forestry as for agriculture, based on other detailed modelling studies. For example, model simulations of the growth of oak in southern England suggest that during the 21st century, there may be an increase in productivity despite the projection of a reduction in summer rainfall for this region[55]. Changing baseline conditions of warmer temperatures and CO_2 fertilisation could push yields

[55] http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-626MXH

upwards whereas more extreme climate conditions (floods, droughts, heat and cold periods) may disrupt production more frequently by the 2050s.

Positive impacts on yield:	**Disruptions to production:**
Warmer temperatures	Increased frequency of floods
Increasing atmospheric CO_2 concentration	Increased frequency of droughts
Increased rainfall (north and west)	Waterlogging
	Pests and diseases
	Further potential risks were discussed in the sector reports and are included in the Tier 1 list in Appendix 4.

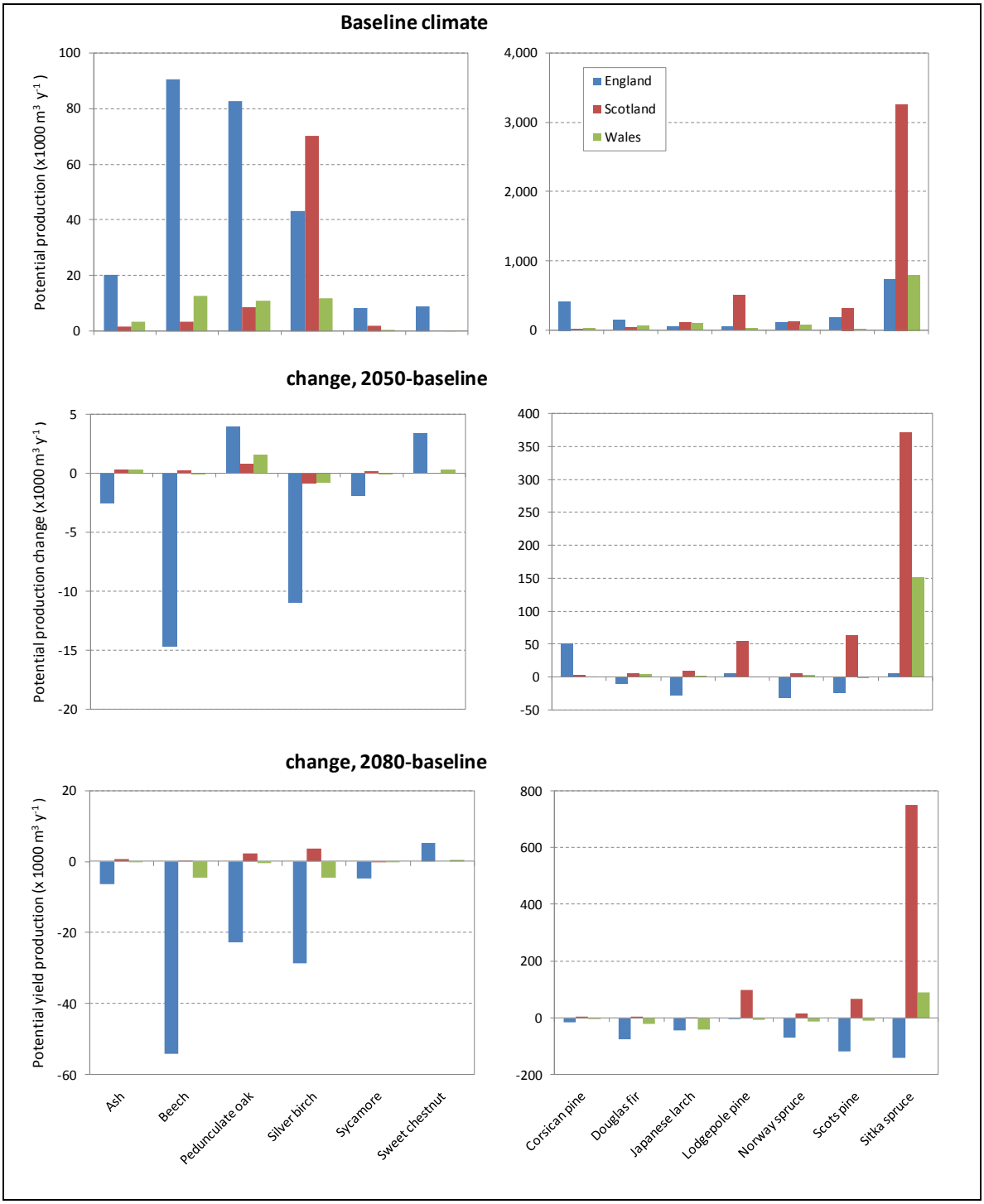
Climate change is expected to have substantial impacts on tree biology, and hence on survival and growth. In turn, these would determine forest productivity, as measured by the rate of timber volume production. For the CCRA, the response of the tree productivity metric to current and projected climate change was explored using Forest Research's Ecological Site Classification (ESC) for Forestry software tool (Pyatt *et al.*, 2001), at a national and regional scale for the public forest estate across Great Britain. The tool was applied to the public forest estate only because there is reasonable information on soil type linked to species distribution for public sector forests. Potential production was estimated as modelled yield class multiplied by existing forest area managed by the Forestry Commission for that species. The calculations have not included any estimate of changing areas in the future. Analyses on different species are shown in Figure 4.2 and in the Forestry Sector Report.

In general, projected climate is likely to detrimentally affect most conifers in England by the 2050s and Wales by the 2080s, whereas potential production in Scotland is projected to increase; markedly so in the case of Sitka spruce, Scots pine and lodgepole pine, where regional variations in soil and nutrient supply allow. Only Sitka spruce production may increase consistently in Wales although Norway spruce is projected to increase in production up to the 2050s, before falling below the baseline by the 2080s. For broadleaved species, there is a uniform picture of declining production in England, but modest increases in some species in some parts of Scotland. Only ash is projected to yield more in Wales, and only by the 2050s in south Wales.

It should be noted that using public forest estate data does not reveal all possible impacts and risks, because the public estate is only 28% of the total area of woodland in the UK. There are unknown differences in species, site types, soils and management between private and public forests. In some areas such as south-east England, the public forest estate is only 14% of total woodland cover, and is dominated by coniferous species, in contrast to privately owned woodland. Therefore, Figures 4.2 and 4.3 under-estimate the likely impact on total production in south-east England, where climate change is expected to exert its earliest and largest effect.

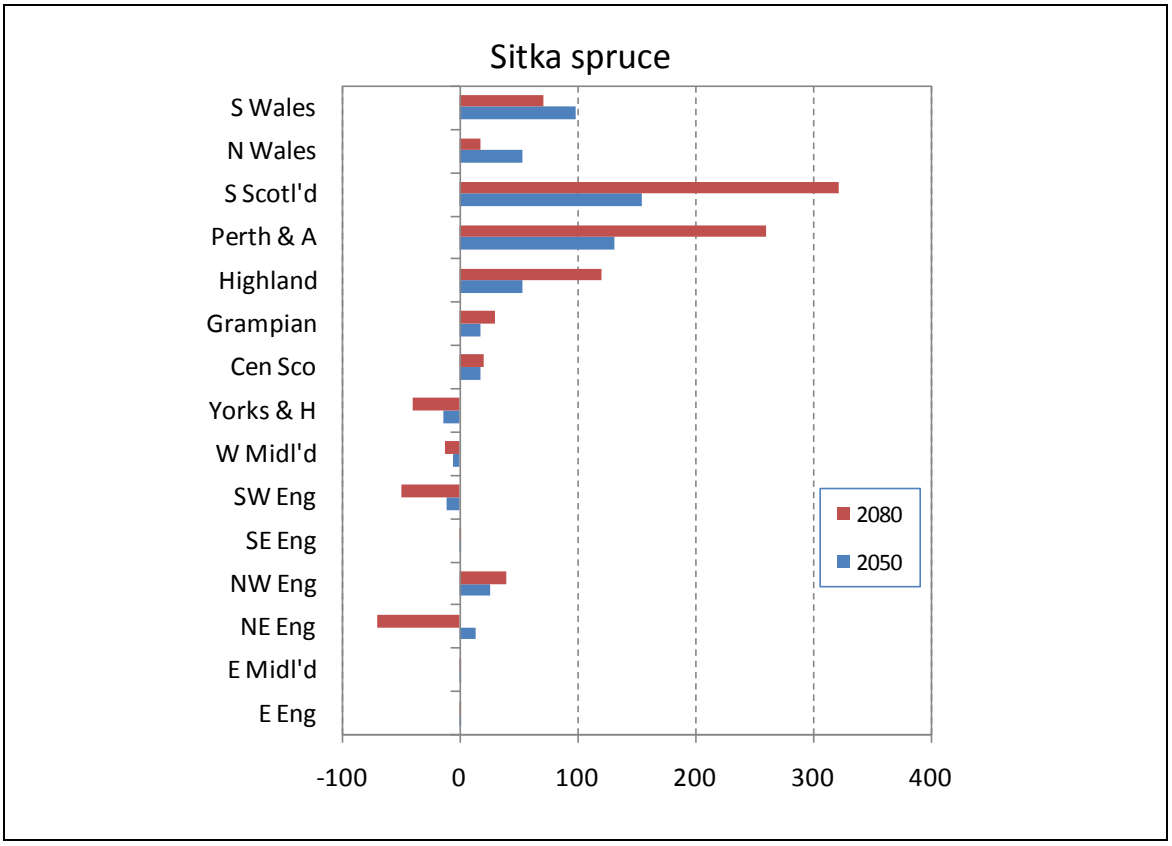
Figure 4.2 Potential production for the 1961-1990 climate (baseline) for selected tree species and the change for projected climate conditions in the 2050s and 2080s on the public forest estate in different countries, assuming areas for each species remain unchanged

(Note the difference in scale between periods and between conifer and broadleaved species)



The broad grouping of results into the three countries hides some important regional differences due to climate. This is particularly the case for differences in projected potential production between the east and the west for species more suited to wetter than drier conditions (e.g. Sitka spruce, shown in Figure 4.3).

Figure 4.3 Change in potential production (*1000m^3/y) in the 2050s and 2080s for Sitka spruce on the public forest estate in different regions compared to baseline (assuming areas remain unchanged)



4.2.5 Impacts of climate change on European agriculture and forestry

Agriculture

UK agriculture operates within the framework of the European Commission and as part of a global market. The comparative advantage of different countries to grow specific crops is expected to change. In broad terms Northern Europe may benefit, while conditions in Southern Europe may become less favourable. Suitability of individual regions for particular crops may also change within the UK.

Extreme events can disrupt global markets, for example drought and potato crop failure in Russia in 2010 led to the first ever shipments from Northern Ireland[56].

Supit *et al.* (2010) studied the impacts of changing temperature and global radiation patterns on potential yield of several crops grown in Europe. The resulting general trend was negative in the southern areas and positive in the northern regions. The results of this study are presented in Figure 4.4 and Figure 4.5. The maps indicate the long term trend in yields, with significant increases in red and declines in blue.

[56] http://www.bbc.co.uk/news/uk-northern-ireland-11904572

Figure 4.4 Recent trends (1976-2005) in the simulated potential yield of wheat and barley
(Source: Supit *et al*., 2010)

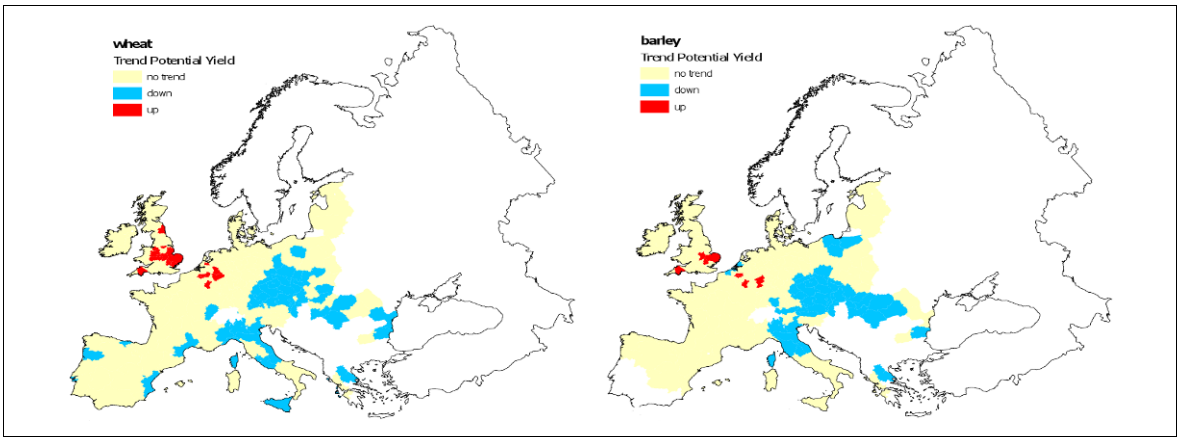
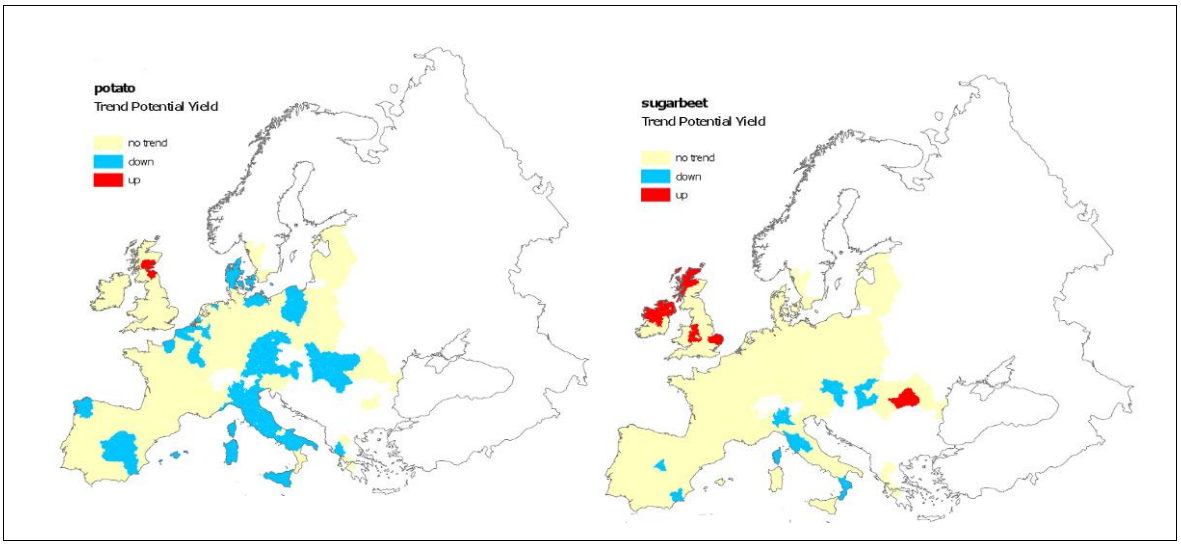


Figure 4.5 Recent trends (1976-2005) in the simulated potential yield of potato and sugar beet
(Source: Supit *et al*., 2010)



The tendency in the UK is:

Positive for:

Wheat (+0.06 t/ha/year)

Barley (+0.05 t/ha/year)

Maize (+0.09 t/ha/year)

Sugar beet (+0.09 t/ha/year)

Pulses (+0.03 t/ha/year).

Negative for:

Rapeseed (-0.04 t/ha/year).

These findings are significant in the context of European production and show that the UK and northern France may increase their comparative advantage for wheat, barley and sugar beet. At a UK regional scale these maps also illustrate that land suitability for potatoes and sugar beet could change within the UK. For potatoes areas further north may become more suitable, particularly where water is available in summer months. For sugar beet, processing infrastructure is based in the East of England and this area

shows an increase in yield so should benefit. It appears that other areas may also become suitable but more detailed UK assessments are needed to confirm this.

Where crop suitability assessments suggest opportunities, there is a need to consider the local factors such as drainage, climate and topography. Additionally, there is a need to make an assessment and judgement on the value of what is being displaced, and whether the change is beneficial overall. This could also have important knock-on effects on the biodiversity of the area, as a changing climate space can severely damage and disrupt ecosystems and affect ecosystem services within the area (Chapter 8).

Summary

- Different climate drivers may have opposite effects and the net impacts of climate change can only be determined using detailed impact models.
- Changes to extreme events are of more significance than changing average conditions so a better understanding of the impacts of floods and droughts is needed in future assessments.
- Overall, climate projections suggest that there are opportunities for UK forestry and agriculture to increase production and efficiency in the near term but this may have to be achieved with:
    - Less water available
    - Lower 'carbon costs'
    - Changes in other factors that are likely to have much greater influence than average climate conditions
    - Trade-off with other ecosystem goods and services currently provided or expected.

Forestry

In the context of the market prices for timber, any changes to UK prices need to be seen in the context of European and even world timber prices, and supply and demand changes, especially in the context of the effects of climate change in other regions. This is beyond the scope of this study, but it is highlighted as a key issue.

Current Common Agricultural Policy (CAP) mechanisms can inhibit new woodland establishment by encouraging agricultural husbandry. In addition, an EU forestry strategy that might counterbalance other land use interests and promote the forestry sector is in the process of revision[57]. The European Commission proposed a European approach to forest protection from climate change in a green paper on Forestry and Climate Change[58] but this has not been supported.

Domestic and European energy policies may affect tree species choice if an increasing proportion of woods and forests are managed for renewable energy production from woody biomass. Species such as Eucalyptus are being seriously considered in this regard.

[57] http://ec.europa.eu/agriculture/fore/events/15-04-2011/report_en.pdf
[58] http://ec.europa.eu/environment/forests/pdf/green_paper.pdf

4.3 Damage and disruption to production systems due to drought, floods, storms and pest and disease outbreaks

In agriculture, occasional weather disruption is inevitable but any increases in frequency of events may change the suitability of land for particular crops and have economic impacts. Plantation forestry systems are relatively robust as considerable early research was invested in choosing tree species that can withstand weather conditions considered 'extreme' in the UK. However, storm events may still have significant consequences for forests and woodland (Quine and Gardiner, 2002).

Agricultural and forestry production systems are vulnerable to extreme weather conditions including:

- Extreme heat
- Extreme cold (frosts, snow and ice)
- Wind storms
- Heavy precipitation (including hail)
- Floods
- Droughts
- Wildfire

4.3.1 The impact of drought on forests

It is widely recognised that drought influences tree health, growth and productivity and can ultimately cause tree mortality, often when in combination with other stresses such as pests and pathogens (Read *et al.*, 2009). Due to the long-term nature of forest production, once impacted, subsequent development and final wood quality may be affected; therefore the consequences may be felt sometime after the initial impact has occurred.

Very dry summers have caused serious damage to tree stands, particularly in species that are not well suited to site conditions.

- In 1975 and 1976 two consecutive dry summers caused serious damage and die back to beech trees in the New Forest (Mountford and Peterken, 2003).
- Very dry summer periods have also caused damage to Sitka spruce on shallow freely-draining soils in eastern Scotland.
- Affected trees have been shown to exhibit 'shake' (stem cracking), rendering the timber to be of poor quality and of no structural use.
- Examples of this type of damage occurred in spruce forests in eastern Scotland in 2003. Droughty conditions can also be the precursor of grass and forest fires (see Chapter 3).

A response function for the proportion of severely defoliated trees and yield loss as a result of dry conditions was produced using data from Read *et al.* (2009). Warmer and drier conditions cause greater percentage increases in impact, although the impact on yield loss is greater than the impact on defoliation. However, this only provided a preliminary assessment and more detailed biophysical modelling is needed to integrate multiple climate drivers with other factors affecting growth.

Beech woodland in the south of England is likely to decrease due to the tree's vulnerability to drought. The response of beech woodland is not linked to a specific climate variable and the range of soil type and topography which beech populates means that it is unlikely to be lost completely (Chapter 8).

It is worth noting that in Scotland, where other climate factors (such as accumulated temperature) are limiting, the impact of drought in isolation may be minimal (Broadmeadow, pers.comm.).

Projected yield losses, compared to those expected for the current climate, are small for the 2020s, rise in the 2050s and are significant for the 2080s (Table 4.2). As forests need to be planned considering long term yields, the potential for drier conditions is important for forest management.	Medium confidence

Table 4.2 Percentage loss of forest yield based on relationship with potential soil moisture deficit

Region	Baseline	2020s			2050s			2080s			Emission Scenario
		l	c	u	l	c	u	l	c	u	
South East England					11	17	22	12	17	23	Low
	14	11	15	20	13	17	23	14	19	24	Medium
					13	18	23	15	20	26	High
Wales					10	14	19	11	15	20	Low
	10	9	12	16	12	16	22	13	18	24	Medium
					12	16	22	15	21	29	High
Northern Scotland					10	13	17	10	14	18	Low
	10	9	12	15	10	14	18	12	15	20	Medium
					11	14	18	13	17	23	High

4.3.2 The impact of heatwaves and drought on agriculture

Observations already suggest that heatwaves have become more frequent over the twentieth century, and that it is possible that this trend will continue.

- It is estimated that human activities have doubled the risk of 2003 heatwave summer temperatures occurring in Europe (Stott *et al.,* 2004).
- The greatest impacts on agriculture were in mainland Europe, for example a record yield loss of 36 per cent occurred for corn grown in the Po valley in Italy (Ciais *et al.,* 2005).

However, assessing the impacts of drought on agriculture and horticulture is not straightforward for a number of reasons:

- The current generation of climate models is not highly skilled at projecting extreme drought (Chapter 2).
- Recent research (Semenov, 2009) suggests that despite higher temperatures and lower summer precipitation, the consequences of drought stress on wheat yield is projected to be smaller than that at present, because wheat could mature earlier in a warmer climate and avoid severe summer drought.

- Although potato yield is greater with increased rainfall, the impact of greater atmospheric CO_2 concentrations increasing yield could potentially negate drought impacts.
- The probability of heat stress occurring around flowering which could result in considerable yield losses is projected to increase significantly. Growers may thus have to contend with increased risks of drought on crop growth in April and May and make choices about how best to avoid yield losses.

Extreme events can lead to near or total crop failure and any increase in the frequency of extreme events would increase this risk. Mechler *et al.* (2010) studied the impact of extreme events on crop yield in UK agricultural production since the 1970s. Conclusions drawn were:

- Some current crop production systems have shown some adaptation to these events and others have not.
- Each subsequent drought or heatwave (1975/6, 1983/4, 1992, 1995, 2003, 2006) resulted in a lower impact than the previous event on potatoes and oilseed rape yield, showing a gradual adaptation.
- Crops such as barley did not show any adaptation. However, any of the events which occurred after the first drought (1975/6) had similar consequences in terms of lost yields.
- The agricultural sector responded to the 1975/76 event by putting in place systems to avoid similar damages from possible future similar events. In potatoes, for example, the installation of irrigation systems started to be popular after this drought.

Access to water resources is a key factor for adaptation in the arable and horticultural sectors. If growers cannot get access to water through storage schemes or abstraction licences they may either need to relocate to areas where water is available, diversify into different crops or find other methods of adapting to greater risk of drought.

Box 4.1 Agricultural drought in Spring 2011

The recent drought in spring 2011 demonstrated the widespread impacts of drought on agricultural crop yields. In East Anglia there were reports of losses between 20-50% in some crops while others (e.g. linseed) exhibited no spring growth having remained as seed in the ground since the first week of March (Mason and Gray, 2011). Crop quality was also affected. The lack of rain resulted in the loss of smaller plants resulting in a thin crop, with the additional problem of a lack of crop colour and fewer shoots, with a consequent lack of wheat 'ears' lowering crop value. Some farmers expected about a 25% loss in value (Mason and Gray, 2011) as a result.

The ADAS Harvest report published on 10th August 2011 stated that with 80% of the UK Winter Barley harvested, the average yield is estimated at 6.0 t/ha. This is 8% lower than the 5 year average. For Winter Oilseed Rape, 86% of the crop had been harvested with an average yield of 3.8 t/ha, which is 15% higher than the 5 year average (although this includes Spring Rape) and over 7% higher than 2010. For Winter Wheat it was still too early to form any firm conclusions because apart from the south-east the harvest had really only just begun (only 5% harvested nationally). A very early estimate puts the yield between 7.0 and 7.4 t/ha (with a wide variation in yield between soil types) which would put production down between -3 and -8% compared to last year.

While the drought clearly affected some regions and farming businesses, an approximately 10% loss of production may be close to the final figure and is within the ranges previously observed.

4.3.3 Heavy rainfall and flooding

UKCP09 projections suggests an increased risk of heavy rainfall in winter months, leading to an increased potential for soil erosion, increases in landslides (including in forests) and an increasing frequency of river and surface flooding (Chapter 3).

- Heavy rainfall events that lead to flooding can wipe out entire crops in the floodplain, and excess water can also lead to other impacts including water logging, anaerobic soil conditions and reduced plant growth (Gornall *et al*., 2010).
- On vulnerable soils increased soil erosion may damage soil structure and reduce soil fertility leading to long term soil degradation; it would also have impacts on water quality of water bodies receiving the sediment and any associated nutrients or pesticides.
- Relative sea level rise also increases the risk of tidal flooding that can affect large areas of coastal land, particularly in the east of England.

A detailed analysis was completed on the Agricultural Land Classification (ALC) data set to estimate the areas of agricultural land flooded to depths exceeding 0.5m from rivers and the sea for selected future scenarios. Agricultural land is generally not as well protected from flooding compared to residential and non-residential areas, and frequent flooding may make the land unviable for high value crops and difficult for the use of machinery at key times of year. The analysis suggests:

In the near term (2020s) there are small increases in the area of high quality agricultural land flooded frequently. Currently in England and Wales 31,000 ha of good quality agricultural land are flooded from the sea or rivers once in every three years. The area flooded only increases to 36,000 ha for the 2020s Medium emissions scenario (central estimate). In the medium term (2050s) there may be a greater than two-fold increase in the area of high quality agricultural land flooded frequently. The area affected in England and Wales once in every three years is projected to rise to 75,000 ha for the 2050s Medium emissions scenario (central estimate). In the longer term (2080s) there may be more than a four-fold increase in the area of high quality agricultural land flooded frequently. The CCRA analysis results indicate that 128,000 ha in England and Wales Medium emissions scenario (central estimate) may be affected, but the range in the results is large.	High confidence

The risks of flooding are currently greatest in the Midlands and South West England but could increase across England and Wales. Figure 4.6 shows the results for UKCP09 regions in England and Wales and Table 4.3 gives the absolute figures compared to the current baseline.

In the near term (2020s), the CCRA analysis indicates small increases in the area at risk of frequent flooding (33% annual probability, 1 in 3 years, or greater) but larger increases in area are projected for flood frequencies of 1 in 10 years or greater. The area of Grade 1, 2 and 3 land flooded by regularly occurring events (33% annual probability or greater) could increase from a baseline of about 30,000 ha in England and Wales to about 35,000 ha by the 2020s. Furthermore, this could double to about 75,000 ha by the 2050s and reach 130,000 ha by the 2080s, about four times the present day area. Total agricultural flooding from a 1 in 10 year, or more frequent, event may increase from approximately 200,000 ha to 500,000 ha; this corresponds to an increase from 2% of total agricultural land to about 5% based on the current agricultural land area of England and Wales. While this is a small proportion of overall land affected, the local consequences may be significant, for example for businesses

reliant on high quality horticultural and arable land (Grades 1-3) located in river floodplains.

Although land may not be lost through flooding, the potential reoccurrence of flood events would make the land untenable for everyday agricultural use, and therefore unable to be used for its intended purpose.

Table 4.3 Areas of agricultural land flooded from rivers and the sea in England and Wales (ha)

Frequencies of less than 1 in 3 years, 3-5 years and 5-10 years for agricultural land classification grades 1 to 3 (horticulture/arable) and 4 and 5 (grassland/grazing), for 2020s, 2050s and 2080s Medium emissions scenarios.

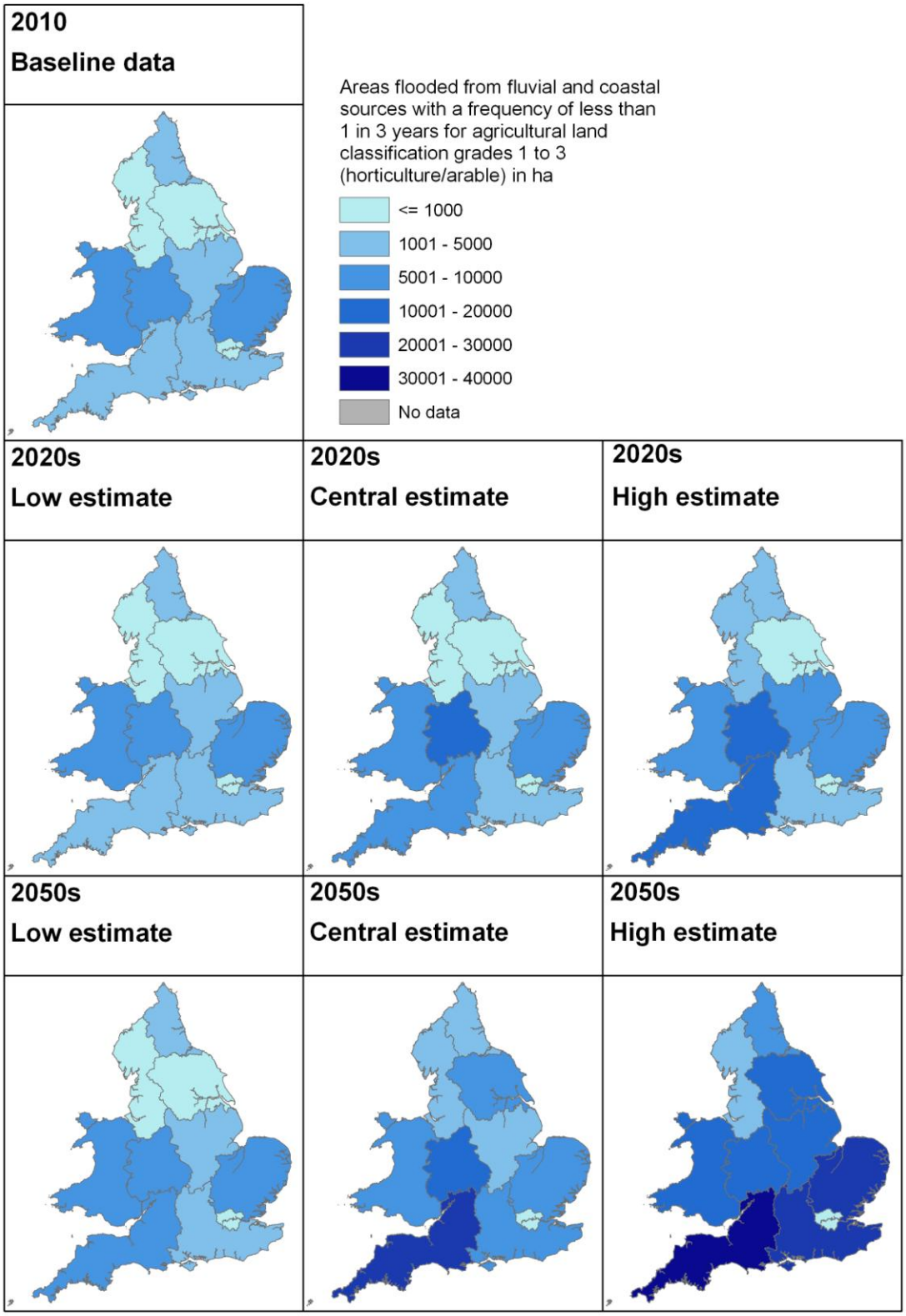
Tidal	Grades 1,2,3			Grades 4,5			Total
Scenario	<3	3 to 5	5 to 10	<3	3 to 5	5 to 10	
2008	5,200	2,000	10,100	3,400	1,300	5,200	27,300
2020s	5,200	5,100	26,700	3,500	2,100	9,700	52,100
2050s	17,400	17,400	25,200	6,400	7,800	5,400	79,600
2080s	42,700	23,800	41,000	16,200	4,700	4,800	133,200

River	Grades 1,2,3			Grades 4,5			Total
Scenario	<3	3 to 5	5 to 10	<3	3 to 5	5 to 10	
1961-1990	24,300	9,900	44,400	15,100	8,300	43,400	145,300
2020s	28,900	32,400	50,700	19,600	33,600	40,200	205,400
2050s	40,100	38,600	68,500	32,000	35,600	47,400	262,200
2080s	54,400	42,900	79,400	43,000	38,700	47,100	305,400

River and Tidal	Grades 1,2,3			Grades 4,5			Total
Scenario	<3	3 to 5	5 to 10	<3	3 to 5	5 to 10	
1961-1990	1,700	1,400	9,500	3,300	1,700	4,800	22,400
2020s	1,800	7,200	17,100	3,500	2,800	7,000	39,400
2050s	17,600	8,000	11,300	7,300	5,900	3,500	53,600
2080s	30,600	10,600	23,400	14,600	3,000	3,700	85,900

Total	Grades 1,2,3			Grades 4,5			Total
Scenario	<3	3 to 5	5 to 10	<3	3 to 5	5 to 10	
1961-1990	31,200	13,300	64,000	21,800	11,300	53,400	195,000
2020s	35,900	44,700	94,500	26,600	38,500	56,900	296,900
2050s	75,100	64,000	105,000	45,700	49,300	56,300	395,400
2080s	127,700	77,300	143,800	73,800	46,400	55,600	524,500

Figure 4.6 Areas of high quality agricultural land in England and Wales projected to flood frequently under a range of future UKCP09 scenarios



Dealing with widespread flooding, covering a large area during the same flood event, is particularly problematic and has high costs in terms of crop damage. Disruption to transport infrastructure can be significant and disrupt the supply chain (Transport Sector Report and Chapter 7), impacting on produce quality and prices.

Table 4.4 Estimated economic costs to agriculture of the summer 2007 flood in England

Sector	Area flooded (ha)*	Loss (£ million)**	Average loss (£/ha flooded) **
Arable	26,500	34.3 (±9.2)	1,293 (±347)
Grassland and livestock	15,600	10.1 (±6.5)	647 (±416)
Other costs		4.2 (±2.0)	100 (±48)
Total	**42,100**	**48.6 (±17.7)**	**2040 (±811)**

*Based on ADAS (2007) using EA sources; **95% confidence interval. Source: Chatterton *et al.* (2009) – (95% confidence limits are shown in brackets)

If the costs for the 2007 floods are used to support an analysis of future impacts (see Table 4.4), the total costs of frequent flooding of agricultural land are £66 million per year by the 2050s.	Medium confidence

Waterlogging

The total number of unworkable days per year due to waterlogging for the agriculture sector is projected to change very little, based on limited analysis of sample sites in Scotland and Northern Ireland (Scotland Report and Northern Ireland Report). However, the analysis suggests that, as a consequence of increased winter rainfall, the proportion of unworkable days that would be projected to occur during the winter would increase slightly. In a very few instances (for very dry climate projections) where dramatic decreases in unworkable days per year are projected, there may be an associated decrease in the number of unworkable days through the winter period.

For the forestry sector, trees that have limited rooting depth on waterlogged soils will be less wind-stable than trees on free draining soils, and therefore have an increased risk of wind damage.

4.3.4 Pests and diseases

There are serious concerns that existing or new pests and diseases may become more effective in a warmer climate and cause major damage to crops, livestock and trees.

Agricultural pests and diseases

Recent research shows that many pests and pathogens exhibit considerable capacity for generating, recombining, and selecting traits that increase their prevalence. So there is little doubt that any opportunities resulting from climate change would be exploited by them.

Considerable research and development has gone into improving crop agronomy with the aims of eradicating climate related diseases. For example, potato blight improvements have been so effective that there are no discernable relationships

between national records of disease and climate variability. Analyses were completed for yellow rust in wheat, beet mild yellow virus (BMYV) in sugar beet and blight in potatoes. In all cases, these crops exhibit reduced effects of climate variability on disease.

Regarding livestock, Haskell *et al.* (2011) reports that environmental change has been implicated as one of the driving forces for range expansions of several classes of pathogens, with changes in climate affecting both established infectious diseases (parasitic and viral) and the emergence of new diseases, such as a Blowfly strike (Morgan and Wall, 2009).

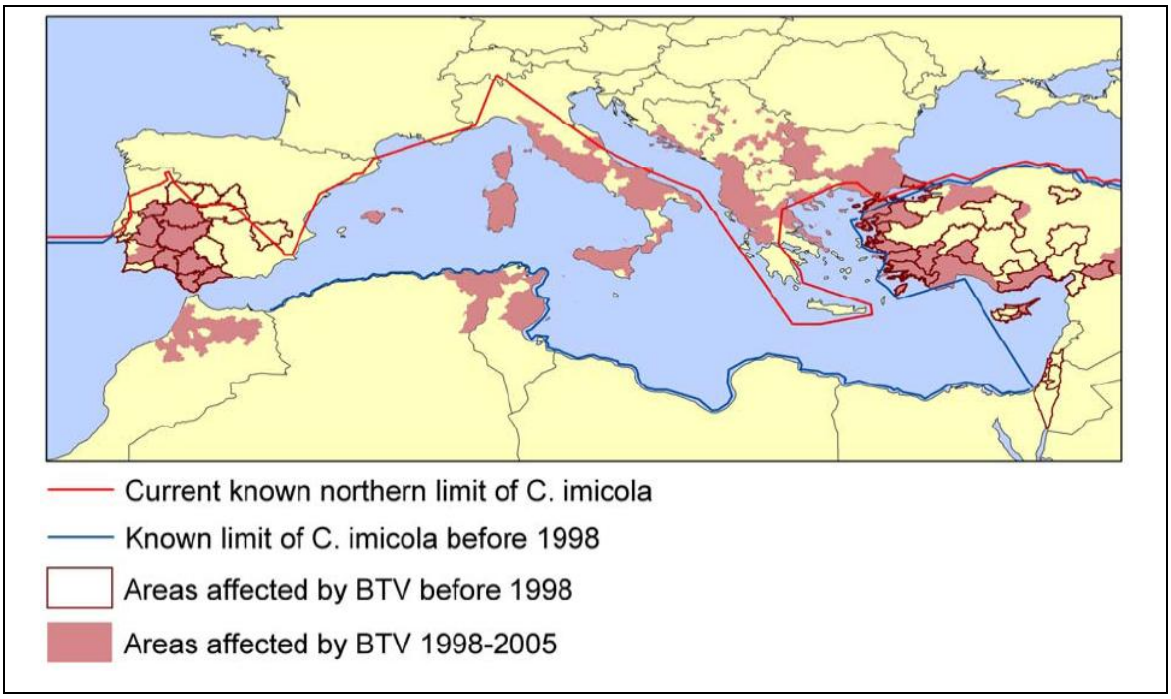
Based on a qualitative assessment, the evidence that climate change will increase pests and diseases is weak (and this is the reason it is considered too uncertain to assess in Figure 4.1). The interactions between crops, pests and pathogens are complex and currently poorly understood in the context of climate change. More mechanistic inclusion of pests and pathogen effects in crop models would lead to more realistic projections of crop production at regional scales and assist in the development of robust climate change risk assessments (Gregory *et al.*, 2009).

Bluetongue virus (BTV)

Bluetongue (BTV) causes serious illness and potentially death in ruminants, including sheep, cattle, goats and deer. Historically, in Europe and North Africa, the species *Culicoides imicola* was the principal Mediterranean vector of the disease, confining outbreaks of BTV to northern Africa, with only a few sporadic instances occurring in southern Europe. Since the 1990s, the incidence of BTV has moved northwards in Europe by 800 km across at least 12 countries (see Figure 4.7). The increase in the area is linked to *Culicoides* midges such as *C. obsoletus* and *C. pulicaris* becoming vectors although it is not fully understood why other *Culicoides* midges became vectors; however, it may be partly climate-mediated. These new vectors inhabit areas that are cooler and wetter. There are evidence gaps in the role of indirect effects and non-climatic drivers which need addressing before a robust link to climate can be made. However, it is possible that rising temperatures, possibly leading to increased population sizes and duration of seasonal activity of these vectors increases the risk of transmission. Furthermore, increasing temperatures have also been shown to directly increase the vectors' ability to transmit disease.

The Foresight project, Infectious Diseases: Preparing for the Future (Purse *et al*., 2006) suggested that conditions within the UK are suitable for the disease, with high possible vector populations, high host numbers and densities and an increasingly warming climate. Recent work has shown that the UK is at risk from bluetongue outbreaks given its current climate and that the risk is greatest when the temperature is between 15 and 25°C (Gubbins *et al.*, 2011). The arrival of BTV in northern Europe in 2006 illustrated the potential for this disease to spread. However, this outbreak is not explained entirely by climate change but by a complex combination of drivers, including climate, probable increased frequency of introduction, adaptation of the virus to new vectors, and a susceptible local livestock population. BTV transmission may be affected by climate change but the links are complex.

Figure 4.7 European map showing the distribution of BTV prior to 1998 and between 1998 and 2005. The distributional information is taken from an extensive literature review and reported outbreaks of BTV
(Source: Purse *et al.*, 2005)



Forestry pests and diseases

Existing pests and pathogens could significantly threaten tree health and forest productivity further through their response to a changing climate. Although there are a number of scientific papers on the potential impacts of climate change on pests and pathogens, there is little published information available that authoritatively describes the relationship between climate and pest/pathogen impact in the UK. There are also other factors, such as the import of pests/pathogens from abroad and the response of management to deal with pests and pathogens, which influence their spread and effect.

Some evidence does exist that may support the relationship between climate and individual pest and pathogen life cycles (Woods *et al.*, 2005a; Watt *et al.*, 2009; Fabre *et al.*, 2011) with some evidence showing that a number of past outbreaks may have been associated with specific weather conditions (see Chapter 8). However, due to the range of interactions between pests, pathogens and tree species, it is difficult to project any changes with confidence.

- In the East of England widespread impacts on the predominant commercial conifer species, Corsican pine (*Pinus nigra* ssp. *laricio*), are occurring. This is due to the damaging effects of red band needle blight (see Chapter 8) caused by the fungus *Dothistroma septosporum*. Reasons for the increase in disease incidence are unclear but could be due to increased rainfall in spring and summer coupled with a trend towards warmer springs, optimising conditions for spore dispersal and infection (Brown and Webber, 2008). Further research is needed into the causes and drivers of this disease in order to understand the threat and to identify any possible control on the spread.
- There have been concerns about the spread of *Phytophthora ramorum*, which is a fungus-like pathogen for which there is no known remedy. The disease has caused significant damage and mortality to trees in America (where it is known

as Sudden Oak Death) and, after initially spreading to Larch trees in the west of England, has been found throughout the UK. The source of this fungus in the UK is possibly due to imported plants, but it can also spread in the air, through mists and fogs and via animals (see Chapter 8 for further details).

- There are also indications that pests, such as aphids (Newman, 2004) and weevil larvae (Staley and Johnson, 2008), respond positively to elevated CO_2.
- As part of the CCRA some new analysis of red band needle blight and green spruce aphid was completed. These two examples were selected on the basis that they are already present within the UK, and that there is existing research on their characteristics and the conditions surrounding previous outbreaks.
- This risk metric was assessed using a semi-quantitative, expert judgement approach and involved discussion with forestry experts. The qualitative response functions described below assumes a causal link between climate and pest/pathogen damage. As this is a complex subject that requires further research our overall confidence in the results is 'low'.

The outcomes of the analysis indicate that the spread of red band needle blight due to climate would have high consequences for the UK forest estate.

The impact of climate change is greater for red band needle blight than for green spruce aphid. Red band needle blight is likely to reach the high impact level by the 2050s, whereas the projected impact of green spruce aphid is low in the 2050s (see Table 4.5). By the 2050s, over half of all pine forests in the UK could be affected by red band needle blight if the pathogen spreads as identified in the response function. By the 2050s, for the Medium emissions scenario, central estimate, between 13 and 26% of spruce forests in the UK could be affected by green spruce aphid if the pathogen spreads as estimated in the response function.	Medium confidence

Table 4.5 National (England, Wales and Scotland) results for percentage of total forest affected by (i) red band needle blight and (ii) green spruce aphid

Pathogen	Baseline	2020			2050			2080			Emission Scenario
		l	c	u	l	c	u	l	c	u	
	Percentage of total pine forest extent affected										
Red band needle blight	11				11-12	49-98	>98	12-25	49-98	>98	Low
		11-12	12-25	49-98	12-25	49-98	>98	12-25	>98	>98	Medium
					12-25	49-98	>98	49-98	>98	>98	High
	Percentage of total spruce forest extent affected										
Green spruce aphid	10				9-13	9-13	13-26	9-13	13-26	13-26	Low
		9-13	9-13	13-26	9-13	13-26	13-26	9-13	13-26	26-52	Medium
					9-13	13-26	13-26	9-13	13-26	26-52	High

The impact of pests and pathogens in the future is also very likely to be influenced by socio-economic dimensions, particularly in relation to the demand for trade and timber imports, as this is a strong vector for their introduction into the country.

4.3.5 Changes in fire risk to forestry

Forest fires are usually caused by human activity, accidentally or on purpose, but the magnitude of these fires is related to weather conditions and exacerbated by drought, high air temperatures and wind. As well as the direct damage to trees, fire can also increase the susceptibility of surviving trees to insect attack, for example from secondary bark and ambrosia beetles in conifer forests (Chapter 3 and Chapter 8). As a result, the forestry sector can suffer financial loss and be faced with the need to replant lost forest areas.

Fire inevitably leads to loss of habitat, possible threat to important woodland species biodiversity and cultural heritage, and increased risk of soil erosion and water pollution (Gazzard, 2009). Moreover, smoke can inconvenience local residents and road users, and the visual appearance of the area after the fire may deter visitors affecting those businesses that exist because of the forest (e.g. bed and breakfast facilities, formal recreation provision) and, during time of high fire risk, there may be reductions for public access and forest operations.

Appropriate infrastructure has been developed in fire prone regions to reduce the risk of forest fires although a large increase in incidences could stretch the capability of emergency services. However, a change in climate could see new at-risk areas emerge, potentially affecting urban areas, e.g. Swinley Forest fire (Box 4.2). During such events, in part due to the often expansive and simultaneous nature of wildfire events, the Fire and Rescue Service (FRS) can be under severe pressure and may struggle to provide their usual range of services at the same time.

Changes in wildfire risk were assessed in the Biodiversity and Ecosystem Services sector. The outputs from the analysis suggest an increase in the index across the whole of the UK by the 2080s. The biggest increase; from between 3 - 4 on the McArthur Forest Fire Index to between 5 - 6, where a value of 5 to 12 is considered a 'moderate' risk, is in south-eastern parts of the UK (Chapter 3 and Chapter 8).	Medium confidence

Box 4.2 Swinley Forest Fire

April and May 2011 saw many large scale wildfires occur across southern England as unusual periods of dry weather, high temperatures and strong winds provided ideal conditions for fire to start and spread.

One of the most high-profile fires was that in Swinley Forest Berkshire, where 300 hectares were affected during the week long fire during the 1st week of May. Over 300 firemen tackled the blaze which involved participation from 12 fire and rescue services (RBFRS, 2011).

Ideal weather conditions combined with extensive dry fuel and underlying peat allowed the fire to start and spread quickly. Winds of 35kph and temperatures of 30°C caused the fire to bridge gaps allowing it to spread quickly and efficiently. As many of the fire crews only had experience of 'urban' fires they were under-prepared for such a large scale wildfire (Oxborough and Gazzard, 2011).

The fire caused extensive damage to the local economic and environmental sectors. Visitor attractions within the forest anticipated losses of £20,000 due to unfulfilled bookings and, as parts of the forest lie within a Special Protection Area (SPA), habitats and populations of threatened birds including the Dartford Warbler, Nightjar and Woodlark were affected.

Ninety hectares of timber plantation required replanting with an estimated 120,000 trees[59], with the £200,000 cost of replanting compounded by the loss of the 20 year-old timber stock. Regeneration of the forest has, however, focused on the need for fire breaks and a wider range of tree species to help reduce future fire damage[60].

[59] http://www.bbc.co.uk/news/uk-england-berkshire-15124574
[60] http://www.bbc.co.uk/news/uk-england-berkshire-14729349

4.3.6 Changes in windthrow and storm damage to forests

Storm damage to trees is not uncommon across Europe and is particularly relevant to the UK, which has a long history of severe storm damage going back to the "Great Storm" of November 26th 1703. More recently, in October 1987, around 15 million trees were uprooted by gusts of up to 100 mph and in October 2000, widespread damage resulted from gusts up to 93 mph[61].

Some climate change models project wind speeds to increase in parts of Europe, leading to an associated increase in economic losses. These already amount to hundreds of millions of euros each year. Managed forests are particularly vulnerable to economic losses because wind damage increases unscheduled costs of clearing up after a storm and disruptions to planning, as well as the reduced yield of good quality timber (EC, 2008). However, according to the UKCP09 projections, changes in winter wind speed are approximately symmetrical around near-zero change. In the summer, it is slightly skewed towards negative in the UK and slightly positive in Scotland under the Medium emissions scenario for the 2050s[62].

4.4 Opportunities for UK agriculture and forestry

This assessment has shown that there are many opportunities for UK farmers and foresters as well as risks associated with floods, droughts, pest and pathogens and water regulation.

Based on a wide range of evidence, opportunities include[63]:

- Increasing sustainable production:
    - Longer growing seasons allow earlier maturity and harvesting for crops and greater annual yields for wood production;
    - Improved plant growth due to warmer weather and higher CO_2 levels (with adequate water supplies);
    - Opportunities to introduce new or novel crops (e.g. soya, navy beans, sunflowers, peaches, apricots, grapes) and timber species such as Norway maple, Douglas fir and Maritime pine[64]. A list of potential species for forestry is also listed in the Read Report (Read *et al.,* 2009);
    - Reduced frost damage to crops and trees as frosts become milder and less frequent;
    - Changing yields and geographical range of some crops (especially those that are limited by temperature), e.g. suitable regions for maize are likely to increase and move northwards, with the Scots Pine extent squeezed north;
    - Increased possibilities of introducing new livestock species e.g. hair sheep and ostriches; and
    - Increased forest productivity where water is non-limiting (North and West Scotland).

[61] http://www.guardian.co.uk/world/2008/mar/10/weather
[62] Further information on probabilistic wind speeds is provided on the UKCP09 web pages : http://ukclimateprojections.defra.gov.uk/content/view/720/500/
[63] Adapted from the Farming Futures project http://www.farmingfutures.org.uk/sites/default/files/casestudy/pdf/opportunities_and_challenges.pdf
[64] http://www.forestry.gov.uk/fr/INFD-8CVE4D

- Reducing costs:
    - Warmer weather may reduce energy costs for buildings, especially new builds (see Energy Sector Report); and
    - Warmer weather may reduce the need for livestock housing. However, rather than to protect from cold, housing may increasingly be required for shade or under extreme circumstances, active cooling. This would have associated energy requirements, possibly increasing costs.
- Developing new markets:[65]
    - Global markets may be affected more severely by climate change, allowing UK farmers and foresters to take advantage of new markets;
    - Global water scarcity may change international trading patterns and create a greater demand for locally produced food, wood-fuel and wood products;
    - Opportunity to supply new markets e.g. non food crops for bioenergy, new/different food crops and pharmaceutical crops;
    - Provision of ecosystem services; for example, forests acting as carbon sinks;
    - Increasing consumer awareness of 'food miles' leading to increased demand for local food and farmers markets;
    - Longer growing seasons allow for a longer period of supply and greater availability of home-grown produce;
    - Altered lambing and calving patterns to fit grass growth enable a longer period of market supply; and
    - Increasing rural tourism and business opportunities such as accommodation, leisure activities, refreshments and farm shop sales.

The opportunities listed are likely to require a change in more than one climate variable and there is a degree of uncertainty surrounding all future projections. Climatic, environmental, economic and social aspects need to be assessed thoroughly and may direct the response of the sector more than a change in climate.

Changing climate conditions are typically associated with opportunities to grow new crops. Changing agroclimatic and soil conditions influences land suitability, both for existing crops and for potential new crops. A wide range of crops have potential depending on exactly how future changes in rainfall and temperature affect overall land suitability. However, these changing conditions may compromise local biodiversity through the loss of marginal and previously undisturbed lands. In turn, this drop in biodiversity may increase soil erosion and water quality issues. As land becomes more suitable for new crop and tree species, this may be as a result of the drying-out of wetland areas. This has implications on carbon storage and flood control and could permanently damage local ecosystems (Biodiversity & Ecosystem Services Sector Report).

In addition to physical properties such as slope and soil qualities, land suitability depends on climate and land conditions at key stages of the year. It includes issues such as land workability and trafficability as well climate factors such as growing degree days and seasonal precipitation.

[65] This assumes that competing priorities for land use, such as National Planning Policy Framework, forestry targets, biodiversity and energy crops are not limiting

There is thus scope for many new crops to enter production and change the composition of agricultural land use, including for example:

- New food crops (e.g. blueberries, maize, table grapes);
- New energy crops (for biogas, biomass or bioethanol production);
- New pharmaceutical crops (drugs or cosmetics); and
- New industrial crops (e.g. for biopolymers, biolubricants, oil, fibre, paper and pulp).

There are already clear trends in the growth of energy crops and trees, although this is driven by the climate change mitigation agenda rather than a response to biophysical impacts.

There are many studies and a consensus that suitable cropping areas in Europe will shift northwards (Olesen and Bindi, 2002).

- Early climate impacts research showed that the area suitable for maize cropping could shift its northern boundaries around 190 km per decade from the 1990s-2050s (Carter *et al.*, 1992).
- Growing period durations are expected to vary and may be reduced in some crops like cereals and increased in others such as root crops (Olesen and Bindi, 2002).

While these changes are likely to have positive consequences in terms of production and farm diversification there are potential negative consequences for new crops, including changes in nutrient leaching, erosion, soil fertility, water use and habitats and landscape. The shift in areas with climatic suitability for crop or tree species may also be similarly reflected in shifts of “climate space” for the pests and diseases that damage them. As previously discussed in this chapter, bluetongue virus, *Phytophthora ramorum*, green spruce aphid and red band needle blight populations may all be, in part, positively affected by changes in climate.

Broad scale European research suggests some opportunities of yield improvements in maize and pulses in the UK (Figure 4.8 and Figure 4.9). However, the projected declines in yield elsewhere in Europe may be of more significance presenting opportunities to export products to areas with declining production.

It is worth noting that the opportunities described in this section may represent competing and potentially conflicting land use options, with the relative merits varying in time. This will produce challenges for policy makers in weighing up costs and benefits for the long term. Additionally, due to the lack of free space within the UK, a change in climate space of crops may act to displace others. If this occurs in a species rich area then there is a risk to biodiversity and the ecosystem services offered. The opportunity for new crops is likely to include a range of social, economic and environmental factors, and may not be decided by the change in climate.

Figure 4.8 Recent trends (1976-2005) in the simulated potential yield of maize and rapeseed
(Source: Supit *et al.,* 2010)

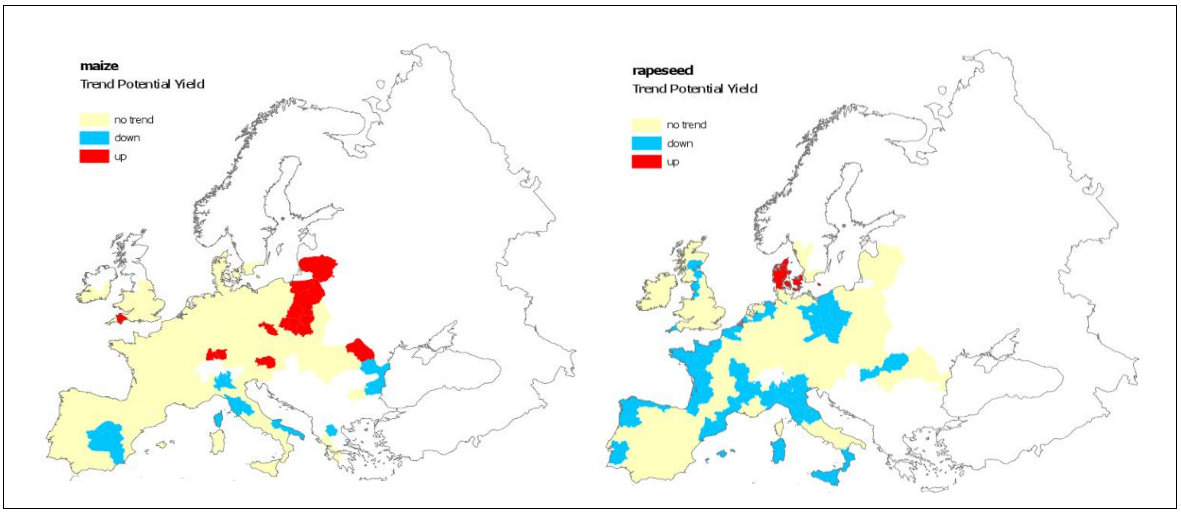
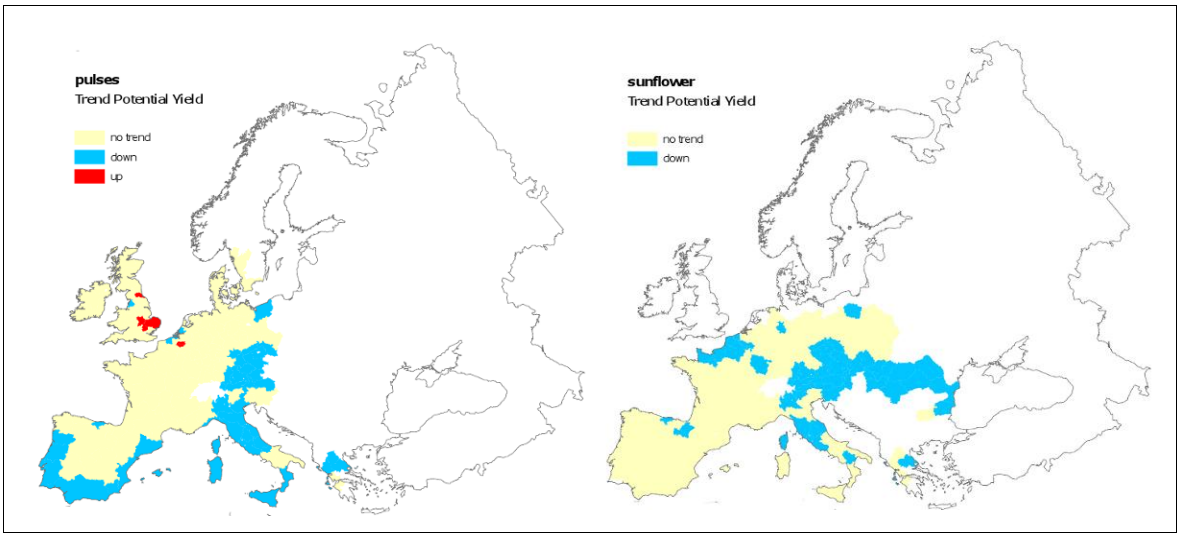


Figure 4.9 Recent trends (1976-2005) in the simulated potential yield of pulses and sunflower
(Source: Supit *et al.*, 2010)



4.4.1 Energy crops

The Government has in place a specific scheme to offer grants for planting of energy crops. This is part of the Rural Development Programme for England and DAs 2007 - 2013, which is jointly funded by the UK and the EU through the European Agricultural Fund for Rural Development. The 2004 Strategy for Non-food Crops and Uses (Defra, 2004) aimed to increase commercial opportunities for renewable energies and fuels. In addition, the Government will be publishing a bioenergy strategy in the New Year, setting out the approach and ambition for sustainable bioenergy use.

Example energy crops include:

Miscanthus (*Miscanthus x giganteus*) is a high biomass generating herbaceous species.

- There is considerable interest in this crop as it is believed that it could be a good energy source for medium-scale applications such as schools and hospitals.
- UK production has increased in the last decade from 52 ha in 1998 to 12,000 ha in 2009, see Figure 4.10 (Defra, 2009a). Despite its high efficiency in water use, it does not tolerate drought, and in order to achieve the maximum productivity irrigation may be required. The most suitable areas in the UK would be the warmer areas of the south, east, west and English Midlands. There are some environmental concerns related to its water use, effect on soil structure (particularly at harvesting time) and nutrient management and an Environmental Impact Assessment is required when grown on previously uncultivated sites. Other concerns include a reduction in water quality and quality for downstream abstraction, recreation and industry.

Oilseed rape (*Brassica napus*) is primarily used for food due to its oil. However, it has potential to be used as a source of biofuel and contribute towards reaching UK renewable energy targets.

UK cultivated area has increased, from 47,300 ha in 2001 to 85,700 ha in 2009.

- Oilseed rape cultivated varieties can be used:
    - For animal feed and human oil consumption
    - To produce biodiesel and lubricants
    - For food (frying oil).

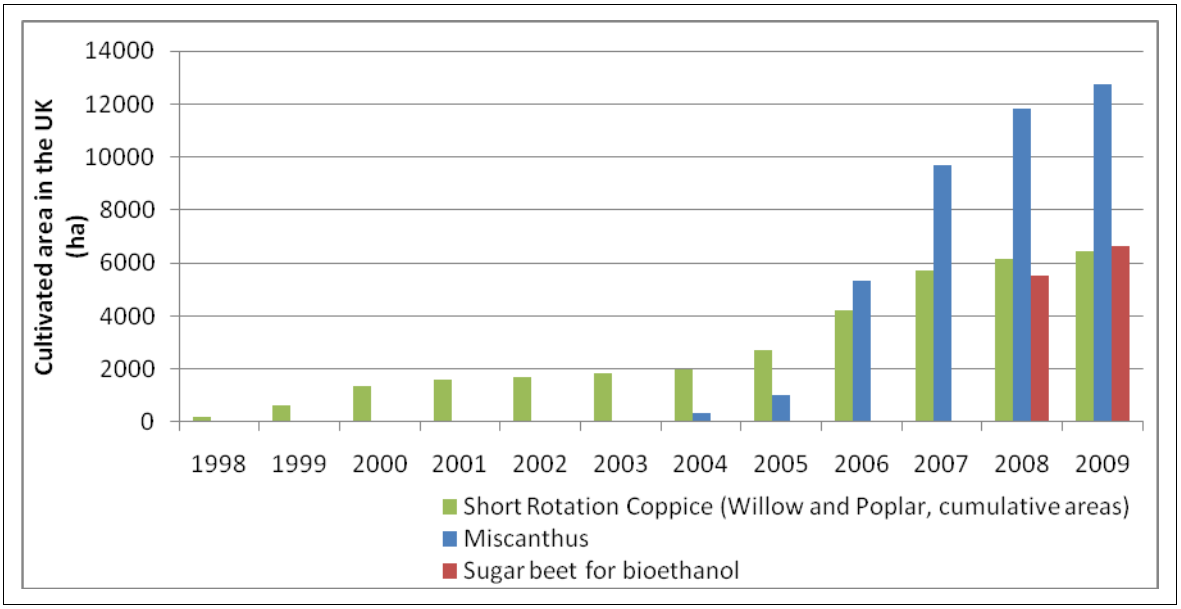
An increase in cultivation of energy crops is a significant indirect consequence of climate change brought about through the need to diversify and de-carbonise energy sources and the provision of incentives to do so. The growth in demand for energy crops may have an impact on the relative balance of these products and other crops currently grown in the UK.

Short Rotation Coppice (SRC) is a high energy crop, which usually consists of fast yielding willow or poplar.

- Sustainably managed SRC provides a source of energy with virtually no net carbon emissions and stems can be cut and chipped in a single operation making a more efficient supply chain.
- Coppice stems can be harvested every 3-5 years, and the stools remain productive for 30 years before they need replacing.
- SRC yields vary according to the location of the site and the efficiency of land preparation. Soil type, water availability and maintaining soil moisture, general husbandry, and pest and weed control also affect yield. Yield following the first harvest of a number of commercial sites was in the range 7-9 odt (oven dried tonnes)/ha/yr. Yields should also increase at second and third harvests up to 15 odt/ha/yr on better sites (Defra, 2007c).

Although new crops are currently being grown, their impact on, for example, the hydrology and ecosystems of the local area are still being investigated. This means that the impact of the changes projected are uncertain and may result in a range of possible opportunities or threats.

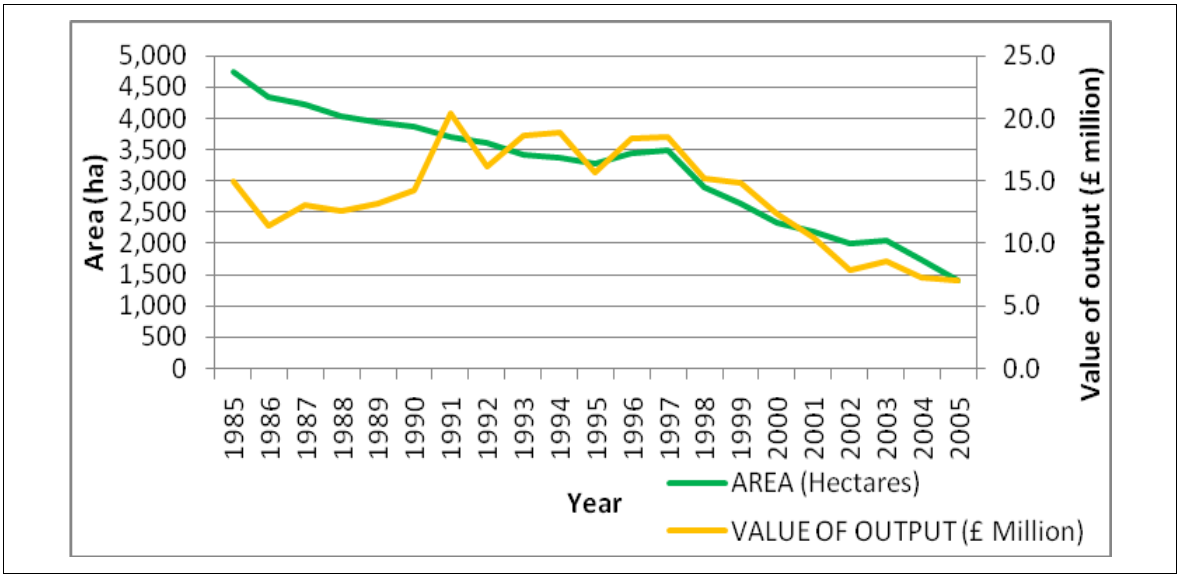
Figure 4.10 UK crop area dedicated to Short Rotation Coppice, Miscanthus and sugar beet for bioethanol production from 1998 to 2009
(Source: Defra, 2009a)



4.4.2 Specialist crops

In addition to energy crops there are important crops for pharmaceutical production, fibre production and brewing. While food crops are grown at a large scale and are therefore arguably more resilient in terms of national resource to regional variations in climate impacts, the relatively smaller scale of crop production for pharmaceutical, fibre and brewing products means that there could be significant consequences for those industries if detrimental climate impacts occur in the relevant regions of production. For example, UK hop production (*Humulus lupulus*) is sensitive to climate. Nowadays national production covers only one third of its former area, see Figure 4.11 (Defra, Annual reports 1985-2005). While this change in area of hop production is more likely to be a feature of market forces, it does leave national production vulnerable to the climatic variations over a small area.

Figure 4.11 Hop cultivated total area (ha) and value (£ million) in the UK from 1985-2005
(Source: Defra, Annual reports 1985-2005)



4.4.3 New crops

Table 4.6 summarises examples of new crops by crop groups. In terms of food crops, suitability varies across the UK. Many new crops may only be possible on a small scale, confined to a small region or have a limited market place. These constraints may have a significant impact on crop choice and whether new crops are chosen to be grown. Despite some of these species being widespread (e.g. nettle and yarrow) there exists the possibility for agricultural production of these as a crop in new regions within the UK. Defra research identifies those listed below as representing new crop opportunities in the UK.

The southern areas of the UK (including South West England, South East England, East of England, English Midlands and south Wales) present good agronomic conditions for:

- Amaranth
- Globe artichoke
- Chamomile
- Dill
- Ethiopian mustard
- Fennel
- Gold of pleasure
- Soya bean
- Sunflower
- Thyme

The central areas of the UK (including parts of the East of England, the English Midlands and north Wales) would be suitable for:

- Echium
- Garlic
- Rocket

With the exception of grapes in the Midlands and garlic in western areas, all these crops would also be suitable for the southern areas of England.

Crops with specialist food uses, such as those below, are suited to all of the UK, including cooler and wetter parts of the UK.

- Elder
- Juniper
- Lupin
- Marjoram
- Nettle
- Peppermint
- Sea buckthorn
- Yarrow

Table 4.6 Crop division by uses and some examples (current and future crops)

Use	Sub-division	Examples
Animal Feed		Amaranth, Artichoke Jerusalem, Canary seed, Maize, Millet, Oats, Peas
Human Food	Processing industry	Chamomile, Coriander, Dill
	Fresh consumption	Globe Artichoke, Blueberries, Maize, Grapes, Pumpkin, Lupin, Peas, Apple
Energy	Biofuel	Barley, Canary seed, Crambe, Gold of pleasure, Oilseed rape,
	Biogas	Maize
	Biomass	Miscanthus, Reed canary grass, SRC Willow and Poplar, Eucalyptus
	Bioethanol (biofuel)	Sugar beet, wheat
Pharmaceutical	Drugs	Caper spurge, Celery, Daffodil, Echium, Fennel, Garlic, Poppy, Yew
	Cosmetics	Bog-myrtle, Chamomile, Lavender, Nettle, Peppermint, Rosemary, Sea buckthorn
Industrial	Biopolymers	Oilseed rape, Sugar beet,
	Biolubricants	Caper spurge
	Oil	Sunflower, Linseed, Oilseed rape, Soya bean
	Fibre	Hemp, Linseed (fiberflax), nettle, switch grass
	Paper and Pulp	Reed canary grass, Barley, Switch grass
	Starch	Maize, Potato
	Dye	Madder, Safflower, St Johns Wort, Woad
	Brewing, distillation	Barley, Grapes
Ornamental		Christmas trees, Daffodil, Mistletoe, Yarrow

The importance of vineyards in the UK has increased in the last decades; vine productive areas grew from 325 ha in 1984 until almost 1000 ha in 2009. While changing climate conditions may help to extend the geographical area where grapes are grown, there are still challenges and risks to extending production.

4.5 Competition for resources

Agricultural water use is a relatively small component of total water abstractions at the national scale. However, access to water at the right time of a suitable quality for irrigation is essential in parts of the UK, particularly for higher value horticultural crops. Within national

abstraction regulatory frameworks, agriculture competes for water with public water supply, industry and the environment.

The recent Foresight (2011b) study on global food security in the 2050s highlighted the growing pressures on water resources and indicated that, at the global scale, water scarcity may have a greater impact on food production than more direct climate effects. In the UK, there is also competition for resources between sectors for both water and land that may threaten food security. Climate change is likely to increase the need for agricultural water abstraction, possibly significantly. This can have a direct impact on a downstream need for water consumption and industrial use. Furthermore, lower flows could result in a greater concentration of pollutants, affecting water quality, which may have a direct impact on agriculture (Water Sector Report).

In the UK, a significant proportion of water abstracted for irrigation is used for quality assurance (mainly for scab control on potatoes). Changes in dietary preferences due to climate change (e.g. switching to a greater dependence on salads and pasta) and/or changes in consumer attitudes to produce quality (such as potato skin finish, shape, size) could have significant impacts on the volumes of water abstracted for irrigation.

The forestry sector has little direct impact on water resources and rarely contributes to water abstraction through irrigation, apart from water use in forest nurseries. The competition for water resources for nursery irrigation will be similar to those of agriculture. Water resources are also important for the forestry sector as the higher water use of trees compared to some other land uses may limit woodland creation where water resources are limited, as outlined in the UK Forestry Standard.

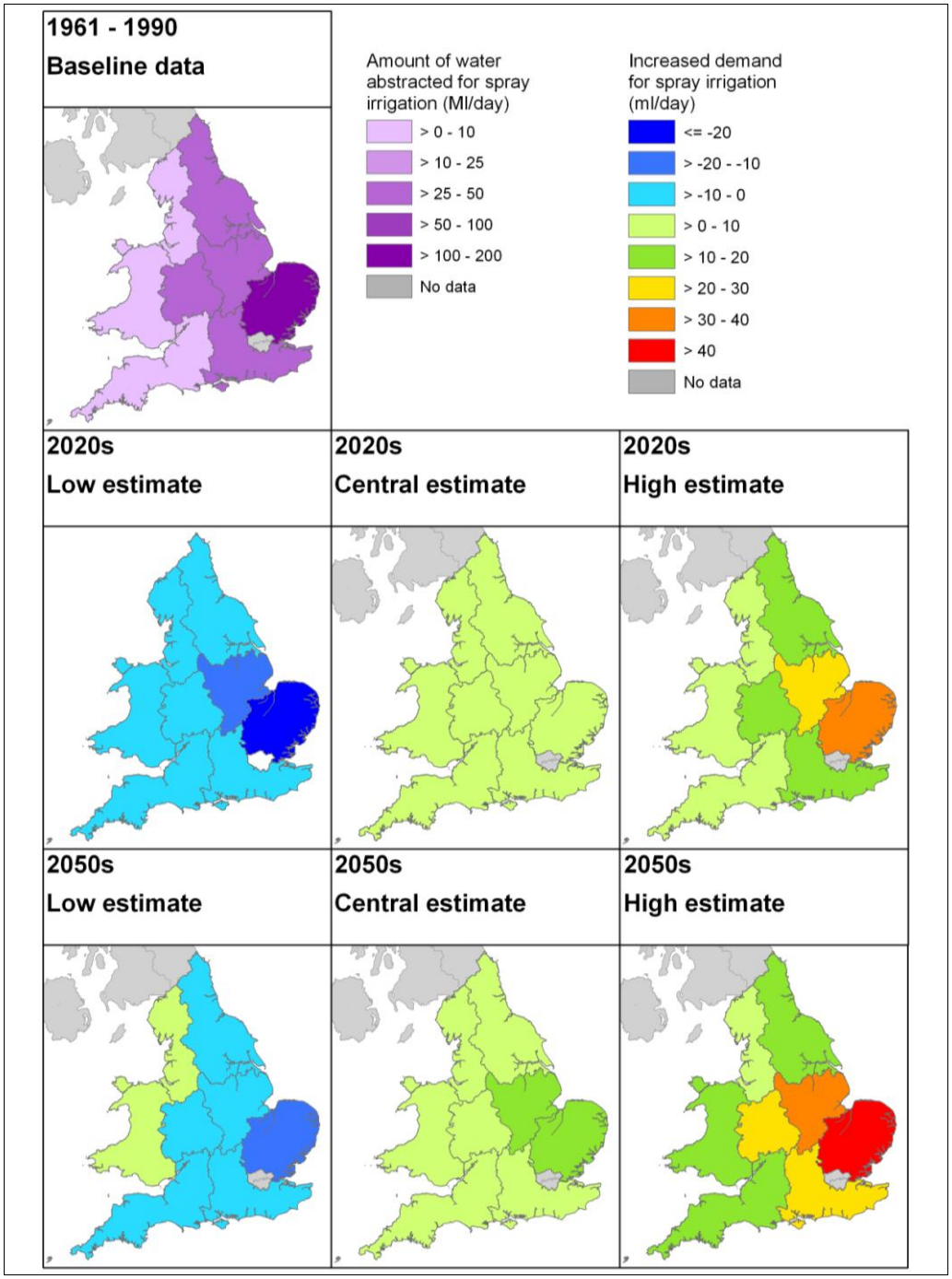
Agricultural water abstraction in England and Wales constitutes a very small proportion (1-2%) of total national abstraction but is concentrated in the driest years, in the driest catchments and at the driest times of year when resources are most under pressure (Knox *et al.*, 2010b). Two targeted analyses were completed in the Agriculture Sector for England and Wales where sufficient data were available, and these are given below.

(i) Calculations of the future demand for water attributable to climate change

This analysis used historical abstraction data from the Environment Agency with data on agroclimate and showed increases in agricultural water demand for spray irrigation of approximately 15% for the 2020s Medium emission scenario, central estimate (range -20% to +52%), rising to 34% for the 2050s Medium emission scenario, central estimate (range -9% to +76%) and 45% for the 2080s Medium emission scenario, central estimate (range -4% to +108%), for locations throughout England and Wales.	Medium confidence

These findings are consistent with recent research by Weatherhead and Knox (2008) who considered future agricultural demands under a range of socio-economic scenarios. That study reported increases of between 22% and 180%, significantly higher than the estimates produced from the metric analysis and climate effects alone.

Figure 4.12 Water abstraction for crops (spray irrigation)



(ii) Estimation of the environmental pressures to reduce agricultural abstraction as part of the Water Framework Directive

This analysis provides an insight into how the amount of water available for agricultural uses might vary with climate change, through consideration of abstractions from sustainable sources (see Figure 4.12). This is an important measure as licences from unsustainable sources may be limited in future with consequences for farmers who may not use licences under the current climate but could need them in the future in order to grow horticultural crops. Conflicts with other water users could also be likely in areas that experience increasing water scarcity due to climate change.

Low summer flows may have a negative impact on water quality and the associated ecosystems. Furthermore, a change in land use due to climatic changes may result in new farmed areas causing water pressures and pollution issues on previously undisturbed watercourses (Biodiversity & Ecosystem Services Sector Report). Reduced flows limit the ability of the receiving watercourse to dilute and disperse pollutants, and this could impact on downstream tourism, leisure and abstractions that have previously been unaffected.

The impact of agriculture and new practices could have an effect on the environment and local biodiversity as historical and some current agricultural land-use practices may cause environmental degradation such as water pollution, reduced soil fertility and soil erosion (Foley *et al.*, 2005). However, agricultural precision could limit the negative impacts. This may be limited with the development of sustainable resource management having a greater impact on farming practices. The emergence of technological precision farming could allow an increase in productivity along with a decrease in waste and costs. Fertiliser applications that are focused on areas that require additional nutrient may limit runoff and improve water quality.

Response functions were developed for England and Wales to link changes in low flows (Q95) with the percentage change in abstractions from sustainable sources. In England and Wales, abstraction licensing is assessed at a catchment scale through Catchment Abstraction Management Strategies (CAMS).

Reductions in summer river flows, as characterised by the Q95 low flow metric, could lead to restrictions on agricultural abstractions. For the 2050s Medium emissions scenario central estimate, there may be an 8% (range 4 to 9%) reduction in abstraction allowed in the Anglian river basin region, which has the greatest demands and a 17% (range 7 to 17%) reduction in the South West England river basin region (Water Sector Report).	Medium confidence

Due to data availability the analysis for this metric could not be carried out for Scotland and Northern Ireland.

4.6 Other dimensions of risk for UK agriculture and forestry

4.6.1 International dimensions of food security and international trade

Agriculture

Recent research on the Foresight Future Food and Farming project (Foresight, 2011b) highlighted the strong linkages between the food systems of different countries that are now linked at all levels, from trade in raw materials through to processed products (Box 4.3). Global population increases, the rise in demand and the strong competition for resources, particularly water resources, are key drivers for future global food security.

Recent concerns regarding future global food shortages have also raised questions about food security at global and national scales (IAASTD, 2009). The UK government seeks to achieve ‘food security’ by guaranteeing households access to affordable, nutritious food (Defra, 2010d). UK agriculture, along with the food industry as a whole,

is charged with 'ensuring food security through a strong UK agriculture and international trade links with EU and global partners which support developing economies' (Defra 2010d). In this regard, it is required to be internationally competitive, whether this is delivering to domestic or international food markets. Climate change could affect not only the relative productivity of UK agriculture but also its competitive position in international markets.

Box 4.3 Selected key findings from the Foresight Future Food and Farming project (Foresight, 2011b)

- Global population increases. Today's population of over seven billion is most likely to rise to around eight billion by 2030 and probably to over nine billion by 2050. Most of these increases are anticipated to occur in low- and middle-income countries; for example, Africa's population is projected to double from one billion to approximately two billion by 2050.
- Changes in the size and nature of demand. Dietary changes are very significant for the future food system because, per calorie, some food items (such as grain-fed meat) require considerably more resources to produce than others. The high carbon costs of meat productions systems and their contribution to greenhouse gas emissions are of increasing concern.
- Globalisation of markets has been a major factor shaping the food system over recent decades, with the emergence and continued growth of new food superpowers such as Brazil, China and India. This may become even more so in the future, with for example Russia having large areas of underutilised agricultural land.
- Climate change may interact with the global food system in several important ways:
  - Rising global temperatures and changing patterns of precipitation would affect crop growth and livestock performance, the availability of water, fisheries and aquaculture yields and the functioning of ecosystem services in all regions;
  - If extreme weather events (such as flooding or drought) become both more severe and more frequent, this may increase volatility in production and prices; and
  - The extent to which adaptation occurs (for example through the development of crops and production methods adapted to new conditions) will critically influence how climate change affects the food system.

Both the Foresight study and this assessment anticipate major issues with water availability for food production. As well as increased need, any increased production may have to be met against reduced worldwide water availability for agriculture – estimated to be a reduction of 18% by 2050 in a recent review (Strzepek and Boehlert, 2010). These reductions will be due to meeting environmental flow requirements, as well as public water supply and industrial demands, which represents the single biggest challenge to agricultural water availability.

At the global scale, out of the total withdrawal of water from available rivers and groundwater basins, 70% is currently consumed by agriculture. This is largely driven by the large amounts of water needed to grow arable crops and to provide the pasture and fodder for livestock. Demand for agriculture could rise by 30% by 2030, thereby increasing pressure on a water resource system that is already at full utilisation in some countries. Furthermore some of this agriculture is based on non-renewable aquifers (such as in the Punjab, Libya, Yemen and Australia). In such areas climate changes in addition to socio-economic changes could see water use peak in the near term and then go into long term decline with serious consequences for some Least Developed Countries.

In terms of climate change adaptation there is significant potential for more efficient global use of water by altering trading patterns, for example by growing food in parts of the world with available water resources and sustainable abstraction. Furthermore, there is scope for greatly improved yields from agriculture particularly in areas such as Africa where yields could be greatly improved, through the application of existing knowledge and technology.

Forestry

The UK forestry sector operates in a similarly international context, not only for trade of products but, as has been seen with the emergence of *P. ramorum* in the UK (Section 4.3.4), the transfer of pests and diseases. The future global supply of wood products is extremely uncertain as is the global wood energy demand; each of which has ramifications for the UK's forestry sector. The opportunity exists for UK woodland creation and management to help meet the rising demand for biomass energy and timber supply.

International and EU-wide research programmes on forest adaptation and related forestry science will be needed. These are particularly important for climate change, given the exchange of information on future tree material and environmental conditions that occurs.

4.6.2 Geographical variations of risk to the UK

Analysis in both agriculture and forestry has shown that there are variations in risk across the UK that reflects current vulnerabilities, different rates of warming and different land use characteristics.

For agriculture, important geographical variations include:

- Increases in grassland and arable yields are relevant across the UK. However, increases in grass yields and the benefits for livestock production are particularly important for major livestock and dairy producers in Northern Ireland, Scotland, Wales and some parts of England. Similarly, increases in sugar beet are important for the East of England, which is home to the major sugar processing plants. Other areas of the UK may become suitable for beet production.
- Higher Potential Soil Moisture Deficits are important for the East of England and southern England as water availability may limit increases in production in the medium to long term. The spread of these drier conditions northwards and eastwards is particularly relevant in England. Drier soil conditions in Scotland and Northern Ireland may be seen as beneficial if these lead to a lengthening of the time periods that equipment can work on the land.
- The demand for irrigation of crops is highest in the East of England. The absolute demand is projected to remain the highest in this region under future climate change scenarios. This area is also projected to have the largest reductions in summer river flow as well as a significant increase in public water supply demand in the 2050s, indicating much greater competition for water resources.
- The risks of river flooding on 'good quality agricultural land' are greatest in the Midlands as is the case for the baseline situation. The increases in risk are greatest in the south and east, which broadly reflects the location of better quality agricultural land.

- The risks of tidal flooding on good quality agricultural land are greatest in the south west. The increases in risk are greatest in the south and east, which broadly reflects the location of better quality agricultural land and also higher rates of relative sea level rise than in the north of England.
- A large proportion of agricultural land in the UK is located within National Parks, contributing to the image and appeal of the natural environment (Biodiversity and Ecosystem Services Sector Report). The land within the parks may offer greater ecosystem services through biodiversity, food and an uplifting cultural experience. Many people travel to the parks to experience and enjoy the natural environment, so farm changes and developments may have a larger impact than elsewhere.

For forestry, important geographical variations include:

- Impacts of increasing incidences of drought is estimated to affect England, Scotland and Wales equally in the short-term (2020s), while as time horizons extend and particularly in the longer term (2080s) the negative impacts on yields are estimated to be felt across the country but greatest in southern England and least in Scotland.
- The need for change of forest species due to the suitability of the climate is estimated to affect England, Wales and Scotland to different degrees.
- Opportunities for increased tree productivity in areas of higher precipitation are most likely in the north and west of the UK, where drought and other pressures are not limiting factors.
- A shift of species northward is likely to see beech becoming under threat in the south, due to reduced rainfall, and becoming more suitable in northern England/southern Scotland. This is likely to alter the associated biodiversity and ecosystems in a similar manner (Biodiversity & Ecosystem Services Sector Report).
- Opportunities for new tree species throughout the UK. Species currently grown in the south may be viable further north, and new foreign species may be possible in southern England. Markets and socio-economic factors may influence decisions and types grown.

4.6.3 Non-climate risks

It is important to remember that UK agriculture and forestry also face a range of ‘non-climate’ risks that could be argued to present a more immediate threat to sustainable production than climate change.

In the agriculture sector, the majority of non-climate risks occur ‘off-farm’ and impact on growers via:

- Various national and European agro-economic policy interventions;
- Increasing requirements of environmental regulations and production standards;
- Limitations in the availability of finance and fluctuating exchange rates;
- Changes in customer demands; healthy whole food popularity as well as better food quality;
- The relative power of supermarkets and the supply chains including market prices and product requirements; and

- Land lost to development and services and the diversification of farms.

Domestic agricultural policy is heavily influenced by EU policy. The Common Agricultural Policy (CAP) provides support to farmers who follow good agricultural practices, and/or offer non-market benefits as well as for those prepared to enter into active environmental stewardship. The current CAP (2007-2013) primarily supports adaptation through Pillar 2 funding, including agri-environment schemes and targeted capital grants. The UK Government believes that there needs to be a fundamental reform of the CAP so that it is simpler, delivers more public goods, including environmental goods, and increases the competitiveness of the EU agriculture sector over the next CAP period (2014-20). Regulatory proposals published by the commission in October 2012 (European Commission, 2011) list 'the sustainable management of natural resources, and climate action' as one of three objectives for rural development.

Livestock farmers also face a range of disease risks, both endemic (present in the UK e.g. Bovine TB), exotic (not usually present in the UK, except during outbreaks, for example, Foot and Mouth Disease) and new and emerging diseases, which have the potential to cause significant economic damage and threat to food production for the UK as a whole, the agriculture sector and individual farms.

The Forestry Sector Report did not explicitly deal with non-climate risks, but factors which may impact on the sector in the future include but are not limited to:

- National low carbon policies (e.g. DECC, 2009a, 2009b), especially in renewable energy and carbon sequestration, and some aimed at protection of soil carbon stocks leading to new policies and financial drivers to encourage sustainable woodland establishment and re-management.
- The increasing use of biomass as a source of renewable energy generation could put sustainable forestry under greater pressure. Current biomass energy production targets indicate lack of capacity within the forestry sector to supply fuel (WFTF2, 2011). Renewable energy policies will affect timber prices and, potentially lead to unsustainable management practices if sustainable Forest management standards and biomass sustainability criteria are not maintained.
- CAP mechanisms which inhibit new woodland establishment by encouraging agricultural husbandry. An EU forestry strategy, that might counterbalance other land use interests and promote the forestry sector, is in the process of revision[66] although European Commission attempts to explore a European approach to forest protection from climate change have not been supported.[67]
- Potential reform of the CAP and Rural Development Programme (RDP) in 2013[68]. Opportunities under the EU Rural Development Regulation (RDR) and the CAP Single Payment Schemes may be exploited more intensively (Silcock and Manley, 2008) to encourage further tree planting on agricultural land. However, the draft Rural Development Regulation published in November 2011 indicates that opportunities may be limited as a result of the proposed ineligibility of income foregone payments to support woodland creation.
- There could be an increased risk of importing wood and plant pests and diseases with an expansion of trade and markets. This may act to compound the effects of climate change and increase areas affected.

66 http://ec.europa.eu/agriculture/fore/events/15-04-2011/report_en.pdf
67 http://ec.europa.eu/environment/forests/pdf/green_paper.pdf
68 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0672:FIN:en:PDF

4.6.4 Climate risks from environmental, social and economic perspectives

The agriculture and forestry sector analysis focused on changes in production rather than the broader social and environmental perspectives. It considered whether projected changes were significantly different to historic conditions (e.g. changes in yield), the potential economic impacts (e.g. in dairy production) and areas of land affected (e.g. tree species change). However, some risks have positive or negative consequences depending on the perspective considered, for example, the frequent flooding of poorer quality agricultural land has negative consequences for farmers but may have positive consequences for the natural environment and some benefits in reducing flood risk downstream.

- From an environmental perspective warmer conditions and increased production may present some benefits but mostly risks. Increases in agricultural and forest production may have negative or positive consequences on the environment depending on how these changes affect overall production systems, and the amount of land in production. Any increases in nutrient and fertiliser usage, water usage, livestock waste and damage to soils is likely to be detrimental but if sustainable production systems can achieve more outputs for every unit of carbon and water used, changes could benefit the environment. A critical potential risk is that to pollinators[69]. Pollination is a key ecosystem service and vital to the maintenance of agricultural productivity. Insect pollination, mostly by bees, is necessary for production in 84% of all crops in Europe, with an estimated value of £440 million per annum in the UK. Adaptation in these sectors will need to consider broader environmental objectives.
- From a social perspective, the rural economy depends upon viable agriculture, forestry, tourism and leisure and other industries. This assessment has not completed detailed work on social aspects of the agriculture and forestry sectors. However, there are potential benefits for people living and working in the countryside if incomes increase in step with increases in production, particularly in marginal farming areas. Improved winter conditions may have some benefits, for example by reducing heating costs, but those living in remote areas or working outside may be exposed to more hazards, including flooding, heatwaves, UV radiation and poorer air quality conditions, which are all discussed in subsequent chapters.
- From an economic perspective warmer average conditions are likely to have benefits for UK agriculture as yields are projected to increase, as long as water availability and nutrients do not become limiting factors. There are some opportunities for new crops and new markets, as demand grows internationally and production becomes more difficult in southern Europe. However, there are also risks that could damage or disrupt agricultural production and other aspects of the supply chain. The increased competition for water resources may have a significant impact on agriculture and may limit the gains in the medium to long term.

4.7 Evidence gaps

A significant amount of research has been completed on the potential impacts of climate change on agriculture and forestry. However, this assessment identified a

[69] It is estimated that during the last 20 years, habitat losses and intensification of agriculture have been responsible for 54% decline in honey bee colony numbers in England.

number of evidence gaps that may require further research over subsequent CCRA cycles:

- Studies have not yet made full use of the UKCP09 projections and more work is required using the projections or RCMs to understand the potential impacts of warmer and drier conditions and particularly drought.
- The impacts on forest biodiversity and other non-provisioning ecosystem services are poorly understood; this requires national level datasets, information on the direct impacts of rising temperatures on vegetation growth and reproduction.
- The impacts of climate change and higher CO_2 concentrations on soils including development, quality, carbon content, soil erosion and oxidation of peatlands.
- An accurate response function for plant and tree productivity due to CO_2 fertilisation and a quantitative analysis of the projected increases in yield. This may have a substantial impact on potato yield.
- Pests and disease impacts through detailed epidemiological information, country-wide data and climate relationships for current and prospective pests and diseases. Much further research is needed into the physiology and epidemiology of tree and crop diseases and a greater analysis in the role of climate variable in the spreading and extent.
- The links between biodiversity and timber production in the face of climate change; guidance on which species are most suitable and how adaptation measures can be implemented sustainably (integrated with the ESC system).
- The scale and direction of the risk of wildfire given not only climatic but also vegetation changes and socio-economic changes, such as visitor numbers.
- Development of a framework for monitoring and evaluating changes in forest growth on an annual basis, nationwide.
- The impacts of saline incursion and intrusion on agricultural abstractions in important agricultural areas.
- A better understanding of the impacts on animal health and welfare, particularly the impacts of heatwaves, droughts and extremes on livestock rather than the influence of average climate that was considered in this assessment.
- Exploration of the ecological, production and treatment consequences of weed species that may increase with climate change.
- The impacts of climate change on the broader food and drinks supply chain including the changing demand for products in the UK and internationally.
- Vulnerabilities and adaptive capacity of rural communities to cope with climate change and its impacts on their lives and livelihoods. Research to test the effectiveness of both methods for understanding climate-related risks to these communities and their adaptation responses.

Further details on evidence gaps are given in the Agriculture and Forestry Sector Reports.

4.8 Summary

Climate change is likely to have positive consequences for UK agriculture in the near to medium term due to the effect of warmer temperatures and the potential impacts of CO_2 fertilisation. Grassland, arable and horticultural yields are projected to increase, as long as sufficient nutrients and water are available. Negative impacts are related to water shortage and heat stress. Drought, fires and pest and pathogen outbreaks could cause damage and disruption to UK forestry. Future possible potential production may increase or decrease depending on region.

Climate change risks and adaptation responses for agriculture must be considered in a wider context, including social and economic pressures on UK farming. The sector will need to respond to a changing climate, in order to manage risks and benefit from opportunities.

The geographical range of existing crops may increase and there could be opportunities to grow new crops, particularly in southern UK. Large areas of forest could become suitable for different tree species to those that are currently grown.

Forestry is unique in the need for such long term planning and while climate variables can have a significant impact, socio-economic variables are just as likely to impact on the sector. New climate change findings should be considered alongside traditional socio-economic impacts to give a holistic understanding[70]. The forestry sector is likely to be at an increasing risk and appropriate management strategies are require now for future forest management. Key findings include the following:

1. More extreme climate conditions such as floods, droughts and heatwaves may disrupt production more frequently by the 2050s. Most crops are sensitive to a changing climate with impacts on both land suitability (for existing and new crops) and productivity (yield and crop quality). The CCRA analysed the potential impact of climate change for a selection of crops and the response of yield was projected to be as follows, for locations where water and nutrients are not limited:

   - Increases in grassland yield of approximately 34% (with a range of 20 to 50%) by the 2050s.
   - Increases in wheat yields of 47% (22 to 76%) for the 2020s, rising to 79% (36 to 137%) by the 2050s.
   - Increases in sugar beet yield of 23% (11 to 37%) for the 2020s, rising to 39% (18 to 68%) by the 2050s.

   In addition, small reductions in mean main crop potato yields e.g. 2% (range -7% to +3% change) for the 2020s, and 5% (range -12% to +1% change) for the 2050s. Larger impacts in important potato production regions were projected: e.g. 5% reduction (range -14% to +4% change) in the East of England by the 2050s due to lower summer rainfall; however, this finding is contradicted by more detailed biophysical models that project an increase in yield due to CO_2 fertilisation effects.

[70] The study is aware of the limitations of not assessing such factors alongside those of climate change.

These estimates do not however consider interactions between different risks. For example, an increase in flooding of land (see Point 5 below) would reduce these projections.

2. Drought already affects tree physiology and woodland ecology in dry periods, but climate change projections suggest that considerable areas of the UK may be progressively affected in the future.

   - By the 2020s, there is estimated to be a 15% (range 11% to 20%) increase in loss of yield from drought in South-East England, 12% in Wales (range 9% to 16%) and a 12% (range 9% to 15%) loss in Northern Scotland, for the Medium emissions scenario.

   - By the 2050s there is estimated to be a 17% (range 11% to 23%) increase in loss of yield from drought in South-East England, 16% in Wales (range 10% to 22%) and a 14% (range 10% to 18%) loss in northern Scotland.

   - By the 2080s, there is estimated to be a 19% (range 12% to 26%) increase in loss of yield from drought in South-East England, 18% in Wales (range 11% to 29%) and a 15% (range 10% to 23%) loss in Northern Scotland.

   The effects of increased drought on productivity would not be felt uniformly across the UK and these estimates need to be checked with a more detailed analysis of drought effects on tree growth and quantification of drought risk in forest areas.

   The interactions with other climate changes including higher temperatures, consequent longer growing seasons and increased atmospheric CO_2 concentration are not included in this estimate.

3. Future possible potential production may also vary. Ecological Site Classification (ESC) modelling uses the climatic variables accumulated temperature and moisture deficit, with information on windiness, continentality, soil type and fertility and tree species characteristics to model the potential yield for the public forest estate in England, Wales and Scotland. These results show a considerable divide between the north and south of the country, with declines projected for most conifers and broadleaves grown in England, but increases, especially for conifers, in Scotland for the 2050s and 2080s High emissions scenario.

4. Water could become less available to agriculture, owing to both changes in its physical availability in space and time, and to regulatory pressures to maintain environmental flows and achieve sustainable use, in whatever form these concepts may come to be defined. The increasing competition for water resources between different sectors and reduction of water availability in the summer months due to climate change would threaten the availability of water in some parts of the UK. Overall, this is a big issue and more work will be needed in the sector in terms of adaptation.

5. The CCRA analysed the potential impact of climate change on losses from dairy production and found that there are unlikely to be significant impacts by the 2050s; there may be a slight national loss (less than 0.03%) of milk production by the 2050s due to heat stress to livestock. In the long term, beyond the 2050s, this impact may become more significant.

6. Floods due to heavy rainfall and coastal flooding have been estimated to increase for the analysis carried out for the CCRA. Land likely to flood at least every three years under the Medium emissions scenario has been

estimated to increase from 31,000 ha to 36,000 ha by the 2020s, with a two-fold and four-fold increase by the 2050s and 2080s from the current levels respectively.

7. Shifting climatic zones could increasingly find some forestry production systems containing species living outside their comfort zones, leading to reduced yields and timber quality.
8. An increase in pest and diseases may occur through shifting climate space or/and increase in trading and imports compounding climatic effects.
9. A change in climatic conditions could bring about opportunities for planting new crops that are well suited to warmer conditions. There is some scope for many new crops to enter production and change the composition of agricultural and forestry land use.
10. There is likely to be scope for the planting of different tree species as a managed response of the forestry sector to adapting to climate change, if appropriate species that are more suited to the future climate can be brought into the nursery market.
11. Opportunities may arise for both the agriculture and forestry sectors to generate additional income through the provision of ecosystems services – an example could be forests acting as carbon sinks or in a slope stability/sediment retention capacity.
12. Ecosystem services are vital for farm production through pollination of crops. Additionally, the attraction of traditional farming landscapes brings a cultural benefit to countryside visitors.

Table 4.7 Scorecard for Agriculture and forestry

Metric code	Potential risks for agriculture and forestry	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
AG9	Opportunities to grow new crops	H	1	1	1	2	2	2	3	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
AG10	Changes in grassland productivity	M	1	1	1	1	2	2	1	2	2
FO4b	Increase of potential yield of Sitka spruce in Scotland	M	1	1	1	1	1	1	3	3	3
AG1c	Changes in potato yield (due to combined climate effects and CO_2)	L	1	1	2	1	1	2	1	1	2
FO1a	Forest extent affected by red band needle blight	M	1	2	3	2	3	3	2	3	3
AG11	Increased soil erosion due to heavy rainfall	L	1	2	2	1	2	3	1	3	3
AG5	Increases in water demand for irrigation of crops	M	1	2	3	1	2	3	2	2	3
AG4	Drier soils (due to warmer and drier summer conditions)	M	1	2	2	1	2	3	1	2	3
AG2a	Flood risk to high quality agricultural land	H	1	1	2	1	2	2	2	3	3
FO4a	Decline in potential yield of beech trees in England	M	1	1	1	2	2	2	3	3	3
BD12	Wildfires due to warmer and drier conditions	M	1	1	2	1	2	3	2	2	3
FL14a	Agricultural land lost due to coastal erosion	H	1	1	1	1	2	2	2	2	3
WA8a	Number of unsustainable water abstractions (agriculture)	M	1	1	2	1	2	2	2	2	2
FO1b	Forest extent affected by green spruce aphid	M	1	1	2	1	2	2	1	2	3
FO2	Loss of forest productivity due to drought	M	1	1	2	1	1	2	1	2	3
AG8b	Dairy livestock deaths due to heat stress	L	1	1	2	1	1	2	1	1	2
AG7b	Reduction in dairy herd fertility due to heat stress	L	1	1	2	1	1	2	1	1	2
AG8a	Increased duration of heat stress in dairy cows	H	1	1	1	1	1	2	1	1	2
AG7a	Reduction in milk production due to heat stress	L	1	1	1	1	1	1	1	1	3
AG3	Risk of crop pests and diseases	L	Too uncertain								

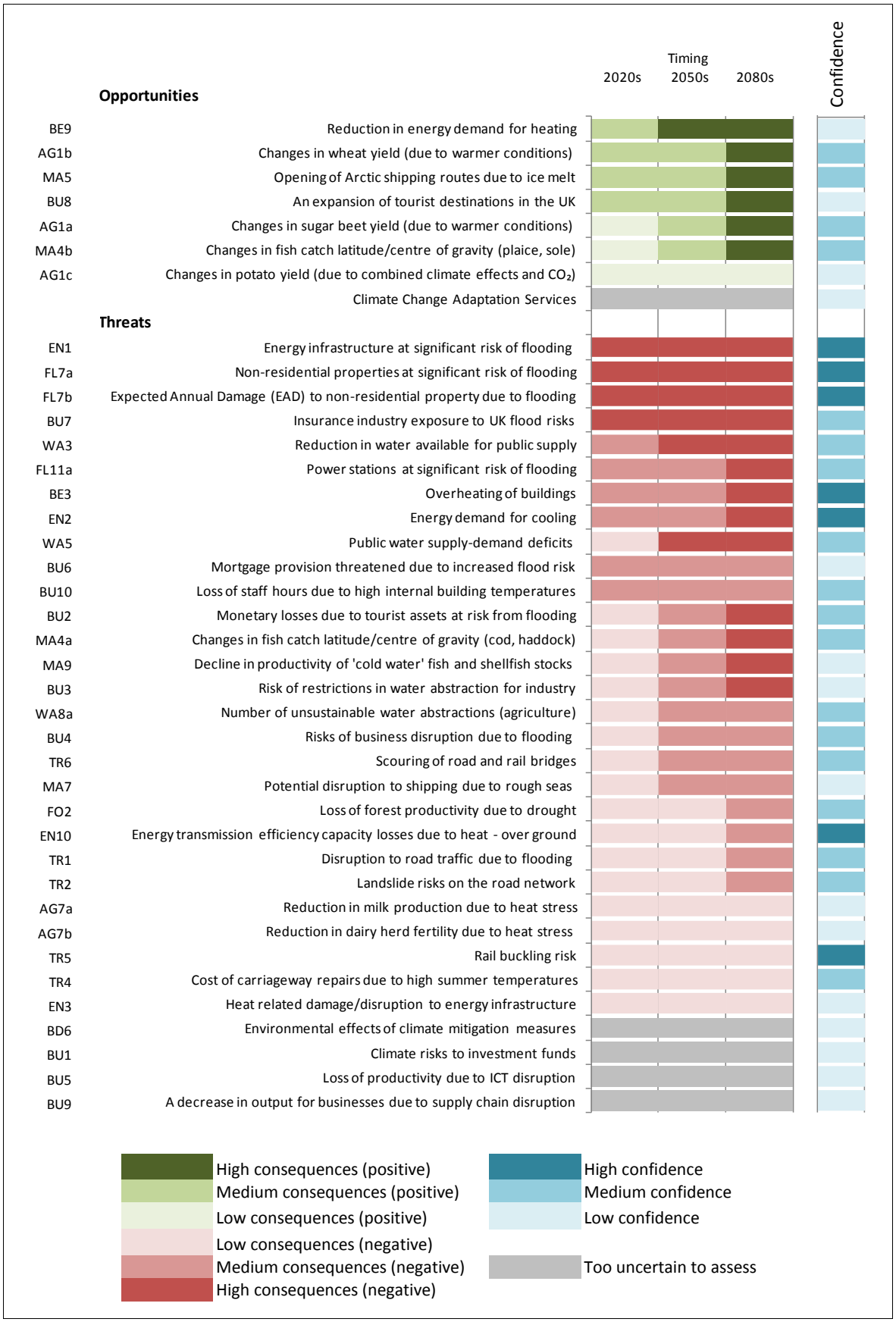
M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

5 Business

Overview	
• Businesses already have to deal with climate related risks on a daily basis. A changing climate does not necessarily create new risks, but typically represents a potential change in the frequency or duration of climate related impacts and their subsequent consequences. • All aspects of businesses are affected, including fixed assets, workforce, procurement (raw materials, supply chains, logistics), operations (supply of services, customer demands, regulation), and environmental and social performance. • A large part of the UK economy relies on imports and exports. Therefore, there is high dependency on activities overseas[71], transport and communication links, the integrity of supply chains and the threats and opportunities that arise from the impacts of climate change in other countries.	
Threats	**Opportunities**
• The main threats facing businesses are related to flooding, heat and water resources. • Damage to fixed assets, stock, etc. such as from flooding. • Loss of business continuity due to flooding. • Increased insurance claims and potential reduction in mortgage value of properties due to flooding. • Loss of assets due to sea level rise (including natural assets such as beaches and built assets such as tourist attractions, historical monuments, etc). • Loss of productivity due to overheating and warm weather periods. • Increased energy costs for summer cooling. • Reduction in available water for abstraction.	• The main opportunities for businesses arise from the move to a low carbon economy and delivery of adaptation measures. These have the greatest potential to benefit the financial, utility, manufacturing and consultancy sectors. • Targeted investment in flood risk management to reduce risks in key economic growth areas. • Changes in domestic weather conditions increase market opportunities (e.g. agriculture may benefit from increased yields and tourism and leisure industries from better weather conditions). • Melting of the Arctic ice creates the opportunity for new trading routes with Asian markets. • By fully internalising climate change risks into fund management, new products for investors seeking climate resilient opportunities could be developed. • Reduced winter heating costs.

[71] Includes most trade related activities such as mining, framing, manufacturing and international service industries such as banking.

Figure 5.1 Summary of business impacts with an indication of direction, magnitude and confidence



5.1 Introduction

Climate change is a key challenge for business, both today and in the future. The main climate change vulnerabilities include: flooding and coastal erosion; the loss of supplies of water; energy and materials; and the disruption of transport networks and communication links. The consequences for business relate to the potential gains or losses in revenue, associated with the adverse and beneficial effects on fixed assets, workforce, procurement (raw materials, supply chains and logistics), operations (supply of services, customer demands and regulatory requirements) and environmental and social performance.

The business theme is very broad and complex, with many interrelated links. Current understanding of this complexity is an active area of research and the risk assessment was therefore based on selected risks supported by case studies to illustrate the nature of the risk. The Business, Infrastructure & Services Sector Report focussed on five sub-sectors: financial services; tourism; food and beverages; primary extractives (oil, gas and mining); and chemical manufacturing. In doing so, this highlights many of the issues likely to be faced more generally, without attempting to be comprehensive. This chapter draws on these findings, a number of the risks reported in the other sector reports and other published work, to provide an overview of the risks to business.

In compiling the summary of impacts for the business theme, Figure 5.1, the risks considered in other sectors that are relevant to business were also included. This remains limited to the risks considered as part of the Tier 2 analysis within this assessment. Some risks have a direct consequence for business, whilst others represent indirect consequences (or in some cases proxies to give an indication of changes that may be important). For example, changing environmental quality as a result of climate change may lead to changes in the regulatory regime, which in turn alters the demands placed on those businesses affected.

Opportunities and threats are listed in Figure 5.1 ordered by magnitude. For clarity this figure only shows how the magnitude of the central estimate for the Medium emissions scenario changes over time. A more detailed summary of the same set of risks, ordered by confidence rather than magnitude is presented at the end of this chapter, Table 5.2. This table provides more information on how the magnitudes of risks vary under the different emissions scenarios, as explained in Section 1.2 and Figure 1.1.

Figure 5.1 and Table 5.2 are designed to give an overview of risks that are likely to be relevant. The list is necessarily incomplete and all the individual risks are discussed in the relevant sector reports. In this chapter we focus on issues that are either considered to be of major significance to the UK economy, or have implications for a broad cross-section of businesses, picking up on some, but not all, of the individual risks included in the Tier 2 analysis and listed in Figure 5.1. The selection of risks presented endeavours to reflect direct and indirect risks. Thus some agricultural opportunities and threats are noted because of the implications for the food and beverages industry, whereas disruption of transport and the supply chain have more widespread implications. The list is necessarily limited to those risks included in the analysis and in the rest of this chapter a broader view is taken to describe the wider risk landscape, including interactions.

This section concludes with a short summary of business activity and current vulnerability of the sector. The remainder of the chapter then addresses:

- Direct impacts for business due to biophysical changes (heat, floods, and water supply); and
- Indirect impacts, including disruption to supply chains and the services provided by utilities (water, energy and communications).

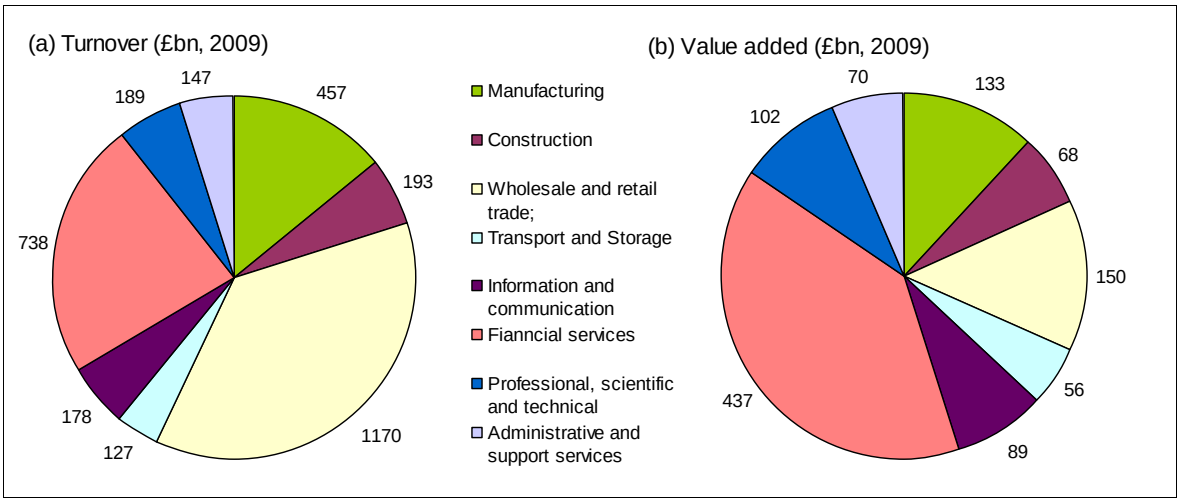
To conclude, two sectors are examined in more detail to explore the interplay of opportunities and threats. The first is the financial services sector (including banking, pensions and insurance) because of its importance to the UK economy. The second is a case study of the tourism industry, which is particularly weather and climate sensitive and where opportunities are likely to outweigh the threats.

5.1.1 Business activity in the UK

Climate change represents a potentially significant issue for all business sectors in the UK from Small and Medium Enterprises (SMEs) to large multi-national corporations. The degree to which individual organisations are affected will depend on their level of vulnerability and adaptive capacity. The issue of adaptive capacity is particularly challenging and has been investigated as part of the CCRA to provide an additional line of evidence for the development of adaptation policies. Despite the evidence relating to climate change, there is still a great deal of inertia within some sectors of business and industry, with companies considering climate change as a future issue (Foresight, 2010a).

Climate change does not necessarily create 'new' risks for business, but some of these may become more significant. For many businesses, climate change represents a change to existing risks profiles – in other words, there are already issues that business and industry have to face on a daily basis. For example, storm-related impacts to transport infrastructure are already an important consideration in the operational management of transport networks. For these risks, climate change simply alters the duration and/or frequency of occurrence of these events, and their consequences for business operations.

Figure 5.2 Turnover and Gross Value Added for the largest Sections of the UK economy



Source Data: ONS Annual Business Survey (ABS) data

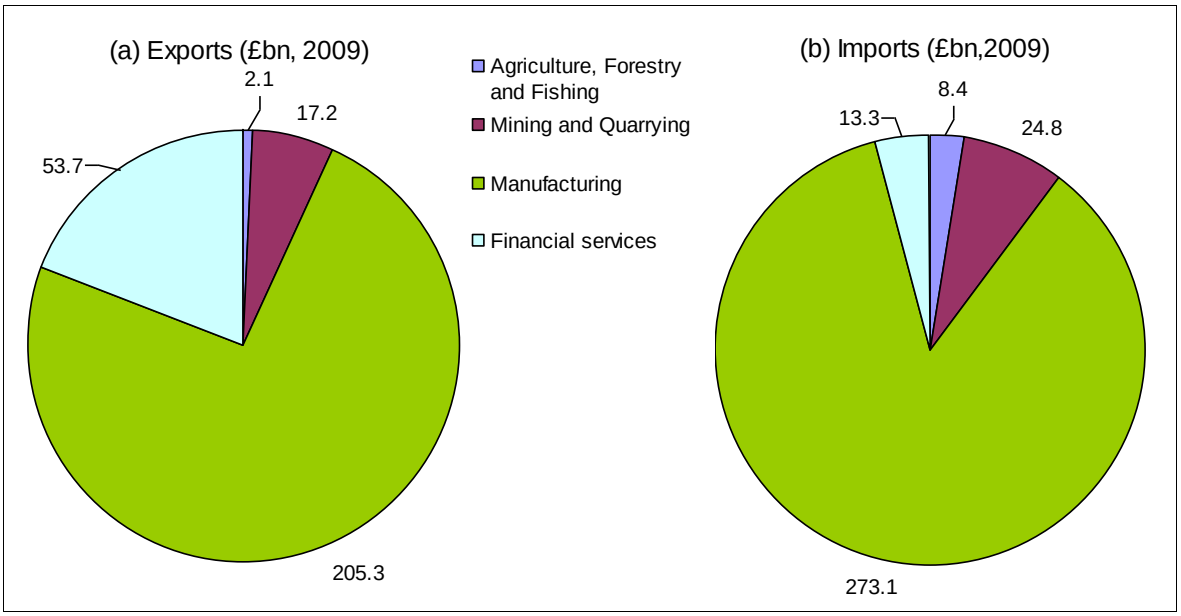
Turnover of the businesses that make up UK trade is currently around £3 trillion (2008/9), employing some 26 million people at a cost of £0.5 trillion (ONS[72]). The

[72] ONS: statistics cited as ONS are taken from the Office of National Statistics web site for the years 2008 and/or 2009.

Annual Business Survey (ONS) provides financial information on business performance. Figure 5.2 shows the total turnover and the approximate gross value added for those Sections[73] with a collective turnover in excess of £100 billion. The gross value added (GVA) represents the amount that individual businesses, industries or sectors contribute to the economy. In terms of turnover, wholesale and retail makes up the largest proportion but a large part of their trading volume relates to goods in and out. When activity is considered in terms of the value being added, financial services dominate with a more balanced distribution across the other seven largest sectors.

A large part of the UK economy relies on imports and exports, which amounted to some £420 and £391 billion respectively in 2009. This in turn introduces a dependency on activities overseas, transport and communication links and the integrity of the supply chain. The main commodities that contribute to the import and export figures are shown in Figure 5.3, where manufacturing makes up by far the largest share followed by financial services, mining and quarrying and then agriculture, forestry and fishing.

Figure 5.3 Exports and Imports for the main commodity sections of the UK economy



Source Data: ONS Trade in Goods MQ10 data

5.1.2 Current vulnerability

Current vulnerability to climate-related impacts can be divided into the following common themes:

Assets Location and design of fixed assets, infrastructure damage, workforce exposure to health and safety risks.

Operations Supply of services, customer demand and regulatory environment, including such things as financial performance, market shifts due to change in public attitudes and/or legislation, business continuity and disruption.

Procurement Raw materials, supply chain and logistics (such as supply of water), energy and materials, reliance on vulnerable transport networks.

[73] Sections are one of the sub-divisions used in the UK Standard Industrial Classification of Economic Activities (SIC).

Environment Including the natural and built environment, the local community, climate-sensitive resources and conflict over their use.

These impacts have the potential to create consequences for individual businesses, including: financial performance (revenue loss/gain); additional expenditure (capital and operating costs); operational disruption; loss of staff work hours; corporate reputation; elevated stakeholder interest; additional regulatory requirements; contractual issues; litigation; and new market opportunities and product diversification. These are likely to be experienced by businesses of all sizes but historical evidence suggests that SMEs are particularly vulnerable as outlined in Box 5.1 from a case study for the West Midlands.

Box 5.1 Vulnerability of small and medium enterprises (SMEs)

Small and medium enterprises (SMEs) are independent firms employing between 10 and 499 staff. There are over four million SMEs in the UK which account for about 60% of business employment and over half of business turnover.

However, this important group of businesses is particularly vulnerable to climate change. A review of weather impacts across the West Midlands over the last ten years shows that extreme weather events have already severely affected many SMEs.

Many of these events have been flood related. Flooding is projected to increase in the future, but also other extreme events, for example extreme heat, would also affect SMEs.

Impacts of extreme events on business in the West Midlands identified from surveys include the following:

- Rail commuters in Birmingham endured extensive delays on 17 July 2006 as the extreme heat caused railway lines to buckle. Many services from New Street Station in Birmingham had to be cancelled and some passengers had to wait more than two hours.
- A farm in Herefordshire indicated that if they had not invested and adapted to hotter summers and warmer damper winters, they would be out of business due to crop failure.
- Based on a 2006 survey, 90% of SMEs are under-insured against flooding, and 70% of those in high risk areas were “not concerned”. In particular, many SMEs do not have business interruption cover which could enable them to continue to pay wages when the business is closed and help them recover more quickly.
- The flooding in July 2007 caused interruptions to electricity and water supplies, and significant disruption to road and rail networks. 350,000 homes had no mains drinking water and many businesses were affected by failures of energy and water supplies.
- Businesses directly impacted by the 2007 floods took an average of 26 weeks to return to normal operating capacity. Some small businesses can take up to two years to recover from a flood - and some do not survive.
- After the flooding in June and July 2007, insurers received 165,000 claims in the UK, estimated to total £3bn in insured damages.
- The overall economic and social costs were far higher, as not all costs to businesses can be insured. About 8,000 business premises were affected in the 2007 floods at an overall economic cost of about £740 million, an average of nearly £100,000 per business.
- A National Farmers Union (NFU) member lost 80 sheep to flooding on land that was traditionally unaffected by flooding.

Sources:
Weathering the Storm – Saving and Making Money in a Changing Climate, West Midlands Climate Change Adaptation Partnership, May 2010.
The costs of the summer 2007 floods in England, Cranfield University on behalf of the Environment Agency, Project SC070039/R1, 2010.

In terms of social vulnerability, climate change impacts on the business, industry and services sector could increase the vulnerability of employees working outdoors or

exposed to heat- or flood-related risks. People unable to get to work or to continue working remotely because of failures of the ICT or transport systems, could suffer a loss of income. The interruption of business services or the supply of basic goods such as food and beverages could see consumer prices rise with a greater impact on low income sectors. However, this assessment found limited evidence on specific social vulnerability issues for the climate change risks analysed in detail, as these focused on business activity rather than the broader issue of corporate and social responsibility.

5.2 Direct risks

Changes in climate, notably temperature and precipitation, may give rise to a range of direct risks. In particular, in the long-term business costs related to overheating may become more significant than those arising from floods and those dependent on large supplies of water may find that this becomes a limited resource.

In this section the risks that give rise to damage and disruption to business activity are considered. The direct risks on the operations of the utility companies are considered in Section 5.3.3, as they have indirect consequences for business, and the implications for buildings and infrastructure are addressed in Chapter 7. The main biophysical impacts are addressed in terms of heat (and drought), floods (and erosion) and water availability.

5.2.1 Heat (and drought)

Changes in climate are projected to influence both the heating and cooling energy demand within buildings. Modern factory buildings are more vulnerable to climate change as a result of their design characteristics. Through increased ambient air temperatures and (if cloud cover also reduced) increasing UV radiation, as well as heat created by plant and machinery, ICT equipment and lighting, internal building temperatures may increase throughout the year and especially during summer months. In the specific case of cooling requirements, longer, drier summer periods may cause overheating in naturally ventilated buildings and affect the capacity of low energy cooling systems to provide comfortable conditions across all building types. These changes may have knock-on implications for worker health and safety, productivity and product quality.

The issue of overheating of buildings was addressed by considering the number of days a year when the temperature exceeds a comfort level taken as the threshold for overheating (BE3 in Built Environment Sector report). To relate this to business interests, the risk metric was extended to consider the implications of overheating on productivity in the work place. Using data from the Inter-Departmental Business Register (IDBR) and the Standard Industry Classification (SIC, 2007), it was possible to make a first assessment of the impact on different business sectors, by relating the statistics for staff numbers to the potential loss in productivity on warmer days and the regional projections for more frequent warm days during the summer months.

The combination of overheating and warm weather periods has been observed to produce two responses in the workforce; increased absenteeism (Kronos, 2007) and reduced productivity (Parsons, 2009). The fall in productivity when working in high temperatures has been examined by the National Institute of Occupational Safety and Health in the US (NIOSH, 1986) and a response function based on an interpretation of their estimates was developed (BU10 in Business, Industry & Services Sector Report).

This can only be regarded as a preliminary estimate, as such a response function needs to be validated for UK conditions and, as reported in the literature, is not simply a function of temperature but depends on humidity, ventilation, building solar gain and a number of other factors. It should also be noted that some researchers have suggested that temperatures can be much closer to the physiological tolerance curve before there is any significant impairment of mental capacity (Hancock, 1981). This would suggest that the response function may be overly pessimistic.

The present day turnover of businesses[74] amounts to some £3.8 trillion with over 23 million staff in employment. Currently, the fall in productivity, based on a 26°C threshold, is equivalent to an annual average of some 5 million days lost, which is 0.1% of the staff time available. This reduces to 3 million or 0.06% using a 28°C threshold. Using the lost staff days and an average staff cost of £150 (average wage plus social costs) this suggests a value of about £770 million, which is 0.09% of payroll costs and 0.02% of turnover (£460 million, 0.05% of payroll costs and 0.01% of turnover for the 28°C threshold). These two figures provide an indication of the uncertainty associated with the choice of threshold, which can only be narrowed by developing a better understanding of the impact of high temperatures on worker efficiency and how this translates to business turnover and profitability. The actual consequence may be greater because for some businesses the lost productivity may be greater than the hours of staff time lost. There may also be consequences due to redistribution, as trade moves to businesses that are less affected or better prepared. The scoring of this risk for Table 5.2 uses expert opinion and the percentage reductions in productivity rather than the potential economic losses.

Lost production exposure is forecast to increase by 50% in the near-term (2020s), increasing by a factor of 2-6 to the 2050s and around 2-20 by the 2080s. Thus, without taking account of adaptation and other changes likely within businesses, the costs have the potential to grow from around £770 million to some £3.6 billion by the 2080s (Medium emissions scenario, central estimate) with an upper and lower bound of £1.1 billion to £15.2 billion (Low emissions scenario, lower estimate to high emission, upper estimate). For the 2080s, the central estimate is an increase from 0.09% to 0.4% of payroll costs and 0.02% to 0.1% of total turnover. The 2080s estimate is approximately equivalent to one day per employee per year.	Medium confidence

A number of assumptions had to be made to get an estimate of how increased temperatures, notably during the summer months, may affect worker productivity. The confidence in some of these assumptions or sources is generally low and hence the confidence in the overall estimates is low. However, they do serve to indicate that this could be a serious consequence with the potential to increase business costs substantially unless suitable adaptation measures are introduced.

One consequence of warmer summers is to increase the energy demand for cooling, particularly for air conditioning in offices and cooling systems for ITC infrastructure.

To explore this issue, both cooling degree days and the work to look at potential trajectories for UK future cooling demand from the 2050s Pathway Analysis (DECC, 2010a) were considered (EN2 in Energy Sector report). The latter provides information on non-domestic cooling demand taking account of both socio-economic and climate changes and suggests that, without adaptation of buildings to improve ventilation and reduce the need for cooling, an additional 20 TWh/year may be needed by the 2020s, increasing to 75 TWh/year by the 2050s. This could obviously increase business costs. Various levels of adaptation are also considered, with the highest level leading to a reduction in demand from present day levels of around 10-15 TWh/year by 2050.

[74] Summed over SIC Sections A-R

Based on climate change alone one might expect this to be countered by a reduction in the need for heating during the winter. However, the 2050s Pathway Analysis (DECC, 2010a) also considered heating demand, again taking account of socio-economic and climate changes (BE9 in the Build Environment Sector report). This suggests that this may also lead to an increase in energy demand of some 15 TWh/year by 2020 and 50 TWh/yr by 2050. Again suitable adaptation to improve energy efficiency, by refurbishment of old buildings and improving new-build standards, has the potential to reduce the demand from present day levels by around 10-15 TWh/year by 2050. Thus for both heating and cooling the future demand will be heavily dependent on the nature and extent of the adaptation response.

Another possible source of loss relates to the impact of drought, due to hot and dry periods, on agriculture and forestry yields, which is considered further in the discussion on supply chains in Section 5.3.1 (see metrics AG7 in Agriculture Sector report and FO2 in Forestry Sector report).

5.2.2 Floods (and erosion)

Many of the consequences of flooding relate to infrastructure and buildings and are summarised in Chapter 7. Where business premises flood, there is the potential for damage to the property itself, but also to the equipment, materials and stock on the site. In addition the disruption caused by the flood may interrupt operations or affect supply chains, as already outlined above. Taken together these can have very significant implications and costs for businesses as was the case in the 2007 flood, Box 5.2. The direct property damages (non-residential) were assessed using the approach adopted for flood analysis throughout the CCRA (metric FL7 in Flood and Coastal Erosion Sector Report) and then used to assess disruption costs to business (metric BU4 in Business, Industry & Services Sector Report). An alternative approach, using the days lost based on the staff numbers of businesses located in the flood zone is also considered as part of the same risk metric.

Box 5.2 Impact of 2007 floods on businesses

Many business properties were flooded during the summer 2007 floods, resulting in damage to premises, equipment and fittings, and loss of stock. They also suffered disruption of business.

Estimates of the number of commercial properties flooded ranged between 7,100 and 7,300. The ABI subsequently estimated that 8,000 business premises had been affected. According to the ABI, in June 2009 there were 35,000 insurance claims by businesses associated with the summer 2007 floods; far exceeding the number of commercial properties that were reportedly flooded.

In addition to damage costs, some businesses claimed compensation from insurance for disruption to businesses where this involved extra costs and lost income. For example, it is known that disruption was acute in many locations, such as in Sheffield, where disruption to business was reported at £50 million.

Overall, the total economic costs associated with business impacts caused by the 2007 floods were estimated as £740 million.

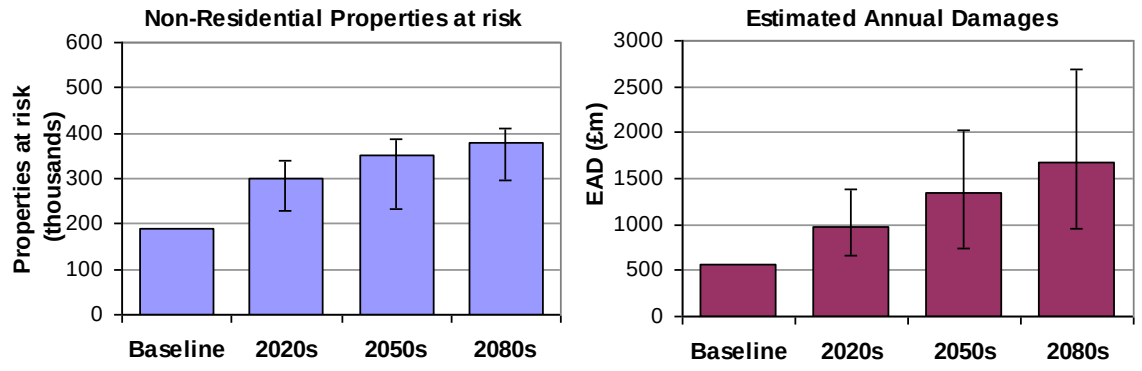
The Expected Annual Damages (EAD) associated with Non-Residential Properties (NRP) are shown in Figure 5.4 for England and Wales. The baseline is based on data for the period 1961-1990 for river flooding and data for 2008 for tidal flooding. These data have been used in the estimation of future climate change impacts on business continuity. In this case, a change in the EAD can be used to scale a similar rise in the losses due to business continuity losses[75]. If it is assumed that business interruption

[75] This includes all types of NRP and hence is greater than the equivalent value for properties associated with business

costs increase at the same rate as EAD, the costs would increase by approximately 75% in the 2020s, 140% in the 2050s and 200% in the 2080s (based on the central estimate for the Medium emissions scenario). These figures do not include socio-economic change. If it is further assumed that the baseline present day business interruption cost is £20 million per year, this would indicate that annual costs would increase to £35 million by the 2020s (Medium emissions scenario, central estimate), with a lower and upper bound of £24 million and £50 million (Medium emissions scenario, lower estimate and Medium emissions scenario, upper estimate). By the 2050s this is projected to increase to £48 million (Medium emissions scenario, central estimate), with lower and upper bounds of £26 million and £72 million (Low emissions scenario, lower estimate and High emissions scenario, upper estimate). By the 2080s this is projected to increase to £60 million (Medium emissions scenario, central estimate), with lower and upper bounds of £34 million and £96 million (Low emissions scenario, lower estimate and High emissions scenario, upper estimate).

A very rapid increase to 2020 is notable in Figure 5.4 followed by somewhat less rapid increases thereafter. In part this is due to the baseline used, particularly for peak river flows, but it is primarily a reflection of the current level of protection and the threshold that was used in the analysis. A "significant likelihood of flooding" was taken to be defined by a 1 in 75 year event. The standard of protection for river defences generally adopted is 1 in 100 years and 1 in 200 years for tidal defences. Consequently, a relatively small increase in flooding (e.g. due to higher river flows) leads to a relatively large increase in the number of properties at risk in the defended areas. As the risk increases still further, the spatial extent of the flood plains and therefore the number of properties protected does not increase as rapidly. The projected increases in flood risk for the 2050s and 2080s are consistent with projections produced in other projects. Because of the issues noted above, the results presented for the 2020s should be treated with caution.

Figure 5.4 Increase in Non-Residential Properties (NPR) at significant likelihood of river or tidal flooding and EAD (excluding socio-economic changes)



The range bars (I) indicate the plausible range about the medium emissions central estimate. Significant likelihood is defined as the 1.3% (1:75 year) risk of flooding.

The floods experienced in 2007 brought wide scale disruption to several parts of the UK and proved highly disruptive for many organisations. A survey by the Chartered Management Institute found that the effects of flooding were felt well beyond the workplace and impacted on staff availability, suppliers, customer demand as well as direct impacts such as loss of power and flooded premises. For example, the survey concluded that the average length of disruption was almost 9 days. This has been used

to estimate the financial implications of lost staff time for those businesses in the flood zone[76].

Present day turnover of businesses[77] in the floodplain is some £151 billion, with over 1 million staff employed. Currently, some 105,000 days per year are estimated to be lost based on the average length of disruption as a result of flooding. This is around 0.05% of the staff days of those businesses in the flood zone and equates to a value of about £5.8 million. Central estimates for the 2020s, 2050s and 2080s indicate that this may increase by around 30, 40 and 50% respectively. These losses contribute to the overall disruption costs, which are much more uncertain. A comparison of the two suggests that lost staff time does not increase as rapidly, reducing from 30% to 15% of the estimated disruption costs. There may also be re-distributional effects, as trade moves to suppliers that are unaffected, although for most flood events this would probably be a short-term shift.	Medium confidence

A number of other potential estimates of flood damage or disruption losses have been examined as part of this assessment, including: damage to tourist assets (BU2 in Business, Industry & Services Sector Report and Section 5.4.2 below); disruption of road traffic (TR1 in Transport Sector report); and damage and disruption to farming activities (AG2 in Agriculture Sector report). There is also the potential for some losses of agricultural land due to ongoing and possible accelerated rates of coastal erosion (see FL14 in Flood and Coastal Erosion Sector Report) and damage to some farm land due to soil erosion, notably on steep slopes or on highly erodible soils, as discussed in Chapter 4.

5.2.3 Water supply

The amount of water that can be abstracted for public water supply, agriculture and industry is sensitive to the annual water balance and subject to changing licence conditions. One of the key findings of the Water Sector report is that water abstraction may become unsustainable in a large proportion of UK rivers due to low summer flows. A shift in seasonal and/or total availability of water resources, as a result of climate change, has the potential to have significant impacts on industry in the UK. A further knock on effect, as a result of policy developments in response to low flows, may be modifications to the regulation of waste discharges, which could also impact on some businesses.

Water abstraction is projected to be more constrained in South East England, South West England, Anglian and Severn catchments (where 13% of total industrial abstraction occurs), although the degree of constraint and the time period over which it would happen varies between scenarios (see WA2 and WA8b in the Water Sector report). Although more constrained than at present, the changes in North West England are projected to be less than the areas in the south. Nevertheless, it should be noted that the large amount of industrial abstraction in the North West could mean that a small shift in long term availability, which consistently affects time of peak demand, could translate into a significant risk for industrial processes.

To examine the sensitivity to water abstraction, those businesses with a requirement for either their own abstraction licences, or the supply of large quantities of water from public water supplies, were identified at the Group level of the IDBR SIC data. These business locations were mapped against the information on water abstraction (WA8b in the Water Sector report). The need for water is assumed to be a necessary contributor to overall turnover and the change in water abstractions scaled in proportion to the

[76] Metric BU4 in the Business, Industry and Services Sector Report
[77] Using the Inter-Departmental Business Register (IDBR) and making use of the Standard Industry Classification (SIC, 2007), summed over SIC Sections A-R

individual turnover of businesses affected, assuming access is restricted for 1 year in 10. This by no means represents the real cost to business of having reduced access to water, but provides a surrogate measure. A more detailed investigation of water dependency for individual groups of industries would be needed to develop more realistic estimates.

The present day turnover of businesses[78] in England and Wales amounts to some £294 billion. By far the largest business section is Manufacturing, with an annual turnover of £192 billion. Mining and Electricity and Gas are the next largest with turnovers of around £50-60 billion. For most sections a loss of abstraction equivalent to 0.2% of turnover is projected by the 2020s increasing to some 0.4% by the 2050s and between 0.5 and 0.6% by the 2080s (all central estimates, medium emissions). The exceptions are Agriculture and Construction, which have relatively small turnovers of £40 million and £2bn respectively but may experience a loss of abstraction equivalent to 0.5% of turnover by the 2020s increasing to some 1% by the 2080s. Allowing for some adaptation these figures are typically reduced by 0.1% and up to 0.3% for agriculture and construction.	Low confidence

The overall results for England and Wales are shown in Figure 5.5 for two cases. The first assumes no adaptation, and the second includes an allowance for the introduction of efficiencies to reduce demand by some 20%.

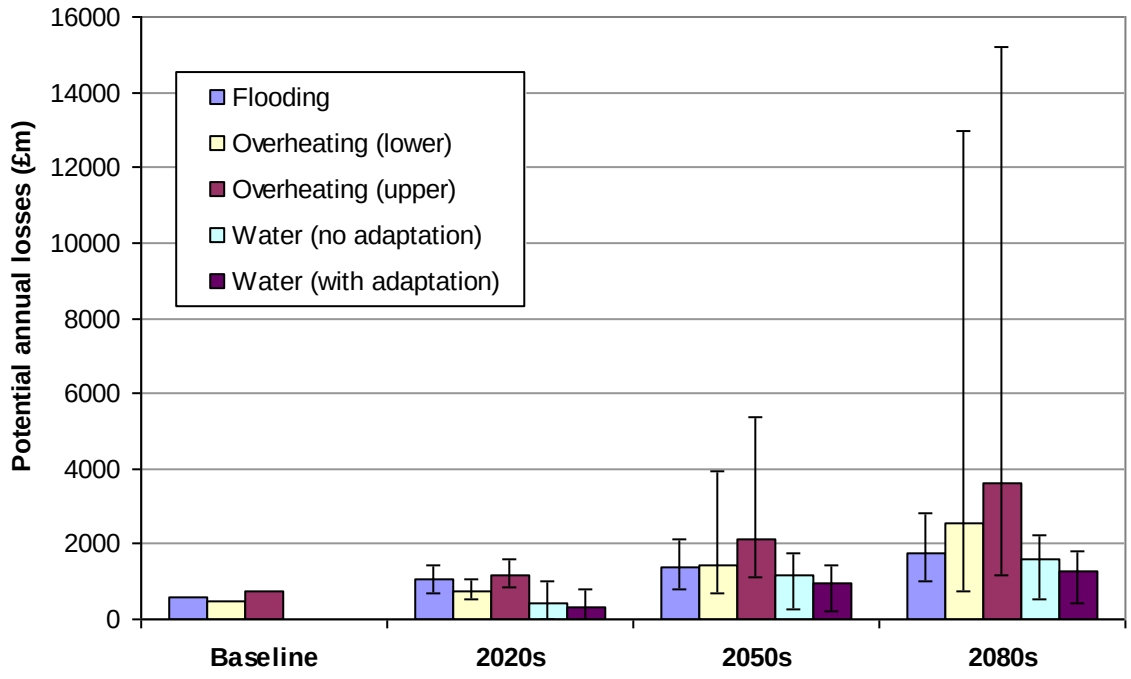
5.2.4 Summary

The metrics developed using IDBR SIC data and the EAD for flooding, provide a crude basis for comparison, Figure 5.5. The flood costs are made up of the EAD to non-residential property and the disruption costs. The baseline is based on data for the period 1961-1990 for river flooding and data for 2008 for tidal flooding. By way of comparison, these were estimated to be about £740 million for the 2007 flood (see Box 5.2). The baseline for overheating is based on data for the period 1993-2006. There is no baseline for the water abstraction values as these are changes from the present day.

On this basis, the increase in potential losses is of the same order for flooding, overheating and water abstraction for both the 2020s and 2050s. By the 2080s the upper estimate for overheating suggests that this could be double the order of costs estimated for flooding and water abstraction for the same time period. However, the size of the range associated with the overheating estimates is indicative of the uncertainties currently attached to these estimates and the resulting low level of confidence in them. With some acclimatisation and changes in work practice (e.g. earlier starts to the working day) it may be that this risk can be significantly reduced without significant adaptation costs. However, given the potential magnitude and level of uncertainty, it would merit more detailed investigation.

[78] Using the IDBR SIC data for 2010 summed over SIC Sections A-F. A Section is a group of businesses, such as manufacturing, or agriculture, as defined for the IDBR data.

Figure 5.5 Potential business losses due to flooding, overheating and water availability (£ million)



Values are for England and Wales, based on climate change only. Water abstraction values are changes relative to the present. For flooding and overheating the baseline loss is calculated for 2010. Upper and lower overheating refer to the temperature threshold used, as explained in Section 5.2.1.

The range bars (I) indicate the plausible range about the medium emissions central estimate.

See text for explanation of metrics.

5.3 Indirect risks

Businesses are dependent on resources, supporting infrastructure and services. So whilst climate may not have direct consequences for a business, any impact on these aspects of the business may result in indirect consequences. Hence, supply chains are critical to most businesses and may be affected by:

- ***External influences, such as national security, governance, finance and changing markets, that are themselves having to adapt in response to climate change;***
- ***Direct bio-physical impacts, such as heat, floods, drought (as already outlined), changes in the oceans and loss of resources derived from ecosystem services; and***
- ***Disruption to services provided by key utilities, notably energy, water and communications.***

5.3.1 Supply chains

Climatic factors have the potential to disrupt UK businesses' supply chains by affecting availability of natural resources and raw materials, or by causing distribution delays. The climate is also a factor in the market demand for goods. If extreme weather events affect key suppliers, and no alternate supply is available, then supply chains are severely interrupted. Each of these risks could increase as the climate changes.

Clearly there is also a very strong international dimension to this risk and therefore UK or non-UK supply chain disruptions can cause significant harm to business operations. They can raise costs, cause inventory overstocks, and lower the market share of a business. Broken supply chains jeopardise production and distribution, reducing revenue when goods can't be manufactured or delivered. Disruptions can also affect credibility with customers, investors and other stakeholders.

Because manufacturing and retail supply chains are complex and dependent on a network of interconnected, yet independent elements, it is not possible to develop a clear and direct causal link between climate change and supply chain disruption. Many climatic factors (e.g. heat, precipitation, flooding) can disrupt supply chains, making a single consequence response function too simplistic. Import intensity could be considered as a proxy for climate change risk, as businesses which are heavily dependent on foreign imports are exposed to climate impacts in other parts of the world. However, this is a narrow view which ignores the fact that even domestic suppliers can be affected by extreme weather events or changes in climatic thresholds. Moreover, it is the ability of retailers and manufacturer to shift suppliers that is more important than the level of international imports, as it is entirely possible that a UK business with no imports may be highly vulnerable to climate change if that business has limited, or no, alternative suppliers.

Supply chain disruptions are costly to business. A 2008 PricewaterhouseCoopers (PwC) report on supply chain integrity noted that disruptions negatively affect company stock price, return on assets, and return on sales (PwC, 2008). The report also states that businesses do not tend to recover quickly from supply chain disruptions. On average, affected companies' share prices dropped 9% below the benchmark group, and two-thirds of affected companies were lagging their peers in stock price performance a year after the disruption.

Climate change is projected to cause shifts in average conditions and may also change the frequency and severity of extreme climate events. These shifts have the potential to affect every aspect of the business supply chain, often in ways that are gradual, diffuse or indirect. Increasing globalisation, outsourcing and just-in-time approaches to inventory already create significant risk exposure. It may be more difficult to map out and understand supplier relationships (supply chain visibility) and contain costs under continuing climate change. Climate-related disruptions all over the globe would not only affect suppliers in their own locations, but would also have knock-on consequences for UK businesses.

As well as disruption of the supply chain, the other potential change is to the availability and access to the necessary resources and commodities. However, the availability of the resources, in a world with increasing population and changing climate may come under increasing pressure in terms of price, or simply availability. An extensive review of how resources and commodities imported from elsewhere may be affected by climate change was undertaken as part of the Foresight study into the International Dimensions of Climate Change (Foresight, 2010a). The main conclusions were:

- Extreme weather and decreasing water availability may impact upon the extraction of petroleum and gas, impacting on UK price and security of supply.

- Failure to move to a low-carbon energy generating infrastructure may increasingly concentrate control of UK fuel supplies into unstable regions, and further increase reliance on vulnerable energy supply infrastructure.
- Price and security of supply of UK electricity imports from France and elsewhere in Europe may be negatively affected by increases in mean extreme temperature and drought frequency, and reductions in precipitation over Southern Europe.
- Beyond the 2050s, the negative impacts of climate change such as extreme heat and water availability become increasingly important, and may affect the security of supply and price of imported UK agricultural commodities.
- Beyond the 2050s, the effects of ocean acidification of the oceans and temperature rises negatively impact upon fishing and aquaculture, which may affect the security of supply and price of imported fish to the UK and increase regional conflicts which may require UK aid or peacekeeping responses.
- Although not directly affected by climate change, the security of supply of rare earth elements may impact upon the UK's ability to develop low-carbon applications.
- Interruptions to energy supply, water and transportation caused by climate change may increasingly subject overseas manufacturing processes that the UK relies upon to short-term interruption.

Some of these impacts may be countered, at least in the short to medium-term by changes that take place within the UK. For example, in relation to agriculture, there is the potential for improvements in crop yield and given that these can be changed on an annual basis, the likelihood of timely adaptation is high (see AG1 in Agriculture Sector report). This may however, be countered by some loss of livestock production due to heat stress (see AG7 in Agriculture Sector report). There may also be some loss of productivity in native forests (see FO2 in Forestry Sector report). The position with regard to fisheries is less clear. A projected northward shift of fish populations is discussed in the Marine & Fisheries Sector Report (MA4) and it is difficult to assess how this would impact on commercial fisheries. Some existing stocks are projected to shift out of UK waters to the north, whereas warmer water species would begin to occupy the southern areas. The overall position is then confused by the interaction with the potential for increased occurrence of harmful algal blooms (MA1), and increased prevalence of disease and pathogens leading to the deterioration in water quality, or the dominance of invasive non-native species (MA2 and MA6). Finally, as noted in the Foresight study (Foresight, 2010b), ocean acidification could have a major impact in the medium to long-term, with particularly severe implications for shellfish fisheries (see MA3 in the Marine & Fisheries Sector Report for a more extensive discussion of the potential impacts).

The potential for disruption in the transport chain is similar to the international position. Delays due to flooding may increase (see TR1 in the Transport Sector report) and additional costs may be borne by the transport industry, as a result of increased damage to the network caused by landslides, rutting of road surfaces, buckling of rail tracks and scour around bridges (TR2 to TR6 in the Transport Sector report). These impacts are discussed in the Transport Sector Report, where some potential benefits are also identified, such as fewer cold winters leading to less disruption to all modes of transport (although it is noted that less frequent cold weather events may lead to complacency and a lack of preparedness).

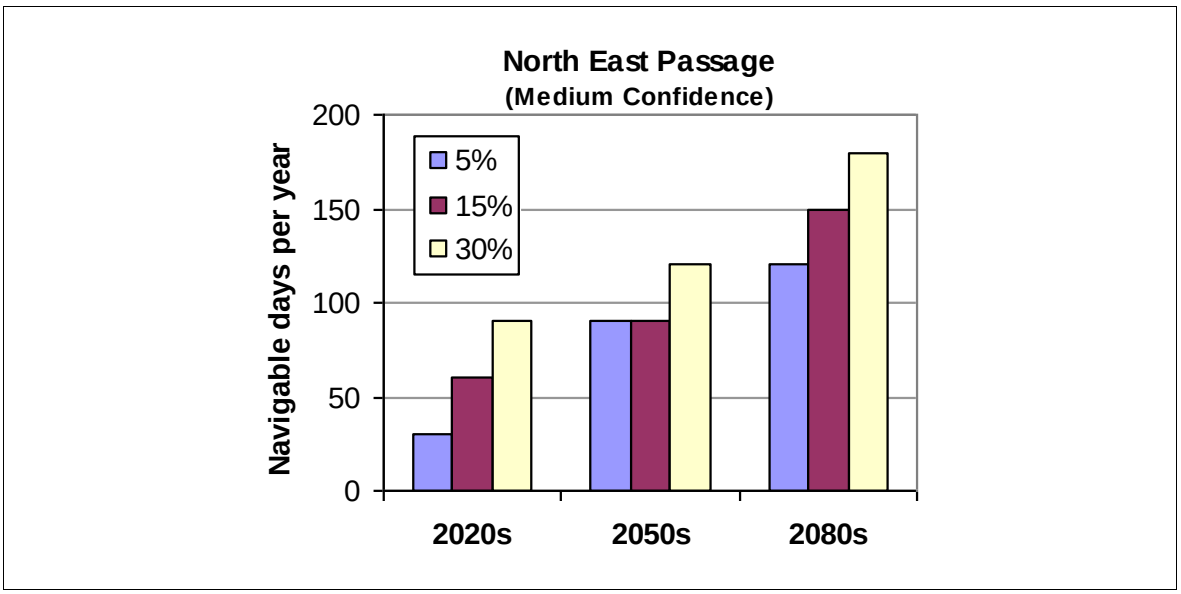
At present, confidence in the wind and storm projections from GCMs and down-scaled RCMs is relatively low, with some models suggesting that the UK might experience fewer storms and others suggesting an increase. For important applications that

depend on wind, such as the offshore renewable sector but also shipping, the uncertainty surrounding this parameter presents a limitation when attempting to predict future risks. Although highly uncertain, it is anticipated that wave climate around the UK in the winter may roughen and this may cause more frequent disruption to ferry services off northwest Scotland, southwest England and across the Irish Sea. This may result in substantial socio-economic impacts, especially where communities are highly dependent on ferry services (see MA7 in the Marine & Fisheries Sector Report).

One potential opportunity is for new trade routes as a result of the melting of sea ice in the Arctic (Foresight, 2010b). The opening up of the North West and North East passages to the Pacific Ocean may lead to a shift in the importance of UK ports from the South to the North West or North East of the British Isles. The North East Passage (also referred to as the Northern Sea Route) from the Far East is more than 3000 km shorter than via the Suez Canal. The timing and extent of this change is examined in the Marine & Fisheries Sector Report and noted in relation to supply chains in the Business, Industry & Services Sector Report. The number of navigable days per year was developed as a risk metric (MA5 in the Marine & Fisheries Sector Report).

In the method used, it was assumed that vessels are able to navigate through ice conditions, whilst some percentage of the area is still covered by ice. Three different ice cut-off scenarios, of 30%, 15% and 5% were considered (i.e. the percentage of the area covered by ice, where vessels would need the support of an ice breaker to make a passage). Hence, under the 30% cut-off it is assumed that vessels are able to make a passage whilst 30% of the area is still covered by ice. The number of occurrences when these routes were observed to be below the threshold and therefore 'navigable' is presented as the number of navigable days per year in Figure 5.6, for each of the three cut-off scenarios.

Figure 5.6 Navigable days calculated for different ice cut-off thresholds (%)



The opening of ship routes via the North East passage has the potential to have a significant influence on UK trade. At present the passage is only open a few days each year and generally requires ice-breaker support. In the future, the viability of this route is likely to increase. With ice-breaker support (i.e. assuming 30% ice extent cut-off) the route could be available for 90 days by the 2020s and as many as 180 days by the 2080s. Under the lowest ice cut-off scenario of 5%, the North East passage is still projected to be navigable for up to 30 days by the 2020s and 120 days as early as the 2080s. This is relevant when considering commercial benefits, as this would require the lowest ice breaker capability or support, therefore lowering costs associated with safe transit.	Medium confidence

Such projections have potentially huge environmental and socio-economic implications. In terms of the UK market, container traffic would be most likely to see a benefit from the potential Arctic shipping routes to/from Asiatic markets. By using the Arctic shipping routes it is considered that there could be as much as a 40% reduction in shipping transportation required to service current flow demand. This would represent huge costs savings in terms of mileage, time and inventory costs, as well as associated costs of skipper inventory, bunker costs and canal charges. The addition of alternative route options may also give operators the option to avoid routes with higher levels of political instability. In addition, the opening of Arctic shipping routes could provide access to increased resources from new Arctic sources including crude oil and coal.

5.3.2 Ecosystem services

The natural environment provides a range of services and resources which are now referred to collectively as ecosystem services. The National Ecosystem Assessment has highlighted how dependent economic activity is on these services and resources. There is also the potential that CSR[79] investment and reporting will promote a deeper understanding of the ecosystem services that businesses depend on, whilst also leading to a greater alignment of businesses to the principles of sustainability. The role of ecosystem services is described more fully in the Natural Environment theme (Chapter 8), with some indication of the sort of services used by business summarised in Table 8.3. The valuation of these ecosystem services is at an early stage of development and may provide a basis for exploring the relative importance of ecosystem services under a changing climate in future risk assessments.

As with business, the natural environment is subject to direct and indirect risks. Direct risks have been assessed to the extent currently possible, reflecting the complexity of ecosystems and the highly non-linear responses that can occur because of the many interdependencies. Some of these would have implications for business, in particular those that affect the provision of ecosystem goods such as food, timber, fuel and water supply and, regulating services; in particular climate regulation, waste breakdown and water quality. Climate change impacts on primary production, water flows, changing yields, geographical shifts in species and the influence of invasive non-natives, pests and diseases are therefore particularly relevant. Within the natural environment, indirect risks relate to socio-economic drivers, together with changing land use and management. Importantly, there is the potential for conflict between business and the natural environment regarding the objectives of both. Marine management is a good example of this. The marine environment is under pressure from rising water temperatures and the heavy exploitation of wild fisheries using methods, such as some types of trawling that negatively impact the sea bed, which plays a crucial role in cycling nutrients and maintaining the productivity of the sea. However, a large number of people in the UK and globally rely solely on the sea for their livelihoods and the UK

[79] Corporate and social responsibility

as a nation relies indirectly on the sea for the goods and services it provides including food, reduction in climate stress, fertiliser and coastal protection to name a few. By way of an example, for 2007, the Office for National Statistics showed that the total sales (turnover) by the UK fish processing sector were £2,567 million (UK NEA, 2011). Adaptation to climate change needs to satisfy both environmental and human wellbeing objectives. The difficulty here also is that socio-economic drivers will change as we adapt to climate change. Consequently the indirect risks on the natural environment, which may in turn give rise to indirect risks for business, will depend on the policies, regulations, working practices, and land use changes (e.g. production of biomass) that take place as part of the adaptation process. This highly complex feedback is, as yet, poorly understood and, together with a more in-depth exploration of the role of ecosystem services, is likely to be developed further in future risk assessments.

5.3.3 Utilities

The exposure of the utilities to weather related damage and disruption varies substantially. Whilst ICT has some exposure in terms of flooding of switching stations and storm damage to overhead lines, it is relatively resilient. In contrast, the water sector may have to address issues related to the supply and demand for its main product. Energy and transport sit somewhere in between with significant exposure to damage from weather events to various parts of their respective infrastructures and operations. The events surrounding the 2007 flooding provide a graphic illustration of some of these impacts as briefly summarised in Box 5.3.

Box 5.3 Impact of the 2007 floods on electricity and sewage provision

The summer of 2007 was one of the wettest on record. On the 20th July, two months' worth of rain fell in 14 hours; 5,000 homes and businesses were flooded and 48,000 homes were without electricity for two days. Electricity supplies were threatened when the Walham and Castle Meads electricity substations near Gloucester became vulnerable to rising floodwater. The Environment Agency worked with the Armed Forces, fire and rescue services and the police to protect Walham substation. The Castle Meads substation was shut down before it flooded, leaving 42,000 people without power in Gloucester for up to 24 hours. The flooding of the Walham substation would have resulted in 500,000 homes being without power.

Crucially, two days after the rains fell, the Mythe Water Treatment Works (operated by Severn Trent) was flooded, which led to its shutdown; 350,000 homes and 7,500 businesses were without any mains water for 12 days and drinking water for 17 days. During this crisis, 1,400 bowsers were deployed and 40 million bottles of drinking water were distributed with 200,000 litres of drinking water delivered to vulnerable people.

Overall, it is estimated that the flooding and water crisis cost the county of Gloucestershire £50 million (Gloucestershire County Council 2011[80]).

These are all direct consequences of climate change and utility businesses would also experience the same consequences as other businesses discussed in Section 5.2. However, any impacts on utility businesses are likely to have knock-on consequences for other businesses. This relates to continuity of supply (and possibly pricing) for water and energy, and issues to do with disruption and loss of service as far as transport and ICT are concerned. Whilst it has not been possible to evaluate the indirect risks (because they highly dependent on the adaptation pathways which have yet to be explored in any detail) the summary of the risks on the utilities provides some insight into the scale of the potential issues.

[80] http://www.gloucestershire.gov.uk/index.cfm?articleid=19605

Water utilities

The water utilities are potentially going to have to manage some very direct impacts on their primary resource – water. Changes in both temperature and rainfall patterns, whilst varying across the country, are projected to alter the supply of water and crucially the reserves available for abstraction. This coupled with changing demands from both households and industry (notably agriculture) means that some significant changes in the supply-demand balance need to be managed. Given the importance of this issue, a number of risks were investigated as part of the CCRA. This included consideration of the bio-physical impacts on aridity and low flows (WA1 and WA2 as summarised in Chapter 3) and the availability of public supply, along with changes in demand and the balance of the two (WA3-5 in the Water Sector report) and how this might impact on unsustainable abstractions (WA8 in the Water Sector report). Nationally it is projected that there is little significant risk to the supply-demand balance in the near-term, but without some future re-distribution of water resources regionally, some river basins may face deficits in the medium to long-term. Abstraction licences may then have to be revised and this may have implications for industry and agriculture, as discussed in Section 5.2.3 above.

Another consequence that affects water companies is the flooding of sewage treatment works. This was highlighted as a risk during the 2007 floods when 40 of the 204 sewage pumping stations and 11 of the 53 sewage treatment works in Gloucestershire were damaged. This included complete inundation and damage to operating equipment and the flooding of site roads which constrained access. It was therefore identified as a risk (FL10 in Flood and Coastal Erosion Sector Report) but at the time the data on the location of these installations was not available, although it is understood that this is being compiled as part of the Environment Agency's National Receptor Database (NRD). Whilst better preparedness may limit this risk in the future, increased flood frequencies would put increased pressure on operators to actively manage this risk.

The very direct link between water, the natural environment and the structure and function of habitats, means that there would also be increasing pressures on the industry to manage the resource in a way that protects the natural environment and, where possible, maximises the opportunity to maintain and restore biodiversity (see Lawton *et al.*, 2010 for justification of the need). The particular issues for the water industry include managing low flows and the ecological status of rivers, which are now considerations under the Water Framework Directive (WFD) and were examined in the Water Sector Report (WA7 and WA9). The results show projected increases under the "wet" scenario for the 2020s, but declines for all other scenarios, with significant decreases by the 2080s (e.g. 80% of sites no longer meeting WFD indicators).

A rather different risk, which is an important performance measure for the water industry but also has consequences for the natural environment, is the frequency of spills from Combined Sewer Overflows (CSOs) during heavy rainfall events. This has been examined based on application of the UKCP09 Weather Generator, looking specifically at the changing frequency of heavy rainfall events over London, Glasgow, Cardiff and Belfast (WA10 in Water Sector report). Projections show an increase in precipitation in winter months, due to a combination of greater depths and more frequent heavy rainfall events. This would result in greater volumes of runoff in urban environments with potential increases in CSO spill frequency (see Chapter 7 for further discussion).

Energy utilities

The main risk that flooding poses to the energy sector concerns power stations, electricity transmission and distribution substations, as overhead lines, underground cables and gas pipelines appear to be less vulnerable to both river and short-term coastal/tidal flooding. The exposure of electricity substations and power stations in

England and Wales was examined as part of the CCRA (FL11 in the Flood and Coastal Erosion Sector Report and EN1 in the Energy Sector report). The results suggest that the number of substations in areas with a significant likelihood of river or tidal flooding may increase from a baseline of 46 to between 55 and 80 by the 2080s (this does not take account of protection currently being put in place by the industry and assumes no further adaptation). In addition, the number of power stations in areas at significant likelihood of river and tidal flooding also increases from a present day level of around 15% (10GW) of total generating capacity in England and Wales to between 22% and 33% by the 2050s and between 29% and 37% by the 2080s. This analysis relates to existing power stations and most of these will be replaced over this timescale (typical life-cycle is approximately 40 years). Many of the new builds are likely to be on the same or nearby sites, but the process of renewal does provide the opportunity to manage the risk.

Available evidence suggests that current energy infrastructure is relatively resilient to increasing temperatures, since similar infrastructure is operational in other (hotter) countries. Therefore, sensitivity to this risk is assessed as low relative to other risks (EN3 in Energy Sector report). However, high temperatures also lead to reductions in transmission and distribution efficiency, i.e. the lower capacity of electrical circuits as they are de-rated in order to maintain appropriate operating conditions as average temperatures increase. Currently in summer these losses can be around 3% of transmission capacity and 10% of distribution capacity, and these are projected to increase in the future under a warming climate (EN10 in Energy Sector report). However, this is relatively minor in respect to both historic and projected load growth (including increases that result from adaptation measures, such as adoption of electric cars, population growth and other aspects of societal change).

Some consideration of cooling demand during warmer summers (EN2 in Energy Sector report) suggests that the projected increase in demand can be met with existing and future capacity. This is largely because of the proportionally higher heating demand that has to be met over the winter. Cooling demand will be strongly influenced by the extent to which additional power driven cooling is installed and the incentives for alternative or low carbon options. Based on current projections, the increased cooling demand over a year is likely to be less than the reduction in heating demand due to milder winters and this shift would affect the economics of power plant operation. This is, however, anticipated to be a relatively minor influence when set against the other changes going on in the industry, driven by energy security issues and actions to deliver a low carbon future.

Communications (telecoms and transport)

The increasing dependence on Information and Communication Technologies (ICT) was highlighted in the recent Engineering the Future (2011) report to government. ICT is now embedded in a complex (and interacting) array of infrastructure networks that supports daily life and of course business, as illustrated by the case study in Box 5.4. The potential for disruption was therefore identified as a risk and considered in the Business, Industry & Services Sector Report (metric BU5). However, further investigation found that very few impacts are expected, largely because the rapid pace of technological change means that the sector has the flexibility to adapt to increasingly frequent occurrences of weather disruption with new, more robust technology (AEA, 2010). It was also noted that the broader ICT structure is robust because the communications grid is much more distributed (than, for instance, the energy grid) as different technologies are being used (e.g. mobile, satellite, etc.), at least during the present phase of evolution. However, the localised effects of weather-related disruption are generally expected to increase and could increasingly affect individual businesses (particularly SMEs) and remote, or home, workers, particularly if they are

located in relatively remote areas where they may be dependent on single electricity and telecommunications connections.

Box 5.4 Flooding at BT Exchange in Paddington, London
It is possible for localised incidents to have a considerable impact, as was experienced when a major flood occurred at a BT exchange in Paddington, London. The flood subsequently led to an electrical fire and affected broadband and telephone services across the UK for several hours in March 2010 (AEA, 2010). According to Gradwell, a business ISP, 437 local exchanges and up to 37,500 Datastream circuits were affected with nationwide repercussions on communications. Vodafone also reported that its network was hit by the incident.

The transport industry may face more severe consequences as most of the infrastructure is directly exposed to changes in the weather. The potential for damage to this infrastructure is covered in more detail in Chapter 7. Here it is simply noted that damage due to increased flooding, landslides and heat damage to road surfaces and rail tracks is likely to increase maintenance and disruption, with implications for both those delivering and operating the infrastructure and users.

One further issue for both sectors is the potential for ground heave to break cables and pipes (Engineering the Future, 2011). This was not looked at explicitly in this assessment, but is likely to occur predominantly in areas of shrink-swell clays. These are also the primary consideration when assessing subsidence, an issue that was addressed (BE2 in Built Environment Sector report). Whilst this does not provide an assessment of the level of potential damage it does provide some indication of the areas most likely to be affected, which in this case are the South East (particularly London) and from the East Midlands eastwards.

5.3.4 Summary

The supply chain is a particularly complex issue that impacts on most businesses. As briefly outlined above it involves the potential for disruption of supply and delivery and also the ability to access resources, commodities and services. These may be affected by a wide range of external influences such as national security, governance, finance and changing markets that are themselves having to adapt in response to climate change, as well as more direct bio-physical impacts due heat, floods, drought and changes in the oceans. This is a risk with potentially very high consequences. Whilst several of the potential consequences are known, as briefly outlined, the complexity of the network means that we have only a very limited understanding of the interactions and dependencies. A similar theme is highlighted in the relation to infrastructure. The recent Engineering the Future report (2011) outlined the need for more system based research to meet this need and such research would also inform supply chain issues. However, the complexity of the issue means that businesses may need to give more consideration to the trade-off between efficiency and business resilience.

5.4 Balancing opportunities and threats

Business is anticipated to be exposed to opportunities as well as threats from climate change. The extent of the opportunities will be dependent on the business, but may be found in new investment opportunities,

changes in supply chain, or advantages that may flow from the changing climate.

To illustrate this two sectors are discussed here:

(i) Financial services where by mainstreaming climate risk management into their processes and practices, UK financial institutions have a role to play in both minimising their exposure and promoting climate resilient investments.

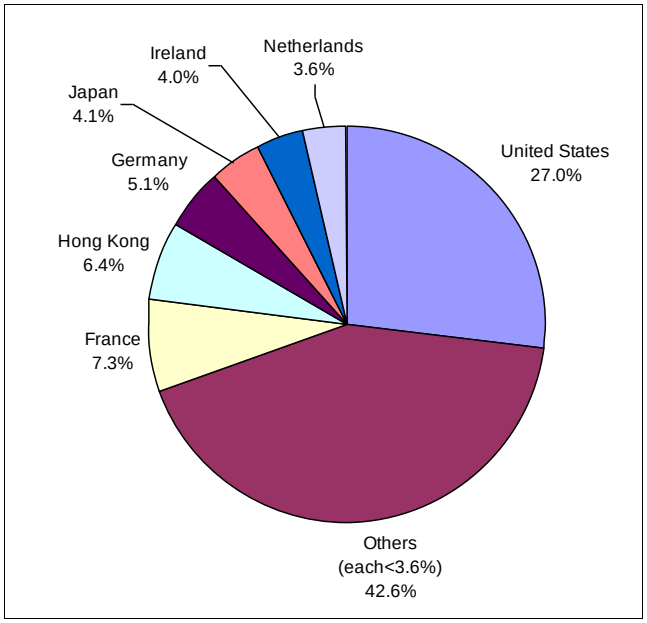
(ii) Tourism to highlight some of the opportunities, which serve to counter the overall impact of the threats identified.

5.4.1 Financial services

In the UK, the financial sector is diverse and composed of various types of institutions: banks, asset managers, pension funds and a number of other financial services providers (such as hedge funds) and insurance. Banking has by far the largest number of employees in the industry, while asset management constitutes a fundamental pillar in terms of total asset value, representing £3.4 trillion of assets under management. This is equivalent to 70% of the UK's GDP in 2008 (AMWG, 2009).

Contrary to common belief, the industry is not restricted to the City of London, although the City represents a major global financial centre. The financial services industry in the City accounts for about one-third of the approximately one million jobs in this sector and yields more than double the economic value when compared to other UK regions (HM Treasury, 2009).

Figure 5.7 Foreign investments by country share as a percentage of investments by UK-owned financial institutions (Q3, 2010)



Source Data: Bank of England, 2010

The UK financial services sector constitutes a core market for financial institutions across the world with more than £10 trillion worth of investments moving in and out of the country. In 2008, UK-owned financial institutions invested heavily in developed countries, such as the USA, France, Hong Kong, Japan and other European countries. Total investments in the developing world are significant, although the share per country is less than 3.6% of total investments, Figure 5.7.

The financial services are a key part of the UK's economy, accounting for up to 12% of the UK's GDP. The UK fund management industry was responsible for a record £4.1 trillion of funds in 2007, UK firms also manage assets overseas, for both UK and international clients, estimated at around £12.4 trillion. Insurance companies controlled 15% of investment in the London stock market in 2006. This compares to 13% held by company pension funds, 3% by banks, 2% by unit trusts, and 10% by other financial institutions (UK Trade and Investment, 2007). The insurance industry is also a major global player with a premium income of £168 billion in 2008, of which some £65 billion was for overseas insured risk managed in the UK (Foresight, 2010a).

There is limited substantive evidence of the consequences of changes in climate on UK financial institutions, with the exception of the insurance industry. The most significant consequences are expected to occur if financial institutions fail to mainstream climate change adaptation considerations into their investment decisions, through changes in investment financial and/or credit performance. Furthermore, financial institutions are exposed to reputational risks, investor pressures, legal liabilities and changes in demand for finance. This was therefore examined as one of the risk metrics in the CCRA (BU1 in the Business, Industry & Services Sector Report) and is briefly summarised here.

Research has shown (UNEPFI, 2011) that financial institutions that fail to integrate climate risk and adaptation considerations into their processes are likely to be affected by climate change through:

- Financial and credit performance of individual investments and investment portfolios (loans, equity, guarantees, etc.) see examples in Box 5.5;
- Reputation, if by failing to assess and manage climate risks institutions fall short of growing stakeholder expectations on adaptation;
- Investor pressures for climate risk and adaptation disclosure, and climate resilient risk management;
- Legal liabilities, if decisions fail to take into account the reasonably foreseeable impacts of climate change and information is not provided on the material risks of climate change; and
- Market changes in the event of a change in demand for finance from governments, commercial and individual clients.

As already noted, this is a global industry and the Foresight study into the International Dimensions considered how impacts overseas might impact on the UK Financial Services. These are summarised in Table 5.1. Whilst noting various threats due to increased bio-physically driven damage or disruption, it also highlights some of the potential opportunities relating to low carbon products and innovative climate related products and services.

Box 5.5 Examples of consequences of climate-related events on financial and credit performance of "real sector" investments

Market conditions

Retailers that understand how weather affects sales and plan supply accordingly stand to benefit from climate-related impacts. For example, the hot UK summer of 2006 caused a reduction in total sales of 5% for the month of July (department stores reported that trade decreased by 7%).

Production output

The 2003 summer heatwave in Europe led to large losses in the agricultural sector totalling 13 billion Euros (~£11 billion) in the European Union. For example, there was a 10% and 20% decrease in wheat output in the UK and France respectively, compared to the previous year.

Commodity prices

Future increased volatility of commodity prices is expected in response to climate change. For example, the Australian droughts were found to have played a role in the sharp wheat price increases observed between 2006 and 2008. Similarly, wheat price doubled in 2010 as a market reaction to a drought induced Russian export ban.

Operating costs

Maintenance costs are likely to increase for some assets if they are to cope with climate change impacts. For instance, a section of the railway between London and Penzance in Southern England is subject to repeated speed restrictions and closures at Dawlish due to seawater overtopping. With accelerated sea level rise, future sea water overtopping at Dawlish is projected to increase by around 120% by the 2020s relative to present day levels – 2006 (Rail Safety and Standards Board, 2008) and further affect the balance sheet of the operator.

Table 5.1 Major risks to UK Financial Services due to climate change impacts overseas

<table>
<tr><th rowspan="2">Risk / Scenario</th><th rowspan="2">Global / Regional implications</th><th colspan="2">Implications for UK (opportunities as well as threats)</th></tr>
<tr><th>Direct</th><th>Indirect</th></tr>
<tr><td>Food scarcity</td><td>Global food shortages, migration and civil unrest</td><td rowspan="4">Increased insurance claims, default on loans, reduced returns on investments, redirection & loss of foreign wealth and capital, reduction in business opportunities, increased commodity price volatility</td><td rowspan="8">Reduction in globalisation and loss of international financial activity, impact on inflation, interest rates and consumer spending, increased uncertainty, reduced access to resources, reduced international cooperation.

Opportunity for risk management products, low carbon and climate-resilient finance.</td></tr>
<tr><td>Ecosystem degradation</td><td>Ecosystem collapse or reduction in ecosystem services</td></tr>
<tr><td>Increased water stress</td><td>Civil unrest, international disputes, worsening international security</td></tr>
<tr><td>Increase in heat related mortality</td><td>Increased humanitarian burden</td><td>Increased demand for aid and life insurance claims</td></tr>
<tr><td>Increased transport disruption</td><td>Slowdown in global trade</td><td rowspan="4">Increased claims, loan defaults, cost of capital, redirection of overseas capital, failure of investment, loss and redirection of foreign wealth, reduction in business opportunities, price volatility, contraction of corporate activity</td></tr>
<tr><td>Infrastructure damage</td><td>Slowdown in global trade</td></tr>
<tr><td>Property damage</td><td>Increasing energy and water costs</td></tr>
</table>

Risk / Scenario	Global / Regional implications	Implications for UK (opportunities as well as threats)	
Increased demand for low carbon products	High demand for low carbon and low water use products	Increased opportunity for manufacturing, carbon finance and R&D	UK opportunity to be a leader of global low carbon economy
Increased demand for climate risk management	Greater awareness of climate risks and demand for financial products to manage this risk	Innovative insurance and other risk management products and services. Financing for adaptation and climate resilient growth	

Source: Foresight, 2010a

Two risk metrics, both related to insurance risk were developed as part of this study. The first relates to the potential loss of revenue for mortgage lenders as a result of changes in insurance cover (BU6) and the second examined the potential increase in insurance pay out costs due to flooding (BU7), both in the Business, Industry & Services Sector Report.

A decrease in revenue for mortgage lenders as a result of insurance cover changes

Climate change is expected to cause an increase in flood probability to properties throughout the UK, including flooding from tidal, river and surface water sources (Pitt, 2008). As the probability of flooding increases, insurance for properties that flood relatively frequently may be increasingly difficult to obtain. There are already cases in the UK where property insurance is either not obtainable or very expensive.

It is a standard condition of all mortgages for a property that they are covered by standard buildings insurance, including flood cover, for the full term mortgage, in order to protect the borrower and the lender. Most properties in the UK are insurable on normal terms, under an agreement reached between the Association of British Insurers (ABI) and Government in 2002 (and updated in 2005 and 2008), known as the Statement of Principles.[81] In order for this situation to continue, the UK Government and Devolved Administrations have committed to capital investment in flood management and to the control of development in flood risk areas through the planning system. Mortgage lenders have a keen interest in insurance remaining widely available, thereby ensuring that mortgages can be offered in flood risk areas. Insurers have committed to continue to make flood insurance for domestic properties and small businesses built before 1 January 2009 available as a feature of standard household and small business policies, if flooding is not a significant likelihood (see below), or if flooding is a significant likelihood but defences are planned that will reduce likelihood below that threshold. The current agreement lasts until 2013.

A particular concern would be if it became unviable for the insurance sector to service a changing flood risk on a large-scale. Insurance contracts are normally only valid for 12 months, and if insurers did not renew cover at the end of this period, it would leave both lender and borrower exposed to an increased risk of loss and potential invalidation of the mortgage. The desire to retain flooding cover as a standard aspect of buildings insurance is, therefore, extremely important to the working of the mortgage market and the wider housing market.

[81] http://www.abi.org.uk/Information/frequentlyaskedquestions.aspx

For this analysis, the number of properties at significant likelihood of flooding[82] (river or tidal) was used as an indicator of the impact of flooding on the availability of insurance, and consequently on the level of mortgage lending exposed. The mortgage fund value (£) of properties at significant likelihood of flooding is calculated for each English region and Wales by considering the overall ratio of mortgage to property price and the number of properties that have mortgages. The mortgage fund value at risk due to insurance becoming unaffordable or unavailable is a small proportion of this total mortgage fund value of properties at significant likelihood of flooding for the following reasons:

- The reduction in mortgage fund value is linked to the property value. RICS (2009) found that only three years after a flood, in many cases, properties returned to pre-flood values. Temporary devaluation ranged from zero to 30% of market value.
- Supply and demand of property (market effects) will have a greater influence than climate change under the existing Statement of Principles and therefore attributing gross value at risk solely to climate change in isolation is inaccurate. However, the future scope of this is uncertain.
- This RICS study suggested that many residents on floodplains had experienced difficulties renewing insurance policies, but in general insurance was available at a reasonable price for residents. Homeowners that experienced difficulties usually obtained better terms by switching insurance company.
- Insurance and mortgage lenders may implement new management techniques to reduce the risk to mortgage fund value.
- Currently, only in extreme cases are mortgages declined on the basis of flood risk. This is supported by the RICS study that suggested that insurance was currently available in most instances and that flood risk was not a major factor in determining premiums.
- Only a small proportion of homes with a 1 in 75 or greater annual probability of flooding will suffer flood damages in any given year on average.
- The housing market may respond to flood risk through reduced house prices for properties in exposed areas. This in turn may reduce the value of mortgages at risk and the exposure of lenders.
- The risk to capital value of homes does not necessarily translate to a loss to the lender; the lender incurs loss if the owner fails to repay their mortgage.

It is therefore reasonable to consider that only a small proportion of the total mortgage fund value of properties at significant likelihood of flooding is at risk. The mortgage fund value at risk due to insurance becoming unaffordable or unavailable may be of the order of £1 to 8 billion by the 2050s and £2 to 9 billion by the 2080s, assuming the value at risk is 5% to 15% of the total value at significant likelihood of flooding, and that this does not spur cost-effective adaptation activity.

Increase in payout costs by the insurance industry due to flooding

The insurance industry has seen an increase in weather-related claims over recent decades, largely due to an increasing number of extreme events and the probability of

[82] "Significant likelihood" is defined as a 1.3% or 1 in 75 annual probability of flooding or greater.

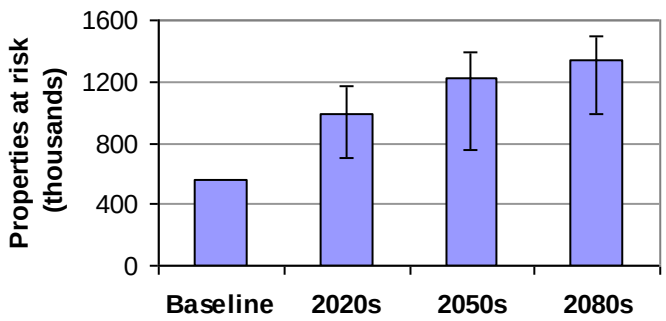
a link between the increasing number of weather extremes and climate change has been noted (Munich Re, 2010). This concern is not new within the insurance industry. In 2007, PricewaterhouseCoopers published results from a survey of 100 insurance industry representatives from 21 countries that indicated climate change was the fourth most important issue for the industry (out of 33 identified), with natural disasters being the second.

It has been estimated that approximately £3 billion of the summer 2007 loss was covered by insurance, with insurers receiving around 165,000 claims. To put this into context, this is eight times the combined cost of the Carlisle flood in 2005 and Boscastle flood in 2004 (both localised events) and makes it the most costly insured weather event in the UK (ABI, 2007). In fact, the widespread flooding of 2007 led to an underwriting loss for the UK property insurance market of £1.5 billion (ABI, 2010).

The baseline insurance claim data was taken to be the UK average from between 2001 and 2009 (for commercial and domestic property). The baseline number of properties deemed at significant likelihood of flooding[83] was also calculated in the same way as for the mortgage metric above. The change in the number of properties at risk was determined taking account of the climate change projections, Figure 5.8. As with Figure 5.4, the baseline is based on data for the period 1961-1990 for river flooding and data for 2008 for tidal flooding. The magnitude of the insurance claims was then scaled accordingly. The notable increase from the baseline to the 2020s, followed by a less rapid increase is due to the definition of significant risk relative to the existing standard of defences, as explained for Figure 5.4.

Excluding data from 2007 (given the extreme level of this event), an estimated average annual claim for flooding in the domestic sector was calculated to be approximately £135 million and for commercial property approximately £70 million between 2001 and 2009. If the 2007 event was included, these average figures (for the nine-years 2001 to 2009) are approximately £180 million and £100 million respectively.

Figure 5.8 Properties at significant risk of river and tidal flooding (climate change only)



The range bars (I) indicate the plausible range about the Medium emissions scenario, central estimate.

[83] Significant likelihood is defined as having an annual chance of flooding (to any depth) greater than 1 in 75.

The outcome of the estimation process is that the combined domestic and commercial claims may double by the 2020s (Medium emissions scenario, central estimate), and furthermore, the increase may be almost three-fold by the 2050s and an increase of between three and four times by the 2080s. This equates to an average annual claim for flood related damage of the order of £700 million to £1 billion by the 2080s (based on present day costs). This is about a third of the total weather-related insurance claims in the record year of 2007.	Medium confidence

A recent insurance industry research paper (ABI, 2009) sought to monetise projected climate change impacts. The approach developed in the study combined results from recent climate model outputs, diverse published data and scientific literature to monetise potential impacts. The research estimated that the impact values of climate change, assuming a global temperature rise of 4°C, are as follows:

- Average annual insured losses from inland flooding in Great Britain could rise by 14% to £633 million.
- The insured inland flood 100-year loss could rise by 30% to £5.4 billion and the 200-year loss could rise by 32% to £7.9 billion.

These are somewhat higher than the values obtained from the method adopted for the CCRA, but are not directly comparable: the CCRA has only looked at river flooding and not at other types of inland flooding; different baselines have been used; and there were differences in the way in which climate projections were applied. Further work is required to develop common baselines and then to develop more robust estimates. At present, the overall impact to the industry is unclear.

As noted in the introduction to this section, the main potential consequences of failing to mainstream climate risk management into investment practices are: (i) reduced return on investment or credit performance of investments; (ii) reduced reputation; (iii) increased investor pressure; (iv) legal liabilities; and (v) lost business opportunity to finance adaptation. The net result of these factors on the industry is unclear, being determined by the balance of pay-out following an event versus the cost of products to consumers (i.e. cost of premiums). The risk is thus fundamentally one of how well the industry understands weather risk (and how this may vary as climate changes). The evidence suggests that the insurance industry is adapting to the challenges arising from climate change.

5.4.2 Tourism as a case study

For many businesses, the sort of threats outlined in the previous sections provides only a partial picture. There could also be opportunities. Within the financial, utility and manufacturing, and consultancy sectors these opportunities may well arise from the move to a low carbon economy and the delivery of adaptation measures. These are likely to involve the development of new products but also innovation to take advantage of new materials and technologies, or the adaptation of existing technologies to new applications.

As part of this assessment, tourism was looked at as an industry that could potentially see significant changes, some of them beneficial and others more detrimental. Changing weather patterns may have a significant impact on both leisure activities and tourist destinations, in the UK and abroad. The choices individuals make reflect a mix of perception and information about the experience on offer and this is sensitive to past events, and the character of both the built and natural environment. An expansion of new or existing tourist destinations in the UK was considered as a risk metric along with the potential threat to tourist related assets, such as beaches, tourism and leisure

buildings (BU8 and BU2 in Business, Industry & Services Sector Report). It should also be noted that changing levels of tourism may impact on other services, such as the demand for water and sewerage services and put additional pressure on local ecosystems.

Historically, one of the longest-established major movements of international tourists has been the annual migration of northern Europeans to the Mediterranean, during a relatively confined summer season. An estimated 84% of the international tourists that visit the Mediterranean come from Europe, mostly from northern and western countries. Based on modelling studies, future climate change may make countries at higher latitudes and altitudes more attractive as a tourist destination, due to the pole-ward shift in the "Tourism Comfort Index" (TCI) (Hamilton *et al.*, 2005; Amelung and Moreno, 2009). Consequently, providing planning and adaptation are considered carefully, future climate change represents an opportunity for that part of the UK tourism industry whose operations and assets are largely based in the UK. Conversely, those parts that rely on the outbound travel market may need to establish new destinations and adapt to any decline that results from this northerly shift.

The TCI was developed to rate climatic conditions for outdoor recreational activities (for details see BU8 in Business, Industry & Services Sector Report) and has been used in a number of modelling studies. There are however, a number of limitations to the TCI:

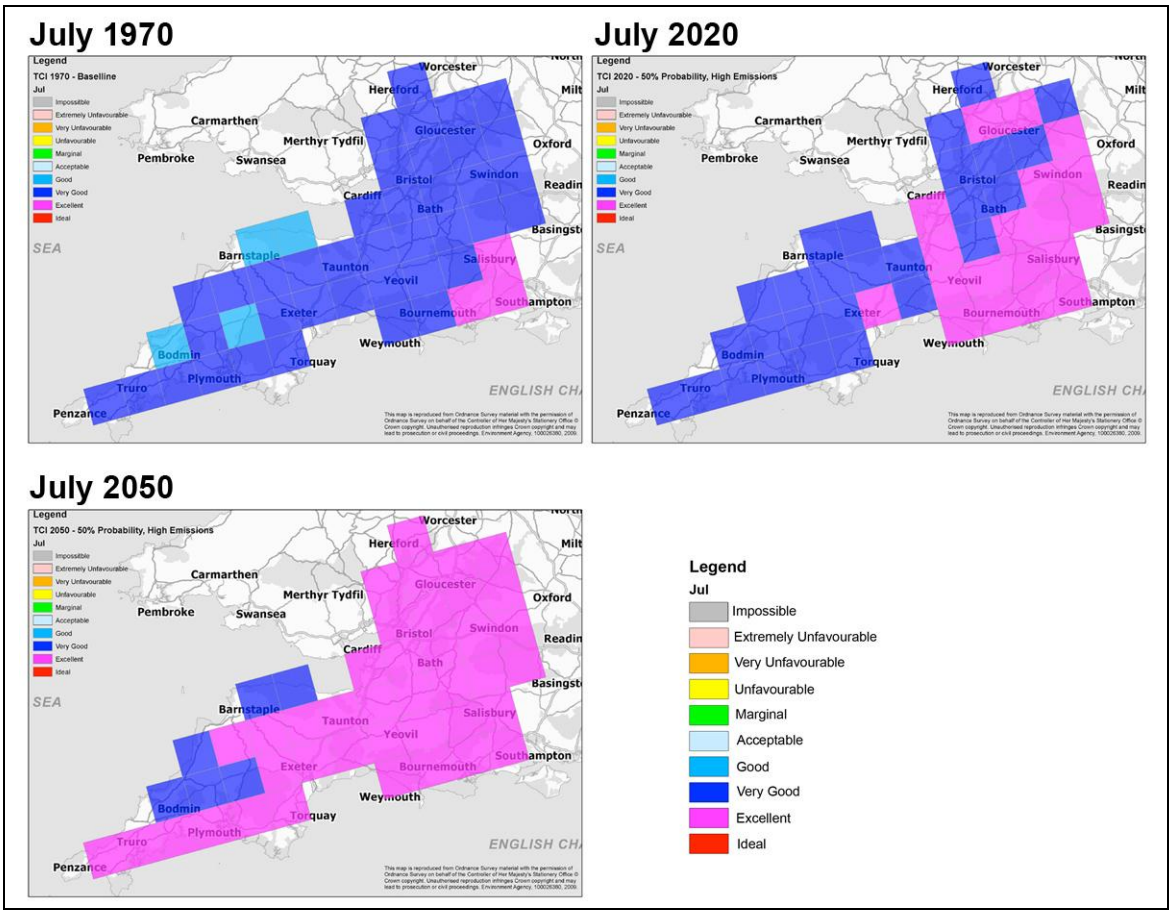
- It is insensitive to the large variety of weather requirements for tourist activities;
- Other climate variables that are important to tourism-related activities, such as wind are not considered; and
- The index is based on expert judgment with only limited empirical validation.

In the UK, research published in 2010 by South West Tourism, in partnership with South West Environment Agency and Amelung Advies, investigated the 2009 UK Climate Projections (UKCP09) for the South West region and explored the potential impact on tourism comfort and seasonality in the 2020s and 2050s. The results of the South West Tourism study (2010) showed that the TCI scores were projected to improve for the whole region for both the 2020s and 2050s (Figure 5.9); a result that is consistent with previous international studies (e.g. Hamilton *et al.*, 2005). For the upper estimates, the improvement in TCI is particularly marked and by the 2050s a large proportion of the region achieves the "ideal" TCI score for the months of July and August. The projected TCI improvement is greatest for the months of June and September, with a reduction in the seasonality, which has the potential to widen the "holiday" season (South West Tourism, 2010).

The environment that develops as a result of such changes is particularly important for tourism and leisure industries. Impacts such as changing habitats and landscapes (BD2, 5 ,7, 9-11), the prevalence of pests and diseases (BD3 and 4), increased fire risk (BD12) and the impact of mitigation measures such as wind farms and bio-energy (BD6), are likely to influence the natural surroundings, as outlined in the Biodiversity and Ecosystem Services Sector Report (see also Chapter 8). These in turn may alter many of the ecosystem services derived from the natural environment. How these changes play out, and so influence the visitor experience, is largely indeterminate at present and will require appropriate monitoring to enable the industry to adapt appropriately.

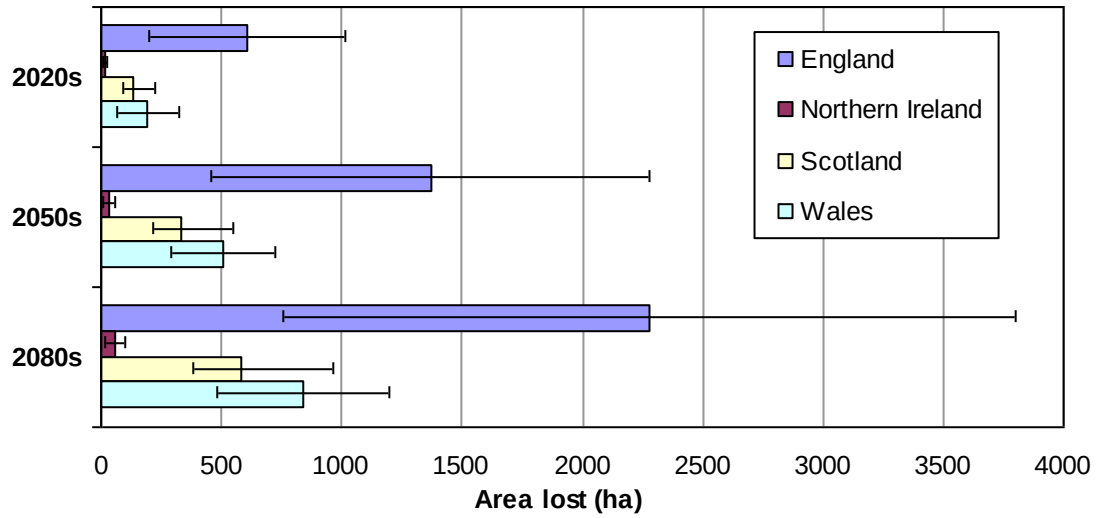
Figure 5.9 TCI for central estimate of the High emissions scenario

(Source: South West Tourism, 2010)



For coastal locations one of the primary assets is the beach. Under rising sea levels and whilst shorelines are maintained in a (relatively) fixed position in order to protect coastal infrastructure and buildings, there is a risk that beaches may narrow and become steeper (Taylor *et al.*, 2004). In order to gain an appreciation of the magnitude of the risk from projected sea level rise to these natural tourist assets, a high level assessment of the potential loss of beach area was undertaken (part of BU2 in Business, Industry & Services Sector Report). Using the UKCP09 projections for future sea level rise, there is a risk of beach loss across the UK of 3 – 16 km^2 (300 – 1600 hectares) by the 2020s, rising to 12 – 61 km^2 (1200 – 6100 hectares) by the 2080s (which is between approximately 3% and 7% of total beach area). This estimate necessarily makes a number of assumptions, as outlined in the discussion of coastal erosion in Chapter 3. .The regional breakdown of these figures is provided in Figure 5.10, which shows that the greatest area of beaches at risk of loss is in England.

Figure 5.10 Projected loss of UK beach area due to sea level rise



The range bars (I) indicate the plausible range about the Medium emissions scenario, central estimate.

More generally, inland as well as coastal sites may be exposed to an increased risk of flooding. The increasing trend in the UK to cater for visitors all year round means that the tourism industry may be impacted, with tourist attractions and facilities damaged by floods. Visitor discomfort, distress, injury or fatality could result in significant negative public relations and reputational risks for the destination and businesses involved, and ultimately reduce visitor numbers and revenues. As an illustration, Box 5.6 describes the impacts of the floods of 2007 on the UK's tourism and leisure sector.

Box 5.6 Impacts of floods of summer 2007 on tourism and leisure sector

During the 2007 floods, businesses in the tourism and leisure sector suffered with fewer customers and lost revenue. Some hotels benefited from people displaced by the floods, demands for takeaways increased with people unable to cook and building firms were inundated as the recovery process began.

English Heritage and National Trust visitor attractions were significantly affected by the floods of summer 2007, as well as numerous World Heritage Sites, suffering both physical damage and lost revenue. World Heritage Sites affected included Birdoswald Roman Fort (part of the Hadrian's Wall Site), Fountains Abbey, Ironbridge Gorge, Derwent Valley Mills and Blenheim Palace. Many listed properties were also affected. During August 2007, DCMS[84] announced a £1 million cash injection to promote tourism, rural destinations and visitor attractions.

Source: Pitt, 2008

To evaluate this risk in a little more detail, information on the assets in the flood zone including listed buildings, churches, tourism attractions, theatres, museums and libraries were identified. The change in flood risk for these assets was then assessed (see Flood and Coastal Erosion Sector Report for details of the approach to flood risk mapping and estimates of the area of Scheduled Ancient Monuments at risk, FL15, and BU2 in Business, Industry & Services Sector Report, for a broader assessment). However, a quantified estimate of tourism assets at risk was not possible and some of the financial implications were assessed using the concept expenditure avoided to provide a high level estimate of the possible consequences. This suggested a total present-day annual average 'damage' value of £2 million per year. Considering the

[84] Department for Culture Media and Sport

potential changes to flood frequency, this annual average damage cost would increase to £5 million by the 2050s and £6-12 million by the 2080s (see BU2 in Business, Industry & Services Sector Report for details).

5.4.3 Summary

This section has used the assessment carried out for the financial services sector and the tourism industry to highlight some of the issues that will need to be addressed and give rise to a complex interplay of opportunities and threats.

Progress to take account of climate risk and adaptation considerations in UK financial institutions is slow and faces considerable barriers, such as the lack of knowledge and perceived lack of information. Failure to resolve these issues could ultimately affect the competitiveness of the UK financial services industry in the international market place. Furthermore, by mainstreaming climate risk management into their processes and practices, UK financial institutions have a role to play in promoting climate resilient “real sector” investments.

The exception to this is the insurance industry which has an active programme of research as a result of which there is now an extensive body of literature. The work undertaken for Foresight (Foresight, 2010a) found the insurance industry to be the least vulnerable to climate change in the financial services sector because of the active risk management that is in place, coupled with the annual nature of the business (premium renewals) and relatively low exposure to the most vulnerable areas.

The tourism industry forms a large part of the local economy for many communities in the UK, particularly on the coast and contributed £115.4bn to the UK economy in 2009 – equivalent to 8.9% of total UK Gross Domestic Product (Deloitte and Oxford Economics, 2010). Increasingly, the impacts of climate change may offer both challenges and opportunities for the tourism sector. Whilst river flooding and coastal storms are more likely to occur outside the traditional summer tourist season, the risk of summer flooding may increase and sea level rise is an ever increasing threat.

At the same time, tourism is climate-sensitive and changes in the weather, seasons and climate would impact on the tourism industry affecting the health of destinations, choice of trip and tourist spending. Modelling studies that utilise the TCI indicate that future climate change may result in an improvement in the attractiveness of the UK as a tourism destination and furthermore, extend the tourist season.

On balance, the benefits should outweigh the additional costs. However, projected changes in climate will need careful consideration in both regional and local tourism development, management and planning. Climate change may not only affect tourism through changes in thermal conditions, but also through ecosystem change, impacts on infrastructure and services, effect on access and transport prices, and even changes in economic growth and prosperity.

5.5 Evidence gaps

Limited data, coupled with the level of system complexity have constrained the analysis in this assessment. Greater pooling of information, without compromising commercial interests, will be needed to make progress on representing and understanding the vast array of interactions that take place and upon which climate change is superimposed.

Key areas where further work could increase understanding of the impacts of climate change, help remove uncertainties regarding their scale and nature, and aid climate change adaptation in relation to the Business sector include:

- At the moment, there is limited substantive evidence of the consequences of changes in climate on UK financial institutions. The confidential nature of the underlying data and the fact that there are many other socio-economic drivers operating, mean that disentangling the impacts of climate change is challenging. Some recent attempts to model this type of system may provide a way forward (Haldane and May, 2011), although the idealisations necessary may mean that such models are best suited to developing an understanding of system behaviour, rather than making detailed predictions.
- The complexity of supply chains is similarly, difficult to analyse because it involves the interaction of a number of networks that are themselves complex. Nonetheless, there may be scope to develop a better understanding of network interactions as modelling improves (e.g. the modelling of container traffic; Sinha-Ray *et al.*, 2003).
- The information on the disruption caused to business by extreme events, such as floods and heatwaves is limited and largely reliant on insurance industry reporting. More systematic data collection would enable a more complete assessment to be developed.
- Two risks were highlighted as potentially becoming increasingly important towards the middle of the century, namely water abstraction for industry and a loss of productivity due to over-heating. Both of these assessments have been made with very limited information on the likely response and the potential of adaptation measures to reduce the extent of the impact. More detailed assessments would be helpful better to understand the likely significance of these impacts.

5.6 Summary

Climate change does not necessarily create new risks for business but a potential change in the frequency or magnitude of such risks. An adequate understanding of these risks should enable businesses to manage these operationally, whilst making the most of the opportunities. For many businesses this may entail a far greater appreciation of their dependence on ecosystem services, which are likely to be particularly susceptible to change.

This chapter has provided an overview of the risks posed to business as a result of climate change, drawing on the risk metrics that have been developed as part of this assessment, Table 5.2. The inherent complexity of the business sector and the dependency on resources, supply chains and infrastructure (which are themselves intricate networks) has meant that disentangling the consequences of climate change is not straightforward. Nonetheless, the majority of the risks identified relate to aspects of the portfolio of risks that businesses already have to manage.

5.6.1 Direct risks

Where economic activities have a particular dependency on weather related events there will be a need to adapt the operational model to reflect a non-stationary climate. This is under active investigation in the insurance industry where pay outs for flood events, storm damage and subsidence are all sensitive to a changing climate. For some businesses changes in crop yield and the dependency on water supply may require particular attention, as discussed in Chapter 4. This may in-turn have implications for the downstream food and drinks industry. The extent to which non-weather related businesses also need to adapt their operations is less clear. If issues such as overheating become prevalent, there may be a need to consider such things as staff work patterns, particularly if there is also pressure to minimise additional cooling both to reduce emissions and minimise any further enhancement of the urban heat island effect.

Flood disruption to business premises and supporting infrastructure is a significant threat but in general is only relevant to those businesses that already have some exposure (i.e. they are located in the flood plain). Similarly, locations prone to coastal erosion are well known and although changes on the coast may lead to some reconfiguration of the coastline, the underlying geological controls mean that those areas that are vulnerable will not change dramatically. However, it should be stressed that these and other threats, such as landslides and bridge scour, are all present day risks that are actively managed. The effect of climate change is simply to exacerbate the risks to varying degrees.

Heat damage is a widespread threat. Overheating may cause damage to equipment and buildings as well as creating uncomfortable working environments. This may be offset by less disruption during winter months, although less frequent extreme cold snaps may mean that the services are less well prepared when they do occur.

Finally, many businesses depend on a supply of water or the ability to abstract their own water from groundwater or rivers. Sustained dry periods may mean that the available supply becomes limited and the need to maintain environmental supplies and

supplies to the general public could further decrease the volumes of abstraction permitted for industrial and agricultural use.

5.6.2 Indirect risks

A reliable supply of energy is fundamental to most economic activities, as is reliable communications. Indeed telecommunications and computing devices are now so widely embedded in all sorts of equipment that they are critical to a huge range of information streams that contribute to management processes. Both have the potential to be put at risk by flood events and periods of extremely warm weather. Lost efficiency when the systems have to operate under higher ambient temperatures and a possible but highly uncertain possibility of some equipment damage during extreme events have been estimated to be of low to medium magnitude. More certain and of potentially greater magnitude is the potential for power stations and substations to be flooded. This risk was highlighted during the 2007 floods and will remain a risk that has to be managed, particularly given that the need for large volumes of cooling water means that plants are unlikely to be sited outside flood zones.

As already noted, however, the main concern for many businesses will be any impact on their supplies, communications or supporting services. A qualitative assessment of supply chains explored the potential for disruption in the UK (reflecting the various risks already highlighted above) but also as a result of breaks in the supply chains overseas. With many businesses currently operating a just-in-time supply policy, such disruptions can have a significant impact on productivity. Although the magnitude of this consequence is highly uncertain and the assessment gives only a low level of confidence, it has the potential to be of sufficient significance that would merit further research.

5.6.3 Business threats and opportunities

Some industries may be net beneficiaries of climate change. For example, a warmer climate may improve conditions for the tourist and leisure industries. Others, such as fisheries, agriculture and forestry may need to cope with more rapidly evolving ecosystems, presenting both threats and opportunities. The National Ecosystem Assessment highlights how dependent economic activity is on a range of services and resources supplied by the natural environment, as outlined in the Natural Environment theme (Chapter 8).

The change in the risk profile for the insurance industry has been highlighted. The interaction between levels of insurance provision and such things as building standards and the extent and design standard of flood defences is already well established through agreements between the insurance industry and government. Perhaps less clear is what will happen if such agreements can no longer be supported, or if some areas become un-defendable (at realistic cost). There will clearly be a cost to individual property owners or to local communities. However, mortgage provision is currently linked to property insurance. If the latter is withdrawn, there is the potential for a reduction in the mortgage market and, hence, consequences for the property market (at least within flood zones). Although this risk is highly uncertain, it has the potential to be of moderate significance in terms of the size of the market.

The exposure of the financial services industry was also identified as a potential but highly uncertain risk due to a combination of:

- The performance of investment portfolios (which may have embedded sensitivities to climate);

- Institutional reputation for managing such risks; investor pressure for climate resilient investments;
- Legal liabilities if they fail to take account of foreseeable impacts; and
- Market changes in the demand for financial services.

Unless businesses and the financial services mainstream an effective consideration of climate change in their decision-making practices, signals from the public, media or as a result of government policy initiatives are vulnerable to misinterpretation by the markets, leading to under performance or losses. This would have implications for the whole UK economy as the markets are so sizeable. However, because there is so much uncertainty about the current state of the financial services sector and its vulnerability to such risks, the magnitude of the risks to which the UK economy is exposed from the behaviour of the financial institutions also remains uncertain.

Table 5.2 Scorecard for Business

Metric code	Potential risks for business	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
BE9	Reduction in energy demand for heating	L	1	2	3	2	3	3	2	3	3
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
MA5	Opening of Arctic shipping routes due to ice melt	M	1	2	2	2	2	3	2	3	3
BU8	An expansion of tourist destinations in the UK	L	1	2	3	2	2	3	2	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
MA4b	Changes in fish catch latitude/centre of gravity (plaice, sole)	M	~	1	~	~	2	~	~	3	~
AG1c	Changes in potato yield (due to combined climate effects and CO_2)	L	1	1	2	1	1	2	1	1	2
	Climate Change Adaptation Services	L	Too uncertain								
EN1	Energy infrastructure at significant risk of flooding	H	2	3	3	2	3	3	3	3	3
FL7a	Non-residential properties at significant risk of flooding	H	1	3	3	2	3	3	2	3	3
FL7b	Expected Annual Damage (EAD) to non-residential property due to flooding	H	2	3	3	3	3	3	3	3	3
BU7	Insurance industry exposure to UK flood risks	M	3	3	3	3	3	3	3	3	3
WA3	Reduction in water available for public supply	M	1	2	3	2	3	3	2	3	3
FL11a	Power stations at significant risk of flooding	M	2	2	2	2	2	3	2	3	3
BE3	Overheating of buildings	H	1	2	2	2	2	3	2	3	3
EN2	Energy demand for cooling	H	2	2	2	2	2	3	2	3	3
WA5	Public water supply-demand deficits	M	1	1	2	1	3	3	2	3	3
BU6	Mortgage provision threatened due to increased flood risk	L	2	2	2	2	2	2	2	2	3
BU10	Loss of staff hours due to high internal building temperatures	M	1	2	2	1	2	3	1	2	3
BU2	Monetary losses due to tourist assets at risk from flooding	M	1	1	2	2	2	3	2	3	3
MA4a	Changes in fish catch latitude/centre of gravity (cod, haddock)	M	~	1	~	~	2	~	~	3	~
MA9	Decline in productivity of 'cold water' fish and shellfish stocks	L	~	1	~	~	2	~	~	3	~
BU3	Risk of restrictions in water abstraction for industry	L	1	1	2	1	2	3	1	3	3
WA8a	Number of unsustainable water abstractions (agriculture)	M	1	1	2	1	2	2	2	2	2
BU4	Risks of business disruption due to flooding	M	1	1	2	1	2	2	2	2	2
TR6	Scouring of road and rail bridges	M	1	1	2	1	2	3	1	2	3
MA7	Potential disruption to shipping due to rough seas	L	~	1	~	~	2	~	~	2	~
FO2	Loss of forest productivity due to drought	M	1	1	2	1	1	2	1	2	3
EN10	Energy transmission efficiency capacity losses due to heat - over ground	H	1	1	1	1	1	3	1	2	3
TR1	Disruption to road traffic due to flooding	M	1	1	1	1	1	2	1	2	3
TR2	Landslide risks on the road network	M	1	1	1	1	1	2	1	2	2
AG7a	Reduction in milk production due to heat stress	L	1	1	1	1	1	1	1	1	3
AG7b	Reduction in dairy herd fertility due to heat stress	L	1	1	2	1	1	2	1	1	2
TR5	Rail buckling risk	H	1	1	1	1	1	1	1	1	1
TR4	Cost of carriageway repairs due to high summer temperatures	M	1	1	1	1	1	1	1	1	1
EN3	Heat related damage/disruption to energy infrastructure	L	1	1	1	1	1	1	1	1	1
BD6	Environmental effects of climate mitigation measures	L	Too uncertain								
BU1	Climate risks to investment funds	L	Too uncertain								
BU5	Loss of productivity due to ICT disruption	L	Too uncertain								
BU9	A decrease in output for businesses due to supply chain disruption	L	Too uncertain								

M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

6 Health and Wellbeing

Overview	
• Climate change (particularly the frequency of floods, hot and cold weather and droughts) may impact on homes, workplaces and lifestyles, which in turn can affect people's health and wellbeing. • Socially deprived groups and those with compromised health (including older people and the very young) would be expected to be more vulnerable to these climate change threats, but may also benefit most from the opportunities. • The health and wellbeing of the UK population in the future may be influenced by socio-economic changes, including the economy, government policy, an ageing population and individual lifestyle choices. Climate change may influence these socio-economic changes either directly or indirectly, but this has not been taken into consideration as part of this assessment.	
Threats	**Opportunities**
• Increased temperatures may lead to increased levels of mortality and morbidity due to heat. • Increased flooding may lead to increased number of deaths, injuries and people suffering from mental health effects as a result of flooding. • Increased ozone levels by the end of the century may lead to increased levels of mortality and respiratory hospital admissions. • Increased temperatures combined with increased periods of time spent outdoors may lead to an increased risk of the number of skin cancer cases and deaths. • Increased winter precipitation would lead to an increase in pollutants discharged from combined sewer outfalls, which may increase risk of human disease at the coast. • Increased sea temperatures would lead to increased marine pathogens and harmful algae blooms which may impact negatively on human health.	• Increased temperatures may lead to decreased levels of mortality and morbidity due to cold. • Increased temperatures combined with increased periods of time spent outdoors could lead to increased vitamin D levels and improved physical and mental health of people.

Figure 6.1 Summary of health and wellbeing impacts with an indication of direction, magnitude and confidence

Note: BE1 is too uncertain to assess UK-wide but has high confidence as the magnitude is site specific

6.1 Introduction

Climate change (particularly floods, hot and cold weather and droughts) is likely to impact on homes, workplaces and lifestyles, which can affect people's health and wellbeing. This could result in a direct consequence, such as heat stress, or indirect consequences such as access to, quality and cost of essential services (Adams, 2001).

Rising temperatures, changing seasonal rainfall patterns, drought conditions and increases in the frequency of floods and hot and cold weather could have an impact on people's homes, workplaces and lifestyles and may result in substantial increased disruption to health care provision and services. The health sector faces a number of challenges in the future, not all of which are associated with the climate, but which could be more difficult to tackle in a changing climate environment, including an ageing population and various inequalities in the use of health care (including hospital services) and wider social inequalities. Health inequalities may also be exacerbated as a result of disrupted access to services, poorer housing conditions and a reduced ability to adapt to a changing climate in lower socio-economic groups. In this assessment the basic building blocks of external conditions and health aspects of personal resources have been covered but the analysis did not attempt to link these explicitly to wellbeing. Methods for measuring wellbeing are in their infancy (NEF, 2011). Climate change may influence wellbeing and the development of sustainable local communities that take positive environmental action would clearly support resilience, risk reduction and climate change adaptation.

Understanding how local communities work effectively is an important factor for both resilience to climate risks and for adaptation as a part of the development of sustainable local communities. In the context of climate change, resilience is important for dealing with extreme floods and other hazards; access and affordability of services is important when consumer tariffs for water and energy may be affected by climate change and social networks; and community groups are important for reducing risks and for environment action including climate change adaptation. Those outside community groups, or outside their community group for whatever reason would however be expected to be at greater risk.

Whilst the CCRA did not explicitly use a wellbeing framework for evaluating impacts in this category, these impacts are considered to relate to overall concepts of wellbeing following the WHO definition of health:

"*Health is a state of complete physical, mental, and social wellbeing and not merely the absence of disease or infirmity*".

This chapter considers how such changes might impact on human health, considering aspects such as:

- Deaths and illness caused by periods of hot or cold weather;
- Deaths and injuries due to flooding, as well as the mental impacts;
- Exposure to increased ozone and UV levels; and
- The implications for changes in the prevalence of pests and diseases.

This is followed by some consideration of the implications of climate change for the vulnerable and deprived members of society and the potential impacts on emergency services.

A number of the risks identified in this assessment may also lead to an increased burden on the health and social care systems. Although impacts on these organisations have not been formally assessed in the CCRA, they may be significantly impacted. Where applicable, this has been highlighted in this section. The risks to climate change are also intrinsically linked to risks in other sectors. For example, impacts on food or water quality would have consequential effects on public health and power/transport disruption are likely to affect NHS services.

Figure 6.1 provides a summary of the risks considered with an indication of how the magnitude of the Medium emissions scenario, central estimate changes over time. Further detail of the risks of relevance to this theme, with more information on how the magnitude of the risks vary under different scenarios is provided in the scorecard at the end of the section, Table 6.1.

6.1.1 Current vulnerability

More frequent flooding and changes in the nature of other extreme weather events, including droughts and heatwaves may increase disruption to services, such as water supplies, energy and telecommunications. Disruption may vary in magnitude and duration, and would be expected to be unevenly disrupted spatially across the UK. In the case of water supply, restrictions to non-essential use are already part of water management in drought conditions. The main concern with climate change is facing more severe, extensive, clustered and longer duration extreme events, outside of those experienced historically and outside of those that the country has prepared for. In these cases, disruption may affect essential services and the consequences of water, energy or telecommunications failure would be expected to be severe. For these reasons the resilience of critical infrastructure has been an important focus for UK Government (Cabinet Office, 2010b).

Warmer conditions, particularly related to heatwaves, would lead to an increased risk of overheating of homes, particularly those that are poorly ventilated and heavily insulated for winter conditions (Built Environment Sector Report; Section 5.6). The risks are greatest in large metropolitan areas that can suffer from urban heat island effects, such as London, Manchester and Birmingham.

Historical evidence indicates that living in cities increases the risks of heat mortality; for example Donaldson *et al.* (2002) gave a breakdown of heat-related mortality by age, sex and attributed cause in England and Wales during the 1995 and 1976 heatwaves. These data indicate that the impact of heatwaves was greater in an urban area (Greater London) than in the population as a whole.

In terms of particular types of places to live, Kovats *et al.* (2006) in their study of mortality by place of death[85] reported:

"After accounting for the usual pattern of mortality by place of death, a larger than expected proportion of the excess deaths in the elderly occurred in hospitals and nursing homes.

In the non-elderly population, there was a large excess of mortality observed in nursing and residential homes, although the absolute numbers of deaths were small."

The quality of housing and local neighbourhoods is an important consideration for overheating, with those social groups considered more vulnerable to significant health impacts (Annex B). Design standards, location of buildings in specific areas of cities, and architectural styles all shape exposure to heat, but UK research (McGregor *et al.*,

[85] This research categorised place of death into the following five types of places: own home, hospices, nursing homes, residential home, and other places

2007) suggested that "*Although housing characteristics appear to play a role in determining sensitivity in the US (Smoyer, 1998), as yet no evidence has emerged of its role during heatwaves in the UK*" (Kovats *et al.*, 2006). On-going UK Research Council studies under the Adaptation and Resilience to a Changing Climate (ARCC) programme are considering these issues in greater detail and it is anticipated that new evidence on the links between housing and overheating will emerge in the next few years[86].

There is evidence that green space reduces the urban heat island impacts as evaporation and transpiration from plants, and their shading effects, can cool the atmosphere (Built Environment Sector Report). In London monitoring of the urban heat island suggests that large park land areas are typically 1˚C cooler than surrounding built up areas (Built Environment Sector Report). In Manchester, woodland areas were noted to be 12.8˚C cooler than town centre areas for the hottest days of the year, and model results indicated that a 10% increase in green space would cool dense urban areas by approximately 2˚C (Gill *et al.*, 2007). Therefore, provision of outdoor space is a key design consideration that can help to adapt existing and new development to a changing climate (GLA, 2005).

Warmer conditions in work places, hospitals and schools are also important in terms of the health of vulnerable groups including elderly and very young people. The TUC (2009) have highlighted the vulnerability of some frontline workers. For example, staff who work in poorly ventilated environments or restricted vehicles were noted to be at higher risk from overheating and extreme high temperatures can be experienced by particular workers. This was exemplified by tube train drivers on the London Underground, who endured temperatures of up to 41.5°C during the summer 2003 heatwave (Metroeconomica, 2006).

Travel to work, specifically journey times and thermal comfort of passengers, have been shown to affect quality of life and both factors are affected by climate conditions. Research studies have indicated that satisfaction scores decline with commuting time (Bacon *et al.*, 2009), and in the context of climate change is mainly affected by flooding of the key transport networks (road and rail). In addition, cold weather can cause numerous issues for transport, including the well publicised failure of Eurostar trains in the Eurotunnel in December 2009, as can hot weather with, for example, buckling of rails as discussed in Section 7.5.2. Thermal comfort of passengers, particularly when combined with overcrowding, could also affect travel choices and the demand for different modes of transport.

6.1.2 Capacity to adapt

Health professionals are confident that they will be able to respond to changing disease patterns. Moreover, working with local authority emergency planning procedures, front line health organisations are developing clinical pathways to provide care in response to climate-related events such as flooding and heat stress. However, the picture is less positive on risks to hospitals and other assets and, therefore, to longer-term service provision.

Future climate impacts have not regularly been taken into account in design of health premises and many are poorly designed for heatwaves and to withstand flooding. These risks must, therefore, be addressed when capital funds are available to refurbish or replace premises; decisions that will often have consequences for health provision past 2050.

[86] http://www.lwec.org.uk/activities/arcc

6.2 Impacts on human health in the UK

Climate change can have direct and indirect impacts on people's health, with some people more vulnerable than others. Targeted adaptation which aims to reduce social vulnerability may therefore be needed.

A changing climate would almost certainly have both direct and indirect consequences for people's health. The greatest concerns relate to extreme weather events, mainly heatwaves and floods, which are projected to become more frequent, potentially causing more direct loss of life, physical and psychological illness, and substantial disruption to NHS services (including access to services).

These could have significant consequences (both negative and positive) in relation to human health, and these are outlined below:

Negative consequences

- Projected increases in temperatures may lead to increased levels of mortality and morbidity particularly during the warmer months (Health Sector Report).
- Increases in the frequency and severity of flooding may lead to an increase in the number of deaths and injuries caused by flooding (Health Sector Report).
- Increases in the frequency and severity of flooding may lead to an increase in the number of people who suffer a mental health effect as a result of flooding (Health Sector Report).
- Increases in levels of ground-level ozone may lead to an increase in levels of mortality and morbidity particularly during high summer ozone episodes (Health Sector Report).
- Projected increases in temperatures as well as changes in levels of UVB exposure may lead to an increase in the number of skin cancer cases and deaths (Health Sector Report).
- Projected increases in temperatures and changes to rainfall levels could influence levels of water, vector and food-borne diseases (Health Sector Report).
- Projected increases in sea temperatures may lead to an increase in the risk of marine borne hosts and pathogens which may increase human infections linked to these pathogens (Marine & Fisheries Sector Report).
- Projected increases in winter precipitation leads to an increase in the risk of pollutants discharged from combined sewer outfalls, which may result in an increase in human disease linked to these pollutants at the coast (Water Sector Report and Marine & Fisheries Sector Report).
- Projected increases in sea temperatures may lead to an increase in the risk of harmful algal blooms which may increase effects on human health (Marine & Fisheries Sector Report).

Positive consequences

- Projected increases in temperatures may lead to reduced levels of mortality and morbidity particularly during the colder months (Health Sector Report).
- Projected increases in temperatures as well as changes in levels of UVB exposure may result in increased levels of vitamin D which is good for skeletal health and calcium metabolism (Health Sector Report).

These health impacts are presented in outline below and a comprehensive analysis of these impacts is given in the relevant sector reports (highlighted above). These impacts highlight significant issues for the more vulnerable sections of society. Those with compromised health (cardiovascular and respiratory diseases) are more susceptible to heat related impacts, and those in the most deprived areas are typically more exposed to flood related impacts. Social vulnerability aspects of climate and health risks are also discussed.

Unless otherwise stated, the results given in this section are based on the central estimate of the Medium emissions scenario for the current population. These estimates could increase by approximately 10%, 30% and 40% by the 2020s, 2050s and the 2080s based on the principal population projections, and by as much as 85% by the 2080s based on the high population projection. Noticeable variations may also occur for the different emissions scenarios, and where applicable these are highlighted. The different estimates for the different emissions scenarios are also given, where applicable, in the relevant CCRA sector report(s).

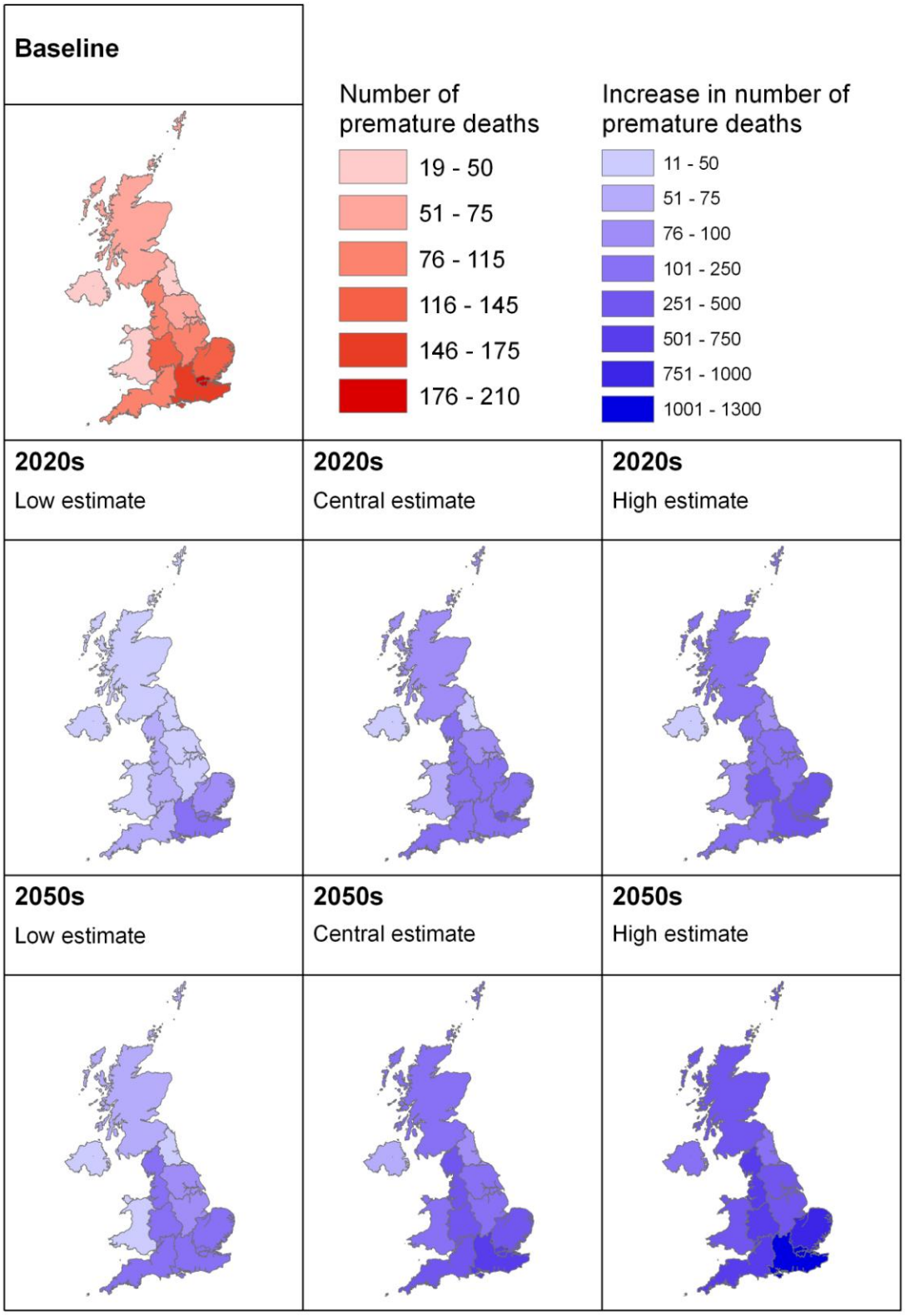
6.2.1 Heat related mortality

Heat-related mortality currently accounts for around 1,100 premature deaths per year in the UK. Heat is also estimated to cause over 100,000 patient-days in hospital per year. However, these figures can increase noticeably for exceptionally hot years such as was experienced in 2003 and 2006, which may be the norm by the time we get to the 2050s.

Results from the CCRA indicate an increase for the Medium emissions scenario, central estimate of approximately 60% in heat related mortality in the near term (2020s), with an approximate 200% increase in the medium term (2050s) from a baseline of approximately 1,100. Between the medium term (2050s) and the long term (2080s), these rates are estimated to approximately double. For the upper estimate of the high population projection in the 2080s, heat related mortality is estimated to increase by approximately 26 times from the current day baseline.	High confidence

Figure 6.2 Premature deaths (heat) per year for the UK

UKCP09 Medium emissions scenario for the 2020s and Low, Medium and High emissions scenarios for the 2050s (current population, baseline period: 1993-2006, no acclimatisation)

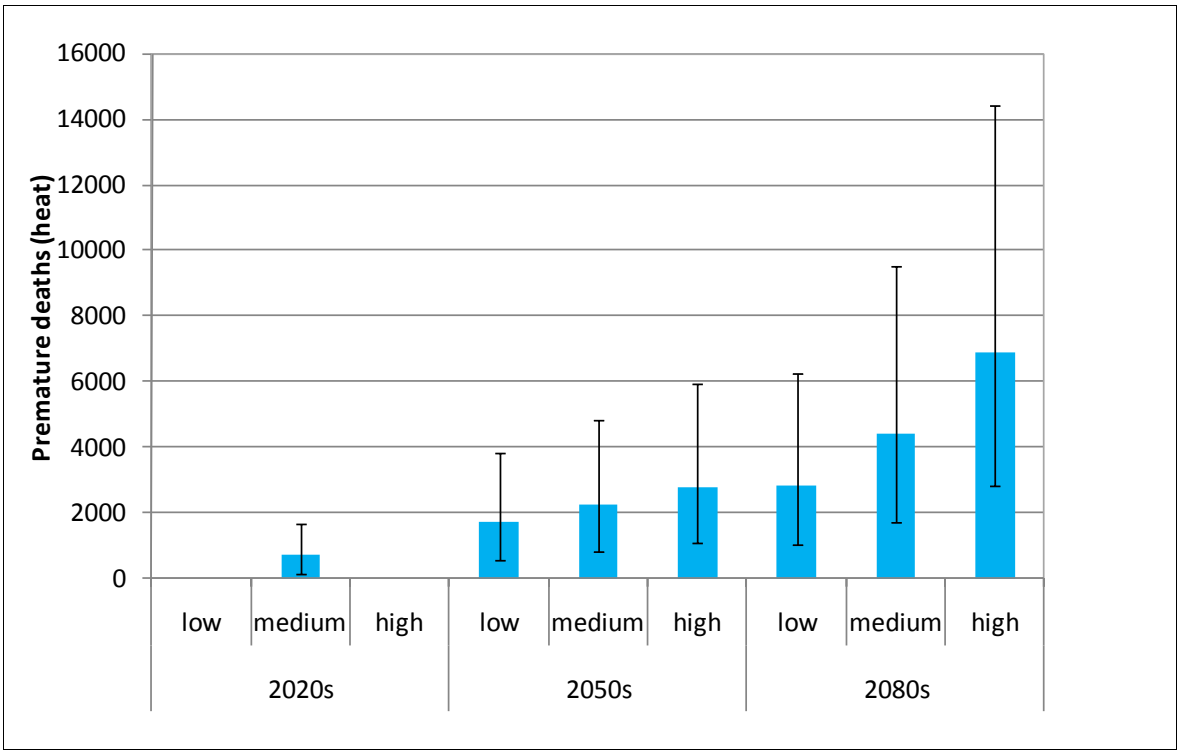


Regionally, estimates of premature deaths show a large increase relative to current day estimates for the south-west and south-east, with a low relative increase for Scotland[87]. However, little regional variation is noted between the 2020s-2050s and the 2050s-2080s. The largest numbers of premature deaths are in the south-east and London which account for approximately one third of the total number of premature deaths that were estimated for the UK for all scenarios considered. The devolved administrations (Scotland, Wales and Northern Ireland) account collectively for approximately 10% of premature deaths for all scenarios considered. The differences between the regional results are partially related to higher densities of populations in the more southerly regions, although the main difference relates to generally higher temperatures in the more southern regions. Relative to population size for example, the mortality rate for London is approximately twice that of the North East.

Regional results are shown in Figure 6.2, with national results in Figure 6.3.

Figure 6.3 Premature deaths per year due to heat for the UK for the different emission scenarios

(current population, baseline period: 1993-2006, no acclimatisation)



The increases are significant and indicate that further adaptation may be needed in the medium term, particularly in the south-east and London, as well as large urban areas (which are affected by the urban heat island effect) and in hospitals and schools. However, the loss of life is usually for retired individuals in poor health, with life expectancy only shortened by a few months. Economic impacts are projected to be reasonably low, in the low millions by the end of the current century. Additional financial costs of planned adaptation (e.g. retrofitting of buildings with cooling devices), and increased energy consumption also need to be considered.

These estimates show the sensitivity to climate change alone, based on the current UK population and age distribution, in the absence of any physiological acclimatisation of the population to heat. A more realistic assumption of a larger and older population

[87] It should be noted that the analysis carried out in this section assumes that there will be no change in the strength of the Urban Heat Island effect. This is a current limitation of UKCP09 and the analysis.

would result in larger numbers of premature deaths per year, while physiological acclimatisation and planned adaptation (e.g. wider use of passive cooling, enhanced heatwave plans, etc.) would reduce these estimates.

6.2.2 Heat related morbidity

There is certain evidence that both very high and very low temperatures have an impact on a range of morbidity outcomes. Morbidity increases in hot weather, particularly in the elderly, very young and sick people (Vassallo *et al.*, 1995). Elderly people are also more vulnerable to heat stress, especially those in hospital or long-term care institutions.

Heatwaves (i.e. continuous days of exceptional heat) in particular have been shown to increase respiratory and cardiovascular illnesses (Patz *et al.*, 2005). Exposure to high temperatures during heatwaves may cause dehydration partly attributable to certain side-effects of drugs (e.g. impaired thermoregulation and suppressed thirst) (Stoellberger *et al.*, 2009). In addition, it can also cause heat cramps caused by fluid and electrolyte imbalances (often as a result of exertion), heat exhaustion, and heat stroke (which can result in organ failure, brain damage or death). Heatwaves have also been linked to mental stress, violent behaviour and suicides which increase during hot weather (Page *et al.*, 2007). There is also some evidence that alcohol consumption and accidents (road accidents, drowning, etc.) increase during periods of hot weather (Kovats and Hajat, 2008 and Morabito *et al.*, 2006).

The extent of increased levels of hospitalisations due to hot weather is difficult to determine. Hospitalisations during hot weather are not paralleled by a similar magnitude increase in heat related mortality. However, this may be because many of the heat-related deaths occur before the sufferers come to medical attention (Kovats *et al.,* 2004a). However, conclusions from the evidence presented in the Health Sector Report are that generally hotter climatic conditions and more frequent and intense heatwaves may lead to an increase in patient-days per year in hospital due to heat-related illnesses. Although little evidence is available to estimate increased levels of hospitalisations, Donaldson *et al.* (2002) indicated an approximate linear relationship between heat related mortality and morbidity. This was therefore used in the CCRA to cautiously indicate potential levels of increased levels of hospitalisations due to hot weather on a UK wide basis.

Results for increased levels of heat related hospitalisations therefore show similar ratios to heat related mortality above, with a current day estimate of approximately 100,000 hospital admissions due to heat each year. This is likely to result in an approximate 60% increase in heat related morbidity in the near term (2020s), with an approximate 200% increase in the medium term (2050s), based on the Medium emissions scenario, central estimates. Between the medium term (2050s) and the long term (2080s), these rates are estimated to approximately double.	High confidence

6.2.3 Cold related mortality

Previous studies have indicated that the positive consequences of warmer winters (reduced health impacts and reduction of fuel poverty[88]) may be greater than the negative consequences of hotter summers. The CCRA also indicated a substantial reduction in cold-related mortality (as well as hospitalisations) due to generally milder

[88] Fuel poverty is defined as the inability to heat a home to an acceptable level for reasons of cost. There are varying definitions between UK Government and the Devolved Administrations (see http://www.scotland.gov.uk/Topics/Statistics/SHCS/UKfuelpoverty), and UK Government are currently reviewing the problem and its measurement, with its final conclusions due in January 2012 (Hills, 2011).

temperatures. In this assessment, an estimate of around 26,000 to 57,000 premature deaths per year due to cold in the current climate was made. However, distinguishing between deaths in winter due to cold, as well as other causes due to illnesses more prevalent in the winter (e.g. pneumonia and influenza) is difficult. This means that these estimates are highly uncertain. Projections of how these estimates (premature deaths avoided) may change under a future climate are therefore also difficult, with a low level of confidence (see also Section 6.4.4).

Premature deaths avoided for the UK are summarised in Figure 6.4 (upper estimate) and Figure 6.5 (lower estimate). These data show the effects of climate change alone on the current population and age distribution, and no changes in resilience to cold. However, there is an argument that people may be less used to cold weather in the future and short periods of low temperatures similar in magnitude to the low extremes recently experienced (during the winter of 2010) may result in proportionally more deaths (as well as hospitalisations) during these periods (see also Section 6.4.4). It should be noted that the numbers of cold-related deaths and hospitalisations per year calculated in this study were smaller than earlier estimates (around 80,000 cold-related deaths per year in the 1990s were reported for the UK by Donaldson *et al.* 2002).

Future premature deaths avoided are estimated to reduce by approximately 15%, 30% and 45% by the 2020s, 2050s and 2080s respectively (Medium emissions scenario, central estimates). These are from a current day estimate of approximately 26,000 to 57,000 premature deaths per year due to cold.	Medium confidence

The results presented in Figure 6.4 and Figure 6.5 indicate a significant number of premature deaths avoided due to rising temperatures. Although no region is noted to have a significant change relative to the current day estimates, there are noticeably low relative increases in the number of premature deaths avoided for Northern Ireland, Scotland and the north-east. The south-east and south-west account for approximately one-third of these estimates for all scenarios considered. Northern Ireland accounts for less than 2% of premature deaths avoided for all emission scenarios. The range shown in these results highlights the uncertainty in the model projections, which are strongly influenced by the choice of the temperature threshold used in the calculations (Health Sector Report, Section 4.2.7.1).

Although the benefits from reduced cold far outweigh the adverse risks from heat, this balance noticeably narrows by the 2080s. The impacts are greatest in the south west and south east of England mainly due to the higher populations.

Figure 6.4 Premature deaths avoided due to cold for the UK for the different emission scenarios

(upper estimate, current population, baseline period: 1993-2006, no acclimatisation)

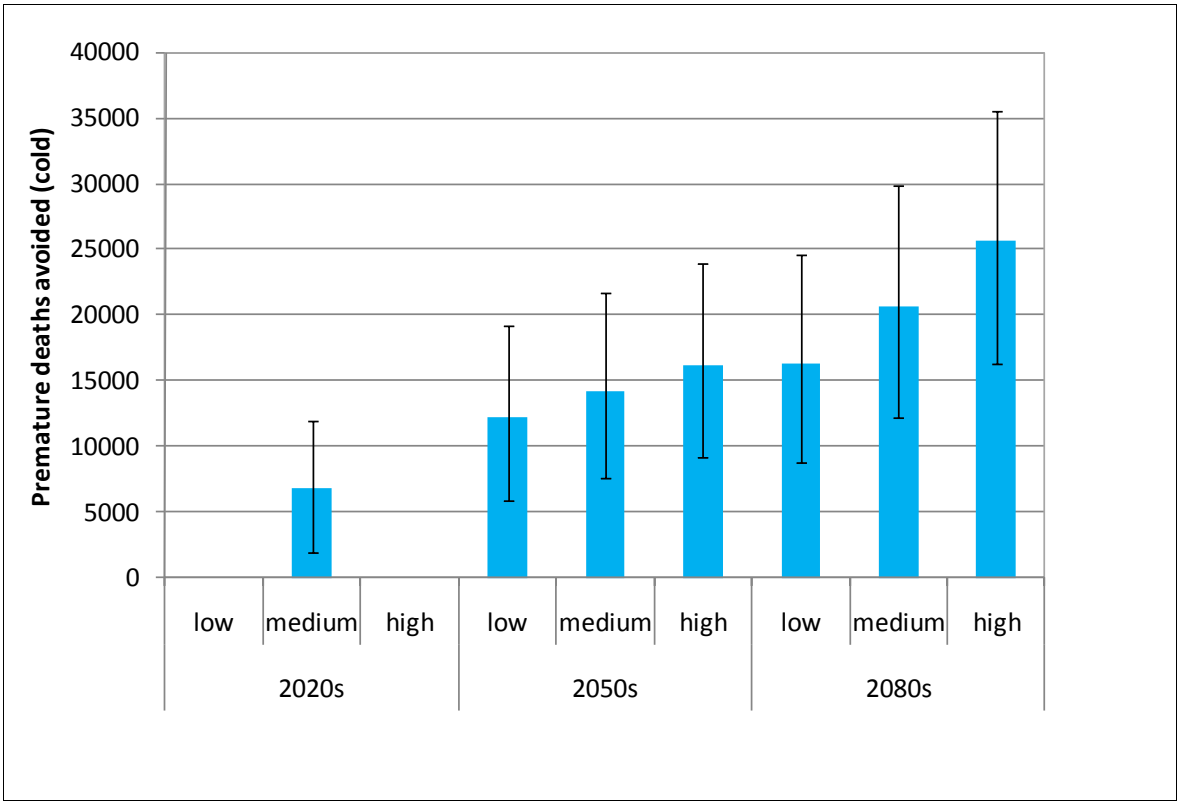
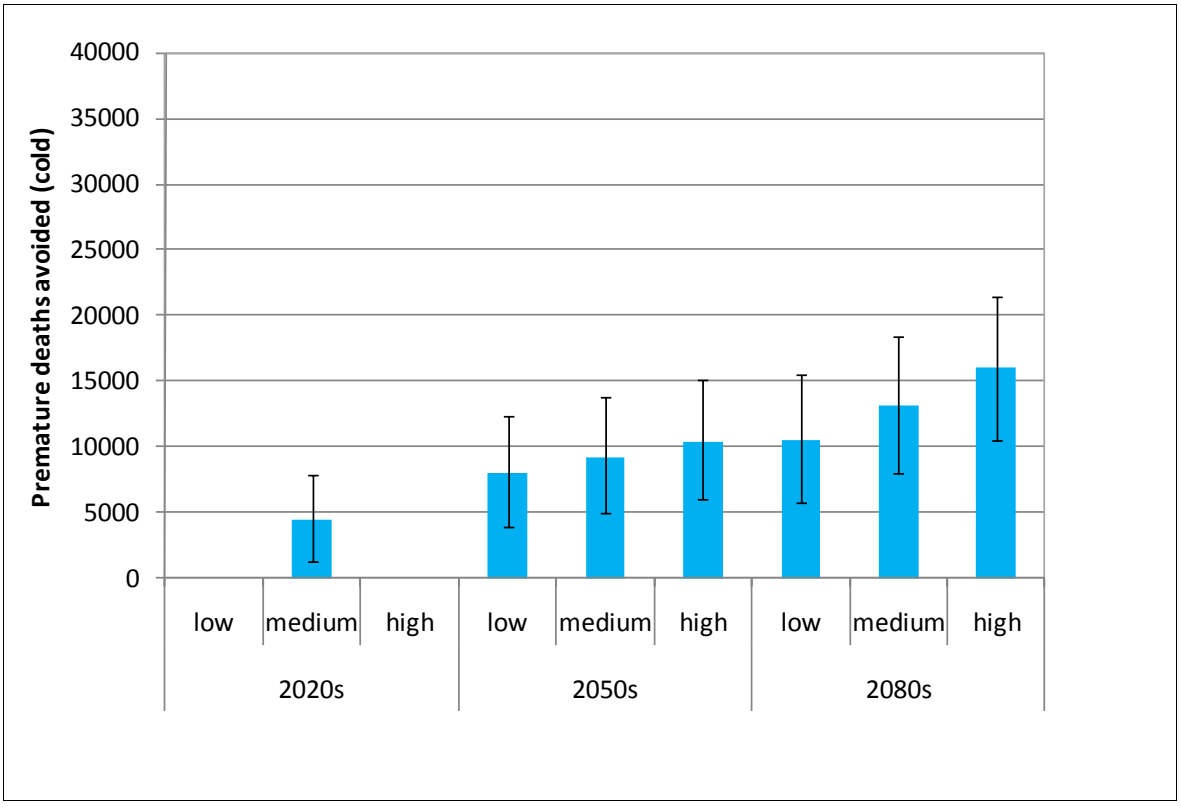


Figure 6.5 Premature deaths avoided due to cold for the UK for the different emission scenarios

(lower estimate, current population, baseline period: 1993-2006, no acclimatisation)



6.2.4 Cold related morbidity

Epidemiological evidence has indicated a causal relationship between mortality (as well as morbidity) and cold weather, with the most important diseases associated with cold-related excess mortality and morbidity being ischaemic heart disease, cerebro-vascular disease and respiratory disease (Hassi *et al.* 2005).

Similarly to heat related morbidity, hospitalisations are difficult to attribute to cold as they are not paralleled by equivalent magnitude increases in cold related mortality. This is further complicated as mentioned above by the increase in hospitalisations due to infectious diseases such as influenza and pneumonia that are more common in the winter. However, based on the same relationship for heat related mortality as indicated by Donaldson *et al.* (2002), this was used in the CCRA to cautiously indicate potential levels of hospitalisations avoided in a warmer climate on a UK wide basis.

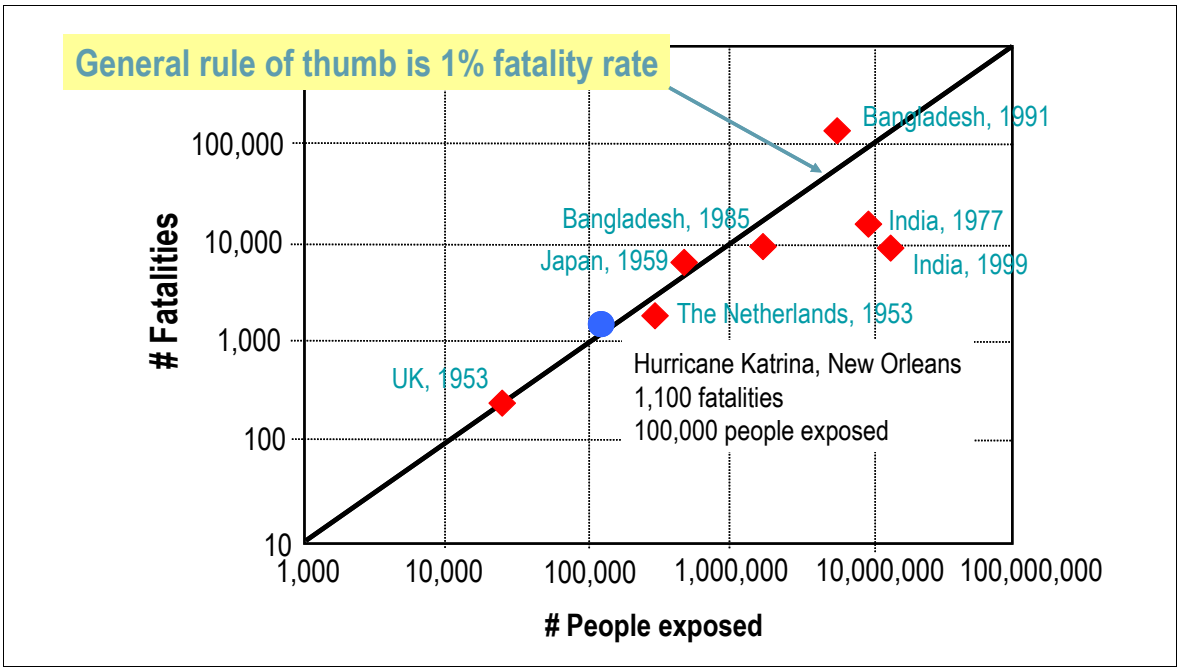
Results for reduced levels of cold related hospitalisations therefore show similar ratios to cold related mortality above with an approximate 15%, 30% and 45% reduction by the 2020s, 2050s and 2080s respectively (Medium emissions scenario, central estimates). This is based on a current day estimate of approximately 2,600,000 to 5,800,000 patient-days in hospital per year.	Medium confidence

6.2.5 Flooding

Floods in the UK that lead to significant loss of life are few and far between, and are heavily driven by the type of flood event and/or warning, the local characteristics of the area and also people's behaviour immediately before and during a flood. Nevertheless, there are typically a small number of deaths every year in the UK due to flooding and occasionally major events can cause significant loss of life. For example, the 1953 North Sea tidal surge on a high spring tide and resultant coastal flood that affected the east coastline of England resulted in 307 UK fatalities and in total over 2000 along Northern European coastlines (Baxter 2005). The Lynmouth flash flood disaster of 1952 resulted in 34 fatalities, and a significant number of injuries, even though a relatively few number of properties, approximately 400, were affected (Penning-Rowsell *et al.*, 2005). More recently three deaths were attributed to the Carlisle flood in 2005, thirteen deaths to the flooding in Summer 2007 (across the UK) and one death to the Cumbria Floods in 2009.

Previous UK research on 'risks to people' provides methods for estimating loss of life related to flood hazard, area vulnerability and people vulnerability characteristics (Defra, 2006a). Global findings are similar for much larger floods, for example, Frieser *et al.* (2005) (Figure 6.6) indicated an approximate 1% fatality rate for those exposed to a major flood worldwide. However, many UK floods are less extreme, and with in general more advance flood warnings in place and a more responsive population, an average UK ratio would be expected to be lower.

Figure 6.6 Relationship between people exposed and fatalities
(Source: Frieser *et al.*, 2005)



For the CCRA a similar approach was taken that assumed for river, pluvial and coastal flooding[89] that fatalities were directly proportional to the number of people exposed to risks in any particular year. Additionally, deaths were also considered due to storm conditions at the coast, resulting in people being struck by waves and sometimes washed out to sea. These fatalities were assumed to be exponentially related to changes in mean sea levels. The full methodology and results for different scenarios, and population projections, are presented in the Health Sector Report, with supplementary information on flood risk based on results from the Floods sector.

The overall findings suggest an increase in fatalities of approximately 70% by the 2020s with a 120% increase by the 2050s (Medium emissions scenario, central estimates). These are from a current day baseline (2010) of approximately 18 flood related deaths per year.	Medium confidence

In addition to deaths, a greater number of people may be injured[90] as a result of flooding. Based on evidence presented in the Health Sector Report, this was taken to increase at the same rate as for the number of fatalities.

The overall findings suggest an increase in flood related injuries of approximately 70% by the 2020s with a 120% increase by the 2050s (Medium emissions scenario, central estimates). These are from a current day baseline (2010) of approximately 350-400 flood related injuries per year.	Medium confidence

These results are summarised for flood and storm related deaths in Figure 6.7 and for flood and storm related injuries in Figure 6.8.

[89] Although pluvial flooding was not assessed as part of the CCRA, the response function for pluvial flooding was assumed to be the same as river flooding, with the consequent single response function applied to the current day estimate of deaths due to river and pluvial flooding.
[90] The definition of an injury in this context has been defined as an injury sustained during an extreme weather event that requires medical attention from a hospital admission.

Figure 6.7 Annual additional number of deaths due to extreme event flooding and storm events

(current population, baseline 2010)

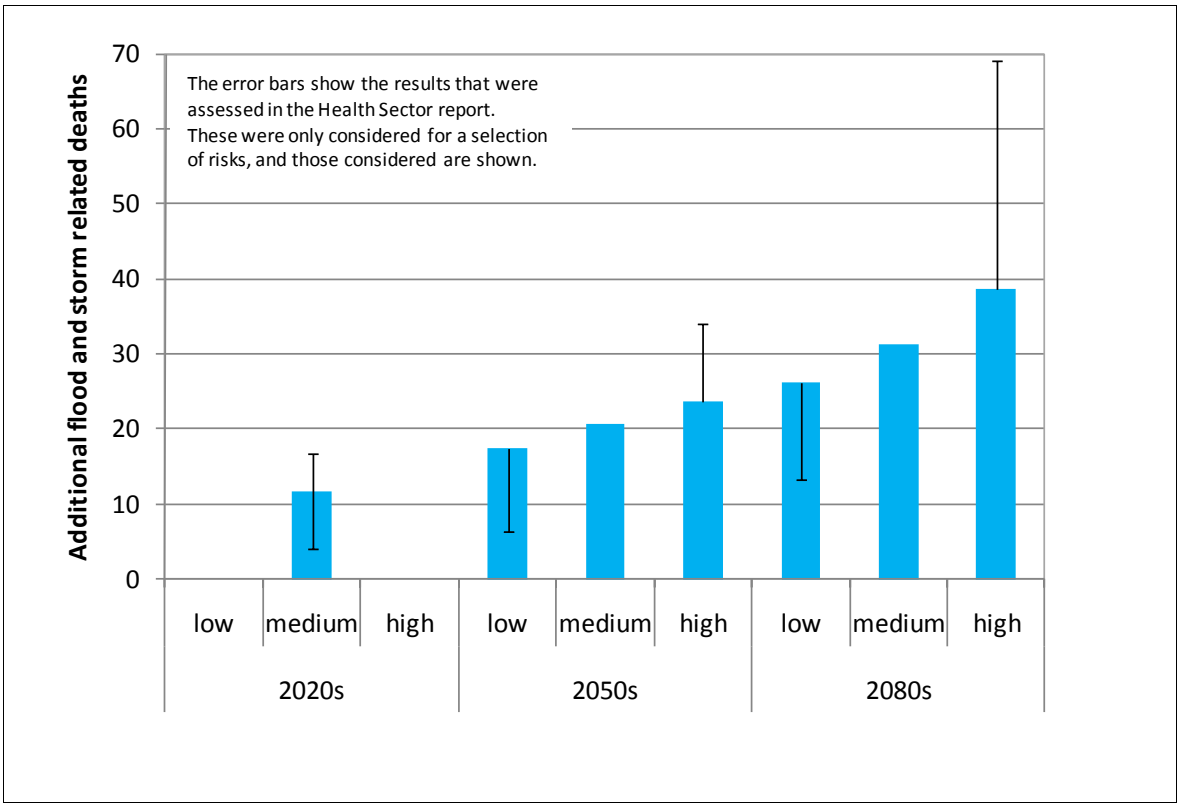
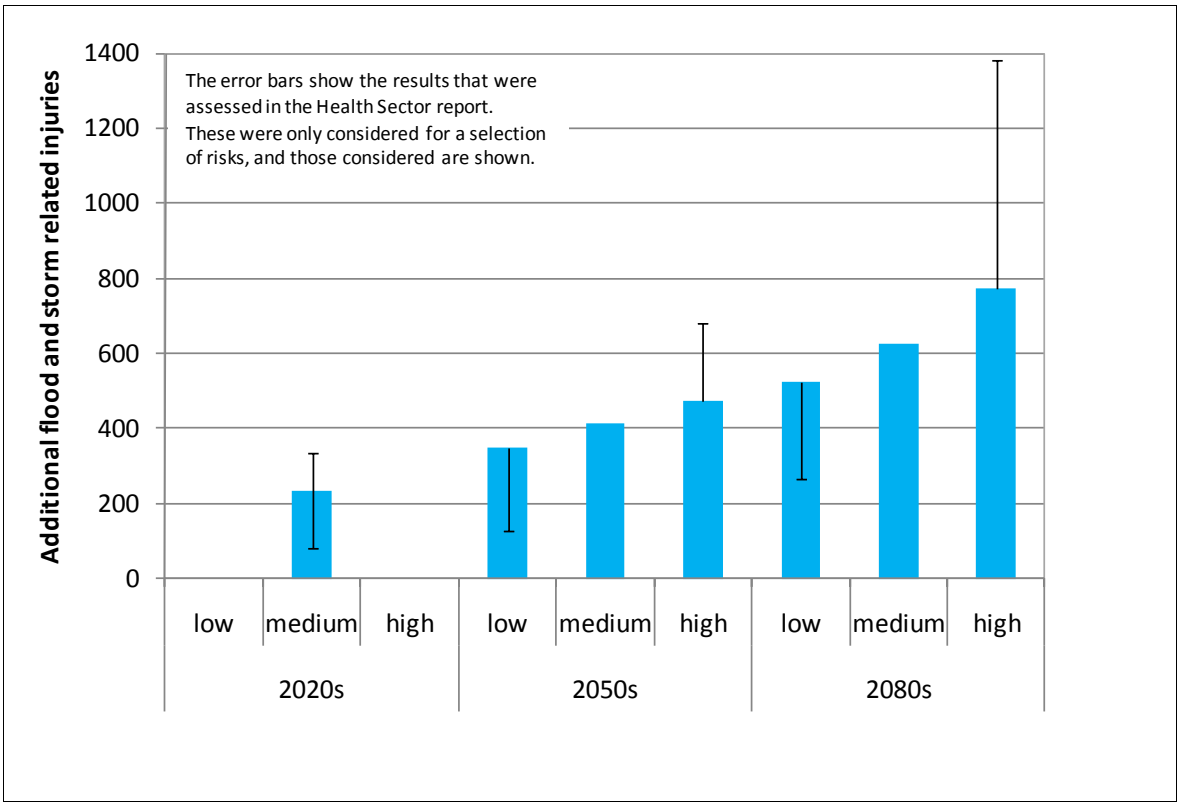


Figure 6.8 Annual additional number of injuries due to extreme event flooding and storm events

(current population, baseline 2010)



6.2.6 Flood risks and mental health

An increase in flood risk would increase the likelihood of a flood as well as the potential magnitude of any flood for those in flood risk areas. This would therefore increase levels of stress and damage caused by the flood, with consequences for mental health. In attempting to estimate the effects on mental health resulting from floods, the shortest version of the General Health Questionnaire, GHQ-12[91] was used. This is now commonly used in flood studies to estimate the mental health effects of flooding (Health Sector Report). Based on the studies assessed as part of the CCRA, the effect of floods on mental health as a result of climate change were assumed to be proportional to the number of people at risk from river or tidal flooding.

In the CCRA this impact was assessed by considering the number of people whose mental health declines as a result of a flood event, which is estimated to be between 30-40% of those flooded each year (Health Sector Report).

The numbers of additional people in England and Wales affected per year according to this metric are estimated to be between 4,000-7,000 by the 2050s and 5,000-8,000 by the 2080s. These effects particularly affect certain vulnerable groups who are more prone to live in flood risk areas, and less likely to be insured. Currently in the region of 3,500-4,500 people in England and Wales suffer a mental health effect due to flooding each year.	Medium confidence

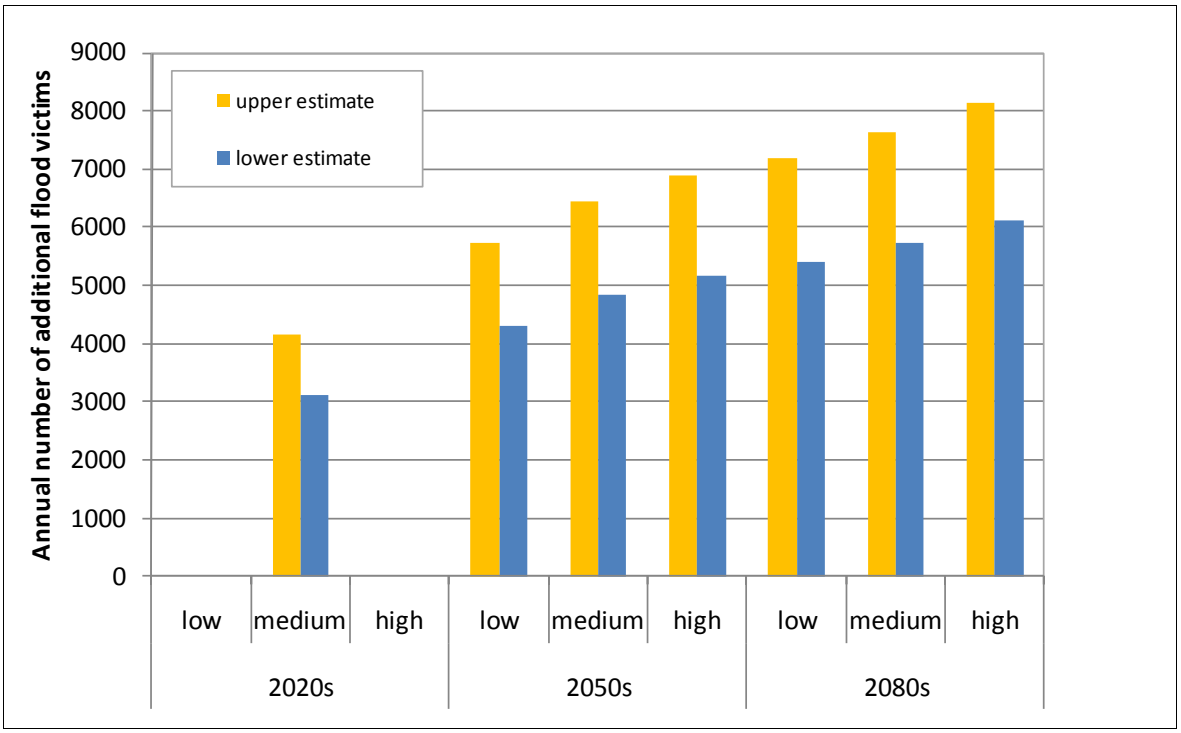
Overall, Tunstall *et al.*, (2006) suggested that the effects of flooding on the mental health of some victims are enduring and not just short-term, and that this burden adds significantly to the strain on medical services, as well as potentially undermining the capacity of health care systems to respond to health crises (Ohl and Tapsell, 2000). An increase in the number of people suffering mental health effects due to flooding indicates that there would need to be an increase in health support for flood victims and better consideration of the knock-on effects of flooding on wellbeing.

Figure 6.9 summarises the analysis of the mental health effects from flooding.

[91] The GHQ-12 is a 12 item questionnaire (maximum score of 12) that assesses a mental health effect as someone who moves from a GHQ-12 score of below 4 to 4 or above as a direct result of a flood event.

Figure 6.9 Annual additional number of flood victims in England and Wales who go from a GHQ-12 score of below 4 to 4 or above as a result of extreme event flooding and storms

median estimate of the current population (baseline 2010)

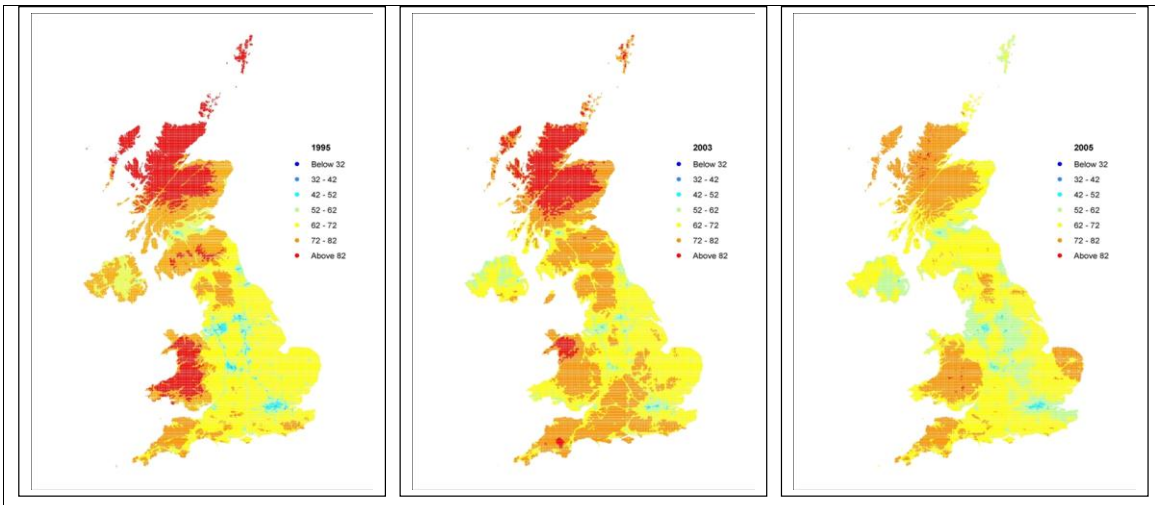


6.2.7 Ground level ozone

Elevated concentrations of ground-level ozone are produced during summer photochemical smog episodes, caused by the interaction of oxides of nitrogen and volatile organic compounds in the presence of sunlight. These can have detrimental effects on human health leading to an increase in hospital admissions and premature deaths.

The key influences on ambient ozone concentration are well understood (see for example NEGTAP, 2001). However, these combine in different ways, and levels are very much dependent on a number of weather, land use and topographic factors (Health Sector Report; Stedman and Kent, 2008). For example, Figure 6.10 shows concentration maps based on Stedman and Kent's analysis that highlights different concentrations in rural and urban areas. The impacts are relevant to climate change because concentrations are strongly affected by year to year variations in weather patterns. Future changes in temperature, specific humidity, wind speed and direction, cloud cover, solar radiation, heat flux and precipitation would all be expected to have a significant effect on future levels but there is limited research in this area, so the CCRA completed some new preliminary analysis to draw out the links between future climate and ozone levels.

Figure 6.10 Annual mean of the daily maximum of the running 8-hour mean ozone concentration (μgm^{-3})
(Adapted from Stedman and Kent, 2008)



(a) : 1995 **(b)** : 2003 **(c)** : 2005

The CCRA analysis indicates that ground-level ozone causes around 10,000 premature deaths and 33,000 respiratory hospital admissions per year in the UK. These estimates, based on a linear non-threshold exposure-response relationship, are in good agreement with ozone-related mortality rates reported by Stedman and Kent (2008) but are larger in the case of hospitalisations, probably due to the regional baseline morbidity rates used in the present study. Future concentrations of ozone depend on a complex relationship between future global emissions of nitrogen oxides and volatile organic compounds (the main ozone precursor gases), synoptic weather circulation, local weather conditions, and land use patterns.

In this study, the impact of climate change on ozone-related mortality/morbidity was assessed for a business-as-usual scenario, i.e. in the absence of any significant changes in ozone precursor emissions (anthropogenic or biogenic) or land use.

Based on these assumptions, it was estimated that there would be between 650 and 2,900 additional premature deaths and between 2,300 and 10,000 additional respiratory hospital admissions in the UK (relevant to the current estimates) by the 2080s for the current day demographics.	Medium confidence

These effects were noted to be greatest in the south-east and north-west and least in Northern Ireland.

This risk appears to have significant consequences for society, including a disproportionately high health risk for people with pre-existing respiratory conditions, such as asthma. In addition, higher ozone levels in the future can damage vegetation and crops, and harm building materials. It should be noted, however, that current trends of rising background ozone concentrations across the northern hemisphere could be changed if more stringent emission control policies on ozone precursor gases are implemented at the international scale. Due to the complex interactions between different factors there is limited confidence in these results, but due to the potential high magnitude of consequences, the risks associated with ozone warrant further consideration as part of the UK's adaptation planning.

6.2.8 UV exposure

As summer temperatures are projected to increase, people may be more inclined to spend longer in the sun, which would almost certainly increase their UV radiation exposure and consequently increase the incidence of melanoma and non melanoma skin cancer in the UK population (Diffey, 2004). This risk may be greater for people occupationally exposed to solar UV radiation, including farmers, construction workers and some public service workers (Young, 2009), although studies indicate that current risk is lower relative to the rest of the population, Autier *et al.* (1994) and Elwood and Jopson (1997). However, UV radiation exposure will also be affected by the rate of recovery of the stratospheric ozone layer, which is expected to be altered by climate change (UNEP, 2010; Health Sector Report). There may also be benefits from increased exposure to sunlight which is known to enhance vitamin D levels (which is good for skeletal health and calcium metabolism) as well as other related health benefits if more time is spent on outdoor activities (Holick, 2004).

Although changes in solar UVB[92] exposure associated with climate change have been linked to melanoma skin cancer incidence and mortality (Fears *et al.*, 2002), the relationship between future incidence of skin cancer and environmental conditions is an extremely complex issue. Changes in social behaviour as well as the stratospheric ozone layer are both determinants of the level of risk. Current climate projections from UKCP09 indicate a slight increase in net surface UVB radiation flux by the end of the century for southern England (up to 5-10% by the 2080s for the High emissions scenario), reducing further north.

This could potentially have an impact on UK society due to increasing skin cancer incidence and mortality. However, this impact could also have potential benefits associated with increased vitamin D levels and improved physical and mental health of people spending more time outdoors.	Low confidence

Overall, the future effects due to future levels of UV exposure are highly uncertain and therefore this may be an area where further monitoring and research are needed to monitor risks going forward. However, although the current evidence of climate consequences is weak, with ‘low confidence’ with respect to future consequences of UV exposure, it is unlikely that this risk will be significant.

6.2.9 Vector, water and food-borne diseases

Vector reproduction, parasite development and bite frequency generally rise with temperature. Therefore, malaria, tick-borne encephalitis, and dengue fever are very likely to become increasingly widespread in certain parts of the world (mainly in tropical and sub-tropical climates) due to projected rises in temperatures (Costello *et al.*, 2009 and IPCC, 2007). This could have significant implications for UK international aid budgets, for which the UK gave £104 million in 2008/09 to combat these diseases (Foresight, 2011a). However, future outbreaks of certain vector borne diseases such as malaria would still be expected to be rare and limited in number in Europe (Rogers *et al.*, 2008).

[92] UVB is the radiation most closely associated with skin cancers (see Health Sector Report, Section 4.6)

The risk of new vector species being introduced to the UK is relatively low (Medlock *et al.*, 2005 and Rogers *et al.*, 2008) although British citizens visiting vector-borne endemic countries overseas may be at higher risk, and increase the risk of imported malaria and dengue to the UK (Lee, 2000).	Low confidence

Lyme disease, for example, may present local problems in the UK, but the increase in the overall impact of the disease would probably be small and mainly dependent on agricultural and wildlife management practices. There is also no conclusive evidence indicating that climate change substantially contributes to tick-borne encephalitis in Europe (Randolph, 2004 and 2010).

Changes in the regional climate of Northern Europe may also lead to an increased risk of the introduction of new diseases to the UK. This could be due to immigration and international travel, with the arrival of affected persons in the UK; an outbreak domestically, due to imported vectors (such as insects) or person-to-person spread; or through the import of contaminated food products to the UK. However, it is important to note that the relevance of environmental change to patterns of disease depends on the susceptibility of local populations to the disease, the robustness of local food and water safety measures, vector control measures and communicable disease surveillance and control arrangements (e.g. vaccination programmes, legislation) (Foresight, 2011a).

However, prompt action to any outbreaks will reduce the chances of endemic malaria transmission in the UK, and it is probable that the public health infrastructure in the UK would prevent the indigenous spread of these diseases (Kuhn *et al.*, 2003 and Hunter, 2003).

Zoonotic gastro-intestinal pathogens present a significant human disease burden. Approximately a third of the UK population suffer infectious intestinal disease each year (>16 million cases) and there are about 2 GP consultations for every 100 person years (Lam *et al.*, 2011). These pathogens have evolved and circulate in animal reservoirs with human infection occurring through exposure via a number of different pathways including food, the environment (direct/indirect contact with animals and their faeces) and water (drinking or recreational contact). This can result in disease outbreaks, in particular Cryptosporidiosis which is the most significant water-borne disease related to public and private water supplies in the UK (Hoek *et al.*, 2008; Nichols and Kovats, 2008). In the marine environment, the only clear epidemiological link with seafood only exists for norovirus, astrovirus, Aichi virus, sapovirus and Hepatitis A virus (Le Guyader *et al*., 2009).

A number of factors impact upon the human burden attributable to these pathogens including anthropogenic and environmental influences. Environmental factors include climate change, which may lead to an increasing frequency of high intensity rainfall events that permit mobilisation of pathogens from faecal material into watercourses, resulting in increased transmission to animals and humans. This was noted by Nichols *et al.*, (2009), who observed a strong correlation between heavy rain events and drinking water-borne disease outbreaks in England and Wales. Other changes may be associated with de-carbonisation of agriculture to mitigate against greenhouse gas emissions, while changes in rural visit patterns may also have an additional effect on zoonotic transmission (McGuigan *et al.,* 2010).

Drinking water may be contaminated with pathogens before or after treatment from a variety of sources including livestock, feral animals or infected humans present in the catchment (Smith *et al.,* 1995). While chlorination is an effective disinfectant against most water-borne pathogens, *Cryptosporidium* oocysts can remain infectious in the environment for prolonged periods and are resistant to normal drinking water

disinfection treatments. Preventing oocyst transmission via physical removal is therefore necessary to reduce potential human exposure.

For the UK, the majority of drinking water supplies, especially in major urban areas, have effective forms of water treatment capable of significantly reducing the *Cryptosporidium* load in final drinking water. However, there are a number of rural communities served by drinking water supplies, where current treatment is inadequate at removing *Cryptosporidium* oocysts. This is more prevalent in Scotland where approximately 3% of the population are on a private water supply as opposed to England and Wales where it is less than 2%, and Northern Ireland where it is less than 1%. With these areas commonly frequented by farmed and/or wild animals, which harbour zoonotic pathogens such as verotoxin-producing *Escherichia coli* (VTEC) and *Cryptosporidium*, the risks are high, particularly following periods of heavy rain (Ogden *et al.,* 2001).

In Scotland in particular, there is an intense and disproportionate public interest in the microbial quality of drinking water, largely due to a number of high-profile outbreaks of cryptosporidiosis and incidents resulting in boil water notices (Mukherjee, 2002; NHS Scotland, 2001). However, most cases of zoonotic gastro-intestinal disease are sporadic and private water supply consumers, who are most at risk, perceive that the risk of microbial contamination is low and/or that they have acquired immunity to these pathogens (SGHD, 2009). With water safety programmes in place for public water supplies, rural and private water supplies are most at risk. Considering UKCP09 projections, by the 2020s it is not likely that the number of cases of cryptosporidiosis or VTEC associated with drinking water should significantly change. For the 2050s and 2080s, projected temperature increases may have a bearing on pathogen survival on land and in drinking water (Chief Medical Officer, 2001), as well as altering the magnitude and seasonality of pathogens discharged into the sea. The evidence for this statement however is sparse and it may be that augmented UV effects have a more significant effect on pathogen survival (Hader *et al.,* 2011).

It is therefore difficult to assess how climate change may affect waterborne disease. Furthermore, increased flooding events may result in overflow of sewage discharge where there is bypass of sewage treatment plants therefore recreational use of water may become more of a public health risk. Cases of gastrointestinal and respiratory illness, ear and wound infections, which have been reported following bathing (Fleisher *et al*., 1996; Oliver, 2005), may therefore increase. A rise in temperature of water bodies can also result in an increase in various plankton blooms, a number of which are directly or indirectly hazardous to human health. These include Cyanobacteria and *Pfiesteria piscicida* which amongst other things can cause respiratory problems and skin and eye inflammation/irritation. Recreational water use could therefore increase the risk of water-borne diseases in people using inland and coastal waters (Zmirou *et al.*, 2003), with particular concerns for local communities that rely on water-based recreation and tourism. This includes commercially harvested bivalue molluscs as these animals are filter-feeders, and consequently may accumulate microbial contaminants which can be harmful to humans if consumed. However, the epidemiological evidence of infectious disease associated with recreational water contact is limited, and this type of exposure is not likely to cause a significant disease burden in the UK population (Hunter, 2003). The potential for any epidemic outbreak of disease is also considered rare in developed countries such as the UK (Malilay, 1997).

It is difficult to assess how climate change may affect waterborne diseases. However, impacts are not anticipated to be significant, although there will be a disproportionate affect for those households on a private water supply.	Low confidence

Ad-hoc monitoring by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) of marine pathogens that can cause stomach problems in humans show that they are on the increase. Of these, the primary disease (hosts and) pathogens of concern are *Vibrio vulnificus* and *Vibrio parahaemolyticus*. Human infections are currently not frequently reported either in the UK or in Europe (Anon, 2001), but there is increasing evidence to suggest that the frequency of reporting and illness is increasing coincident with sustained periods of warming (Baker-Austin *et al.*, 2009 and Martinez-Urtaza *et al.*, 2010). *V. parahaemolyticus* causes acute Gastroenteritis. It is highly dependent on seawater temperature with rapid proliferation occurring at seawater temperatures above 16˚C. UKCP09 models suggest increasing sea temperature of several degrees in the coming decades. Sustained warming events (>20°C) are the most significant risk factor associated with *Vibrio* outbreaks.

A number of recent reports suggest that increases in seawater temperature may be directly responsible for outbreaks in the US and elsewhere. Paz *et al.* (2007) found that pathogenic strains of *V. vulnificus* responsible for disease outbreaks in Israel in 1981 and 1996 followed unusually warm, wet summers and were identical. The authors suggest that the pathogens lie dormant in marine sediments and re-emerge to cause disease outbreaks when climatic conditions are favourable. These findings suggest that environmental disturbances, such as increases in water temperatures and transient decreases in salinity, may be important in increasing the risk of infection and illness. However, these risks are mainly limited to individuals with liver disease and other conditions that cause elevated serum iron levels, as *V. vulnificus* requires a high level of iron to grow and cause disease.

Studies at Cefas show pathogenic *V. parahaemolyticus* is present in seafood from the UK, during summer months. The frequency and seriousness of these occurrences is increasing. Rising temperatures may also increase the range and prevalence of *V. vulnificus* and other marine *Vibrio* species in the UK. Infections of *V. vulnificus* are currently rare (<100 yr in the USA), but carry the highest mortality rates of any bacterial pathogen. If treatment is delayed more than 36 hours then the mortality rate is 100%.

Based on the analysis carried out for the CCRA, there is the potential for an increased risk of illness in humans through *Vibrio* pathogens under the UKCP09 scenarios. However, given the lack of data and other evidence on current risks, there is very low confidence in any statements concerning future outbreaks in the UK.	Low confidence

The risk was flagged in the CCRA as the potential consequences are severe for anyone infected. More surveillance should enable the risks of future marine *Vibrio* outbreaks to be established more precisely.

In recent years there has been an apparent increase in the occurrence of Harmful Algal Blooms (HABs) in many marine and coastal regions (FAO 2006). Around the UK and Ireland, a strong regional distribution is observed for toxic HAB species, which are more regularly detected along the Irish South and West coasts and in Scotland.

Climate change has the potential to heighten the incidence of HABs in UK waters due to a number of biophysical impacts including temperature changes; increased winter runoff that may increase inputs of nutrients, sediment, and contaminants and changes in stratification of the water column (see Section 3.4.3). However, changing pollutant loads due to population changes, sewerage standards and land management may have a far greater influence than climate change.

There is a tendency for the number of cases of food poisoning to rise during the summer when warm weather favours the multiplication of pathogenic micro-organisms (Bentham and Langford, 2001). There is also good international evidence that

norovirus outbreaks are linked to rainfall driven pollution events (Lees, 2000), particularly when these occur in the winter months. Higher temperatures as a result of climate change might exacerbate the food-borne disease problem (e.g. food poisoning, *Campylobacter*, Salmonellosis, *Salmonella Typhimurium* infections and *Salmonella Enteritidis* infections) in the UK (Kovats *et al.*, 2004b), although in the marine environment there is little evidence as yet that climate change has affected incidence rates of water and shellfish-related illness. Greater winter rainfall events may also increase the number of shellfish related notovirus illness outbreaks, as was demonstrated for the winter of 2009/10 when there were a number of significant precipitation events (Westrell *et al.*, 2010).

Given the current level of food poisoning notifications, an increase of 1˚C, would result in an approximate 4,000 additional notifications[93], although due to under reporting, the real level of additional cases could be around nine times this figure (Stanwell-Smith, 2008). Approximately 19 million days are lost every year due to infectious intestinal diseases, 11 million of which are amongst people of working age (based on research by Tam *et al.*, 2011). Based on the Medium emissions scenario, this indicates a 1-7%, 5-14% and 8-21% increase in notifications by the 2020s, 2050s and 2080s respectively. However, the impact of climate change on this aspect of UK public health is likely to be relatively small compared to other factors such as food hygiene (Lake *et al.*, 2009). There is also significant work already underway by amongst others the Food Standards Agency to manage and reduce food-borne disease, looking at all factors and causes, including the impacts of climate change.

Despite the historical impact of sewage discharges on marine pollution, the improvement in treatment levels means that contamination due to CSOs and land runoff are now considered more significant. Despite considerable dilution by surface water runoff, storm sewage discharges from CSOs may contain significant loads of pathogenic bacteria and viruses, among other pollutants (see Lee *et al*., 2003). Although only discharged intermittently, CSOs have a long history of causing problems in the microbial quality of shellfisheries and there are over 600 CSOs impacting directly on tidal waters in England and Wales. In addition, the operation of sewers and storm drains are highly vulnerable to flooding. Changes in precipitation coupled with increasing urbanisation would increase both the volume and speed of storm water runoff which may contain microbial content from animal waste and debris. This has been demonstrated for the CCRA based on a case study for the River Dart in Devon. For the central estimate of the Medium emissions scenario, the risk of a decline in water quality is given as a medium/high risk in the 2020s and 2050s, and a medium/high/very high risk in the 2080s. With all regions of the UK with the exception of north-west Scotland projected to experience an increase in the magnitude of winter flash floods, this indicates that a similar level of risk could be experienced over most of the UK, particularly in the south of England and southern Scotland where significant increases in winter rainfall are projected.

Surveys undertaken for shellfish production areas by Cefas on behalf of the Food Standards Agency (FSA) have highlighted that, in addition to continuous and intermittent discharges, land runoff and contaminated river sediments are also important in determining the magnitude of faecal indicator organisms in commercially harvested shellfish. These factors often act to produce pronounced seasonal variations in contamination (see Lee and Morgan, 2003). Significant inter-annual variability has been detected in some rivers, with the number of peak flow events increasing in recent years (Cefas, 2010). High risk periods can be associated with increases in summer tourism activities and the application of sewage sludge/manures to land during the winter, and spring. For areas surveyed, the critical period of contamination in shellfish (detected by the routine monthly sampling programme), was demonstrated to be the

[93] There are currently in the region of 100,000 reported cases of food poisoning cases in the UK every year, NHS (2011).

first three days after a rainfall event. An overall increase in winter rainfall and changes in the wettest day of winter could result in quicker and more frequent contamination events in shellfish and increasing difficulties in implementing control strategies.

6.3 Vulnerable people and deprived communities

Some of the findings of the CCRA indicate an unequal burden of risk for some of the most vulnerable groups in society. Early adaptation actions may therefore be needed to protect these groups from these increased risks as well as ensuring that essential services remain affordable to those on the lowest incomes.

There is increasing evidence that the consequences of flooding, drought and heatwaves may be far greater for vulnerable groups, such as the elderly, young people or disadvantaged. Factors affecting vulnerability may be different for each type of hazard but common themes are evident in the research on floods and heatwaves. For example the following groups are expected to be more vulnerable to extreme heat. Those marked with * are also more vulnerable to floods:

- Elderly people (over 75)*, especially those who are socially isolated or living on their own.
- People with compromised health* (chronic cardiovascular, respiratory illness, diabetes, etc.) may be at higher risk during heatwaves due to heat stress and dehydration, and increased exposure to ozone pollution.
- Pregnant women may be more vulnerable to heat stress (Kovats, 2004).
- Hospital inpatients and care home residents* will be at risk if indoor temperatures are not appropriately controlled.
- The elderly affected by side-effects (impaired thermoregulation, suppressed thirst) of certain medications may be at higher risk during heatwaves.
- Deprived people living in densely populated urban areas, particularly in large cities where temperatures are greater as a result of the Urban Heat Island effect.
- People with mobility or cognitive constraints* (including those with Alzheimer's disease) would be at higher risk during extreme weather events, such as floods and heatwaves, as they may be unable to adapt quickly and follow guidelines.
- People with pre-existing mental health conditions* would be at an increased risk of mental health problems during a heatwave.
- People consuming too much alcohol or taking illicit drugs* may also be unable to adapt quickly and follow guidelines during extreme weather events (Vardoulakis, 2010).
- People with outdoor occupations, including construction workers and drivers.
- Sports persons and amateur athletes exercising outdoors.

The evidence that vulnerability to heat increases with age is a key health issue because it is linked to intrinsic changes in the regulatory system or to the presence of drugs that interfere with normal homeostasis (Vassello *et al.*, 1995). There are other environmental and situational factors linked to age, such as reduced mobility, that also need to be considered.

Knowlton *et al.* (2009) found that there was a significant increase in numbers admitted to Emergency Departments during the heatwave in California in 2006; with children up to the age of 4 and those over 65 years especially at risk. Johnson *et al.*, (2004) also found that the worst affected by the 2003 heatwave in England were those who were over 75, both in terms of excess deaths and additional hospital admissions.

Melanoma and non-melanoma skin cancers also increase with age (Cancer Research, 2010). Vardoulakis (2010) also indicates that people with pre-existing respiratory illnesses are more likely to be affected by Summer Air Pollution.

As outlined earlier, a number of studies have made the link between climate risks and vulnerable communities. In England and Wales, flood risk management strategies consider the distributional impacts of flooding by considering the number of flooded properties in the category of 'most deprived' households using the Index of Multiple Deprivation (IMD). This is defined as the number of households in the most deprived 20% of the UK population[94]. Figure 2.5 illustrates these data for each country with the most deprived areas shaded in the darkest colours. The overall pattern of deprivation in urban centres, remote rural areas and specific places, like former coal mining areas in Wales and the north-east is clear.

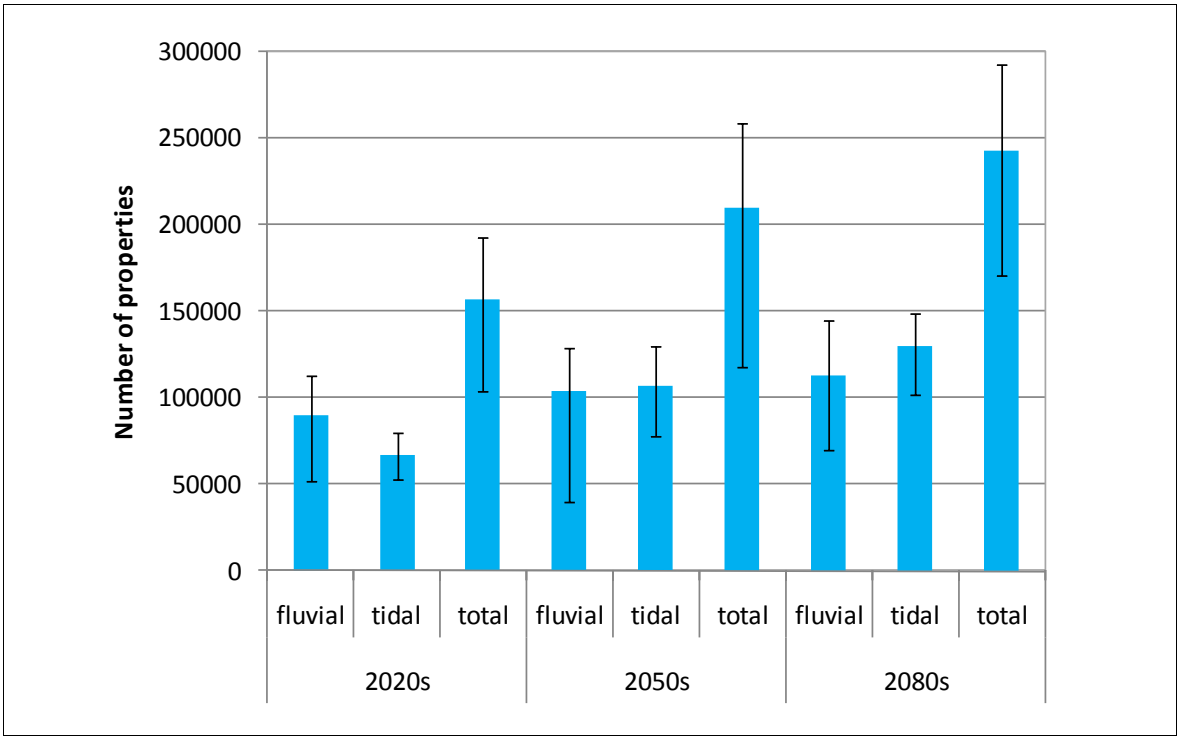
As part of the Floods sector analysis, the number of properties in the most deprived areas at significant risk of flooding was estimated for future climate change scenarios. This analysis showed that:

- Approximately 70,000 of the properties in the 'most deprived' areas are currently at significant risk of flooding;
- A two-fold (~1.5 to 2.8 times) increase in the number of properties at risk for the 2020s; and
- A three-fold (~1.7 to 3.7 times) increase in the number of properties at risk for the 2050s.

These estimates only consider the sensitivity to climate based on current population and the figures are significantly larger under the principal and high population forecasts. The numbers of properties in England and Wales for each scenario are summarised in Figure 6.11 and the full data set is included in the Flood and Coastal Erosion Sector Report.

[94] http://www.neighbourhood.statistics.gov.uk/dissemination/Info.do?page=analysisandguidance/analysisarticles/indices-of-deprivation.htm

Figure 6.11 Number of properties in England and Wales in the highest 20% of deprived areas at significant risk due to river (baseline 1961-90) and tidal (baseline 2008) flooding



One aspect that was clearly indicated by the CCRA analysis was how geographical variation may change in future due to climate change factors alone. For example, our analysis indicates that at present there are similar 'orders of magnitude' of deprived people affected by flooding in different parts of England and Wales (Figure 6.12). This pattern is projected to change and regional "deprivation hotspots" may emerge starting with the north east of England and then followed by the north-west and Wales (Environment Agency, 2006). This is caused by the lower current standards of protection and asset conditions in these areas combined with higher average increase of flood flows than in the south east. Other social science evidence, using different social indicators, shows that vulnerable groups are already more likely to be at risk than others (e.g. Fielding, 2007). Private tenants or low income homeowners are less likely to have contents insurance, which would exacerbate the financial effects of a flood, and the consequential health effects (Fordham and Ketteridge, 1995). Paradoxically however, social tenants may suffer less due to an obligation to re-house them if their property floods. These are potentially significant findings of the analysis as they indicate that policy intervention may be required to prevent an unequal burden of risks both geographically and between different social groups. It suggests that particular consideration might be given to social vulnerability criteria for targeting flood risk aspects of the national adaptation plan.

There are specific vulnerability issues related to human health. McGregor *et al.* (2007) point out that deprivation explains most of the geographical variation in life expectancy in the UK (Woods *et al.*, 2005b) and so differences in responses to heatwaves may reflect variations in deprivation. People living in areas of deprivation already have lower life expectancies so it might be reasonable to assume that there would also be more deaths from heatwaves than in less deprived areas.

Furthermore, Middelkoop *et al.* (2001) found that in data from under 65s in The Hague, mortality risk generally increased with an increase in deprivation score of a residential area. They found that the key diseases contributing to mortality differences between

the high and low deprivation quartiles were ischaemic heart disease and other diseases of the circulatory system. The findings are interesting as these diseases increase sensitivity to heat, suggesting that sensitivity to heat may be partly conditioned by the degree of deprivation.

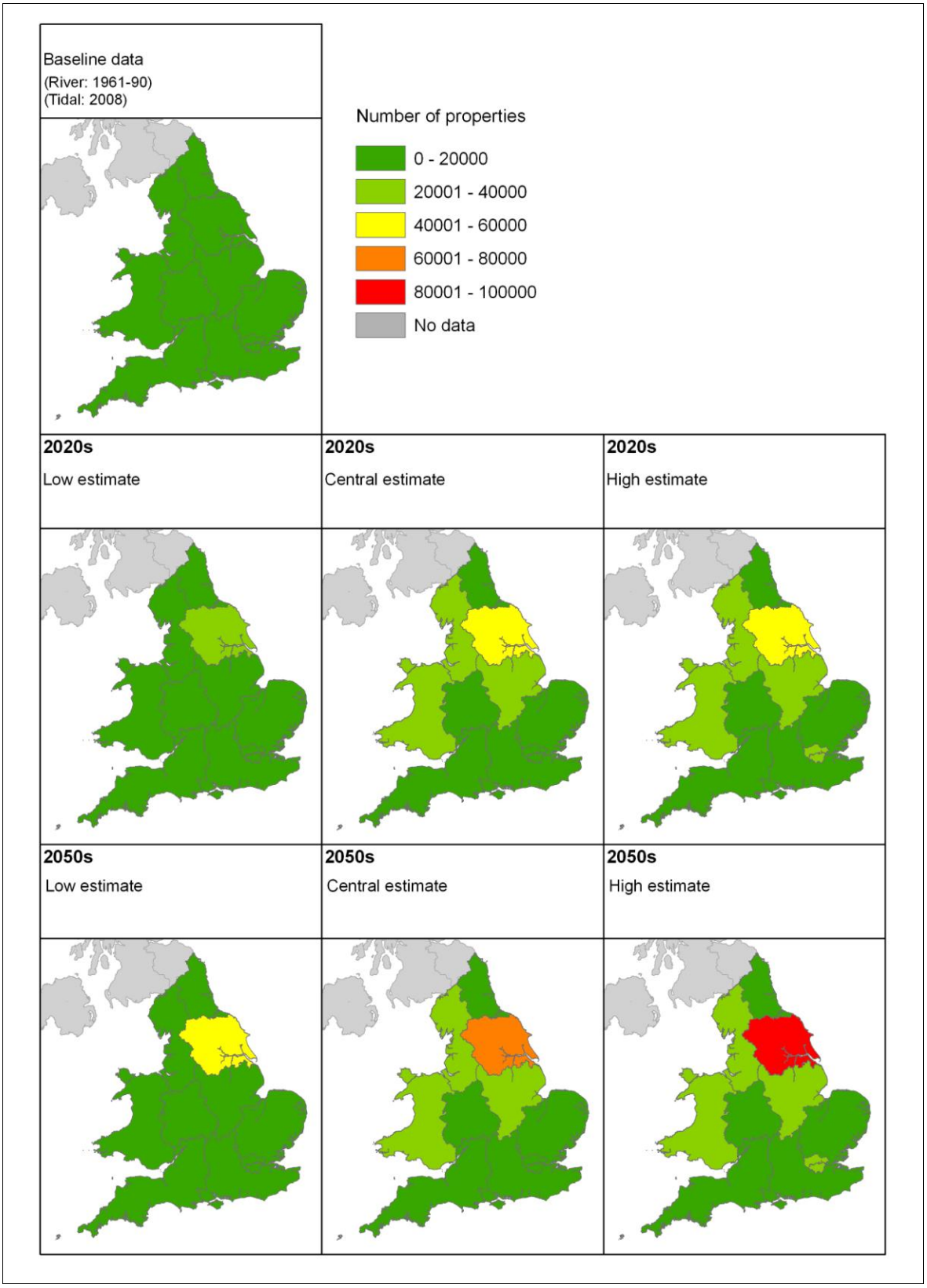
A study across 11 European countries showed that high excess mortality among the elderly population of lower socio-economic status (as measured by education and housing tenure) constitutes an important health problem for Europe (Huisman *et al.*, 2005). In absolute terms more elderly people died who had lower educational status than those with higher educational status, than would be expected. In terms of housing tenure, the relative difference in mortality between homeowners and renters declines in the over 80s, however, differences in absolute mortality levels peaked in the 70 – 79 age range with more people dying who lived in rented accommodation than those living in their own homes. People living in care were not included in the Huisman study, but the issue of overheating in hospitals and retirement homes was raised as an important issue and is discussed in Section 7.2.2.

Donaldson *et al.* (2002) report that preliminary analysis for the 1995 heatwave in Greater London, England and Wales (McMichael *et al.*, 1998) suggested that heat related excess mortality was proportionally higher in deprived areas. More recently research by the Joseph Rowntree Foundation described the factors that make groups that are vulnerable to heat stress overlap with certain communities of disadvantage e.g.

- *"Low income jobs are more likely to involve outside labour or long hours spent in confined spaces such as driving cabins (TUC, 2009) which increases exposure to heat.*
- *Low income groups may be more likely to suffer from poor health in general, which could increase sensitivity to heat.*
- *Low income householders are also more likely to live in social housing and have lowered capacity to adapt their homes either for tenure or affordability reasons, which reduces their capacity to adapt to high temperatures"* Benzie *et al.*, 2011, p 59.

For those parts of the UK that may suffer from an increased risk of overheating, these are important considerations for health, social and built environment aspects of adaptation planning.

Figure 6.12 Number of properties in England and Wales in the highest 20% of deprived areas at significant risk of river (baseline 1961-90) and tidal (baseline 2008) flooding



6.4 Emergency response

Emergency services may have to respond more frequently to extreme events and the severity of these events may also increase. Flooding events (particularly for areas affected by tidal flooding) could be expected to be the greatest concern in the near-term (2020s), with increased frequency of heatwaves and wildfires becoming a greater concern in the medium to long-term (2050s to 2080s)[95].

6.4.1 Floods

Emergency services (police, fire and rescue and medical) respond to a range of flooding incidents, which can vary from a single property or small group of properties to widespread flooding on a regional scale as for example occurred during the widespread floods across the UK in summer 2007.

Although the precise location of future floods cannot be determined a long way in advance, areas at risk of flooding in the future can be identified, as can the magnitude of the risk, the nature of the flooding and the potential impacts. The analysis carried out for the CCRA shows that the distribution of potential floods is not uniform across the country, but concentrated in particular areas. In addition, emergency responses are also concentrated over small periods of time. For example, 60% of the Fire and Rescue Service response in South East Wales to flooding incidents over the one year period between 1st July 2008 and 1st July 2009 was concentrated in a three day period. In addition, patterns of disorder change during natural disasters putting a greater strain on emergency services. This was highlighted for example following the summer 2007 floods where arguments and tensions within communities were caused by the scarcity of drinking water (Pitt, 2008).

Climate change may increase the frequency and severity of all types of flooding, and the frequency of flooding incidents may increase for all scales of event, from minor flooding to major widespread flood events. Flood risk is, as stated above, not uniform, and (for example) flat areas adjacent to existing floodplains may see a significant increase in the area and population at risk of flooding. Areas not currently at risk may also become vulnerable to flooding in the future. As a result the Emergency Services would have to respond to more events, both minor and major.

Based on the assessment described in the Flood and Coastal Erosion Sector Report, the number of people at significant risk of river flooding is estimated to increase from about 900,000 to 2.3 million by the 2080s (Medium emissions scenario, central estimate), with a comparable increase in the number of residential properties at significant risk of flooding[96]. This indicates the significant increase in effort that would be expected from the Emergency Services. On the assumption that the effort required by the Emergency Services is in direct proportion to the numbers of people or/and properties at risk, the figures suggest an approximate 2.5 increase in effort by the 2080s. Costs may also increase at a similar level, although potentially could be higher considering the greater effort that would be anticipated for the most severe events. In addition, an increased risk of flooding of hospitals would put an increased burden on the emergency services (particularly medical), with (for example) a 40% increase in the

[95] This does not mean that flooding will become less significant than heatwaves.
[96] The CCRA has not considered pluvial flooding, therefore these figures will almost certainly be an underestimate. However, the proportional change in effort outlined for the Emergency Services outlined is unlikely to be noticeably different from the estimates given.

numbers of hospitals at significant risk of flooding by the 2080s (Medium emissions scenario, central estimate).

6.4.2 Heatwaves

Heatwaves can have a number of health impacts. They have been shown to:

- Increase the incidence of respiratory and cardiovascular illnesses;
- Cause dehydration;
- Cause heat cramps caused by fluid and electrolyte imbalances;
- Cause heat stroke, which can result in organ failure, brain damage and death;
- Be linked to mental stress, violent behaviour and suicides;
- Increase alcohol consumption; and
- Increase the number of accidents, such as road traffic accidents and drowning.

Although there is wide evidence that heatwaves cause an increase in the number of (premature) deaths (Schwartz *et al.*, 2004, Donaldson *et al.*, 2002), the evidence is less clear for heat related emergency admissions (as noted in Section 6.2.2). However, there is evidence for heat related increases in emergency admissions for respiratory and renal disease in children under 5 years of age and for respiratory disease for those over 75 years old.

During the August 2003 heatwave there were an estimated 2,000 more deaths in England and Wales than for the same period averaged between 1998 and 2002. Most of the excess deaths were concentrated in the south east of England, particularly in London and most notably among those over 75 years old. Hospital admissions in London, however, showed no increase for those under the age of 75 (Johnson *et al.*, 2004) [97].

However, it remains reasonable to suggest that more frequent heatwaves would be expected to lead to an increase in patient days per year in hospital in the UK due to heat-related illness and it has been suggested that associated with this there would also be expected to be a corresponding increased demand for emergency services. Included with this, there may be situations under a warmer climate where emergency services may be required to respond to other events triggered or exacerbated by high temperatures, such as wildfires (see Section 6.4.3).

The number of times regional temperatures are projected to exceed trigger temperatures[98] specified by the regional Heatwave Plan for two days or more were used to assess the probable response of the emergency services to heatwaves. This analysis indicated a potentially significant increase in effort required by the Emergency Services, particularly by the end of the current century. Although heatwaves may currently be expected every few years, by the 2080s heatwaves may occur during most years, with some regions expecting more than one a year. On a regional basis, it is anticipated that heatwaves would occur on average six times more often by the 2050s and nine times more often by the 2080s. This also increases the probability that during a heatwave there will be other events that are exacerbated by the high temperatures. By the 2080s the effort required by the Medical Emergency Services in particular may be more than ten times greater.

[97] In the 2003 heatwave there was an increase in the number of emergency hospital admissions for those over 75 years of age, but a reduction in the emergency hospital admissions for the age range 65 to 74, which meant that the overall increase in emergency hospital admissions was only 1%, although there were significant regional variations.
[98] Regional temperature time series were based on data sets provided for this project by Armstrong *et al.* (2010).

A further consideration is the effect of heat upon social behaviour. Although warmer weather would generally be expected to have a positive effect on mood and social interaction, there is evidence of episodes of hot weather being associated with a variety of negative effects. In particular this includes an increase in the occurrence of violent and property crimes (e.g. Michael, 1986) as well as outbreaks of more widespread civil disturbance (e.g. US Riot Commission, 1968). However, this relationship appears to be curvilinear, and these effects start to reduce beyond a certain temperature (Baron, 1978).

6.4.3 Wildfires

As discussed in Section 3.2.6, the risk of wildfires could also increase in hotter, drier conditions. It is estimated that the risk of wildfires in the UK could increase by between 10% and 50% by the 2080s.[99] This increased risk of wildfires varies across the UK, with the greatest increase (over 40 %) occurring in the South East of England and extending into south Wales. The smallest increases in the index are along the north coast of Scotland.

It should be noted that this is just an increase in the conditions that have the potential for wildfires, but that an event also requires a trigger. Although there are natural causes of wildfires, such as lightning, most wildfires are the result of human actions. Therefore, there is a greater risk of wildfires during periods of the year when there is greatest human activity, such as bank holidays and school holidays.

Wildfires occur mainly during a few months of the year (presently during spring and autumn). It is anticipated that the main period for wildfires would be in the autumn and that the wildfire season may extend later in the year. This would be due to a combination of factors including a preceding dry summer period and plant growth. However, this does not mean that wildfires would not happen at other times of year, especially during periods of increased human activity.

Based on projections for increased wildfires, the number of incidents attended by Fire and Rescue Services may also increase by up to 50% (depending on location) by the 2080s. However, these would be concentrated within the wildfire seasons, which may put significant pressure on services during these months.

6.4.4 Extreme winters

The climate change projections for the UK have projected warmer winter temperatures and so it has been assumed that the incidence of extreme winter weather will reduce with a corresponding reduction in the load on the Emergency Services. This also includes a significant reduction in the number of days where temperatures fall below zero degrees. However, recent work (Petoukhov and Semenov, 2010) suggests that the situation may be more nuanced. They argue that the reduction in winter sea ice in the Barents-Kara seas can heat the lower layers of the atmosphere and hence affect the weather systems over Europe. Using a general circulation model they have shown that this could lead to an increased probability of cold winter extremes[100]. An analysis of climate model simulations and observations by Kodra *et al.*, (2011) also indicates that extreme cold events would probably persist over the rest of this century, and possibly increase in some regions (Vavrus *et al.*, 2006) even though mean winter

[99] Based on McArthur Forest Fire Danger Fire Index results for the UK using UKCP09 projections.
[100] This would be expected to substantially reduce the estimates of premature deaths avoided estimated in Section 6.2.3. Colder winters than those currently experienced or greater variations between winter and summer temperatures could even “increase” winter deaths, resulting in cold related mortality being classified as a risk rather than an opportunity.

temperatures are projected to significantly increase. This raises the possibility that the recent cold winters may not an anomaly, and that in the future extreme cold winters or spells may persist or even increase putting greater pressure on the Emergency Services. This is an area for future research and monitoring.

6.4.5 Local resilience

Understanding how local communities work effectively is an important factor for both resilience to climate risks and for adaptation as a part of the development of sustainable local communities.

The Civil Contingencies Act 2004 required the setting up of local resilience forums around the UK which would integrate emergency management procedures in the event of an extreme event. This co-ordinated response allows responders to access a forum to consult, collaborate and disclose information with each other to facilitate planning and respond to emergencies. Community risk registers also allow resilience forums to prioritise their response based on impact as well as potential likelihood. Community Flood Groups and Community Flood Plans now exist in some parts of the country, with the Flood Groups usually comprising a formal structure that includes representation from local and County councils.

As part of this Act, organisations at the core of the response to most emergencies must provide Business Continuity and Major Incidence Plans that aim to ensure the sustainability of services in all circumstances to the benefit of those affected. Within the health sector for example, this includes the NHS Emergency Planning guidance (DoH, 2005) and the NHS Resilience and Business Continuity Management Guidance (DoH, 2008), which aim to ensure the sustainability of the health care service in all circumstances to the benefit of patients and communities. Similar guidance documents also exist for Scotland, Wales and Northern Ireland.

Concern about the impacts of extended periods of high temperatures on health has also led to the production of the Heatwave plan for England, which was initially launched in 2004 and updated annually, as well as a similar plan for Wales.

In addition, civil contingencies legislation has been a significant development for the voluntary sector in clarifying its contribution to emergency planning and civil protection within the UK. The Act, Regulations and Guidance require Category 1 responders "to have regard" to the activities of voluntary organisations in the course of carrying out their emergency and business continuity planning duties. Voluntary sector organisations make their resources available to Category 1 and 2 responders, through their Local Resilience Forum/Strategic Co-ordination Groups.

As Category 1 responders consider the implications of reduced funding, they are displaying increased interest in the capability and capacity of the voluntary sector to contribute to local emergency planning and response, particularly community resilience and recovery.

6.5 Climate induced migration

Climate change-related migration, if it becomes significant, could have an impact on UK demographics and influence the health needs of the population. The evidence, however, is weak regarding the extent to

which global migration will increase in the future and whether the UK would be significantly affected.

Developed countries are seen as the main destination of migrant flows in many studies after floods (Perch-Nielson, 2008), although change-related migration trends are difficult to assess (Foresight, 2011d). However, if immigration to the UK is affected, especially in the event of 'catastrophic' climate change, with large overseas areas being severely affected and uninhabitable, then the influx of new immigrants might change the proportion and composition of ethnic groups in Britain (Foresight, 2011d).

A number of climate change migrants may arrive with limited financial resources. Socio-economic deprivation in general tends to be associated with a lower health status which includes standard of living, lifestyle and occupational risk factors and barriers in access to health services (which can be language, educational or financial barriers). These new immigrants may therefore present a range of challenges for health services, although many of these challenges will probably be similar to those of existing immigrant communities.

Immigration could affect the disease burden of the UK, since many of the particularly vulnerable areas of the world also have a higher rate of endemic disease and immigrants from those areas may enter the UK with pre-existing disease or higher risk factors for developing the condition after they have settled in the UK. For example, tuberculosis is especially prevalent in sub-Saharian Africa and South-East Asia (WHO, 2010), HIV infections are most prevalent in sub-Saharian Africa (UNAIDS/WHO, 2008) and almost 80% of people with diabetes live in low or middle-income countries (WHO, 2009). However, some of these differences in risk factors are associated with lifestyle choices and public health conditions in the originating country, and may disappear after the first generation.

On the other hand, an influx of immigrants could also have some benefits for the UK. For example, as population growth trends are higher in the developing world, immigration could contribute young people to what is expected to be an ageing UK population. Immigrants may also add to the workforce, including staff in the health services.

The impacts of climate change overseas might also have an indirect effect on mental health in the UK. This effect would probably occur mainly through immigration of populations with mental health conditions that were either pre-existing or due to the migration process itself. For example, adverse psychological and psychosocial outcomes are well documented in the aftermaths of natural disasters (such as major depression and post-traumatic stress disorder (Galea, 2007)). Should either temporary or permanent migration occur into the UK as a result of extreme weather events it is possible that migrants would be at increased risk of mental ill health (Page and Howard, 2010) and may be in need of psychological support.

Another potential cause of mental stress in migrant populations can be culture shock. Most of the migration is expected to occur from the developing world to the developed world, and there are different cultural norms of family size. Family planning programmes, for example, would need to respect and protect human rights.

6.6 Evidence gaps

To improve the characterisation of the risks due to climate change there is a need for a better understanding of the physiological response to temperature and the implications for human activity and mental health,

as well as mortality. Improved understanding of ozone concentrations and UV exposure are also needed.

Key areas where further work could (a) increase understanding of the impacts of climate change, (b) help remove uncertainties regarding their scale and nature, and (c) aid climate change adaptation in relation to Health and Wellbeing include:

- Although significant progress has been made in recent years researching the mental health effects of flooding, little is known about the effects long term. The methodology commonly used in flood studies uses the GHQ-12 to assess mental health effects. Although this methodology indicates that a mental health effect has occurred, it is unspecified and gives no indication of the nature or severity of the effect.
- Important knowledge gaps exist in relation to long-term anxiety and depression, as well as the indirect effects on mortality and the use of health care services following a severe weather event (Kovats and Hajat, 2008).
- The relationship between temperature related mortality, deprivation and social capital is very complex and not possible to characterise within this assessment. It is also believed that there is limited published research in this area (Wolf *et al.*, 2010, Hajat *et al.*, 2007, Wilkinson *et al.*, 2004).
- There is limited published evidence on cold mortality thresholds in the UK. This means that estimates are unreliable and can vary significantly between different studies.
- No known research has been carried out on temperature mortality response relationships for Scotland and Northern Ireland.
- There is limited published evidence on hospital patient days related to either temperature or temperature related deaths.
- A surveillance system is required for the rapid monitoring of temperature and mortality.
- Little work has been carried out on the effects (including mental stress) of extremes of temperature on vulnerable groups such as older people and the most effective ways of reducing these effects.
- There is no known quantifiable research on how people's behaviour would change as a result of projected warmer temperatures, and how the consequent risk in terms of UV exposure would change as indicated by Autier *et al.*, (1994) and Elwood and Jopson (1997).
- Little research has been carried out on the relationship between extreme event flooding and storms and the link to deaths and injuries.
- More research is required on future ground-level ozone concentrations and how climate change might affect them.
- There is a lack of concrete evidence on potential prolonged exposure to aeroallergens such as pollen. The effect of climate change on winter air pollution (nitrogen dioxide and PM10) has not been investigated, as this would require extensive modelling work and large input datasets.
- More research is required on the disruption to maintenance work as a result of heatwaves and algal growth in buildings.

- A surveillance network to ascertain the potential risks of *Vibrio* pathogens in UK waters needs to be established.
- More research is required to better understand the cause-effect pathways that determine bloom formation in HABs.
- A more thorough assessment is required for all catchments of the risks associated with releases from CSOs and the consequential changes in associated illnesses (Norovirus) at the coast.
- More research is required on the types of hospitals (as well as other buildings) that are more safe under different climatic conditions.
- The cost-effectiveness of different adaptation options for the National Health Service needs to be investigated.
- Little research has been done on the joint occurrence of extreme events, such as a heatwave occurring at the same time as poor air quality.

6.7 Summary

The dominant health risks relate to extended periods or extremes of hot or cold weather and flooding. Other risks that may potentially increase include impacts due to ground-level ozone and UV exposure for which the evidence is currently limited.

Future wellbeing is most likely to be influenced by the following projected changes in climate; warmer summers (both positively and negatively), warmer winters (positively), increased flooding and other extreme events (negatively).

The health sector faces a number of challenges which are not directly associated with the climate, but could be more difficult to tackle in a changing climatic environment. These include:

- An ageing population and the increasing health care expenditure required for treating the elderly;
- Inequity in the use of health care (including hospital services) and wider social inequalities;
- Risk from infectious disease outbreaks and global trends in communicable diseases;
- Risks related to new technologies and environmental hazards;
- Pressures caused by the obesity epidemic, alcohol, tobacco and illicit drug abuse;
- Health staff shortages; and
- Financial risks posed by global economic crises.

Climate change could magnify some of these risks, and this may have a disproportionate effect on the elderly and those in poor health. Some health inequalities may also be exacerbated as a result of climate change due to disrupted

access to services, availability of cooling devices etc. Tackling these social inequalities must therefore go together with tackling climate change (Marmott Review, 2010).

However, not all impacts show a strong link to climate change. Ground-level ozone for example is more sensitive to changes in atmospheric emissions (of nitrogen oxides and volatile organic compounds) in the UK and abroad.

In this assessment, the current climate vulnerabilities, including estimates of the current risks in the sector, have been analysed and compared with future risks. These risks may increase gradually with time if unmitigated, and there is no clear evidence of onset timing. In some cases, where exposure-response thresholds apply (e.g. heat-related mortality), future impacts on public health may be significantly larger for greater or more rapid changes in climatic conditions. Although England and Wales already have Heatwave Plans in place, similar to plans adopted in other European countries after the severe heatwave of August 2003, rapid changes in climatic conditions may result in the need for a change in policy.

Certain risks will probably not be evenly distributed across the UK. Currently, urban areas (London in particular) and the warmer parts of the UK, namely the East and South East of England appear to be more affected by heatwaves and heat-related mortality. A reduction in cold-related mortality and morbidity has more of an effect in the south-east and south-west of England. In a future climate (without taking adaptation into account), heat-related mortality and morbidity may increase more in large urban areas partly as a result of the urban heat island effect.

Ground-level ozone concentrations and related health impacts are greater in the south east of England due to the high population density in this region compared to the rest of the country (except for London). Rural and suburban areas usually experience higher concentrations of ozone than city centres, which explains the relatively small health impacts due to ozone in London. A future increase in ground-level ozone attributable to climate change may be larger in urban areas, especially in the south east, although this trend is still uncertain and heavily dependent on global emissions of precursor gases.

Coastal and river areas will remain at a higher risk of flooding and related physical and mental health impacts. Finally, there is evidence that an increase in UVB radiation flux associated with climate change, and potentially the incidence of skin cancers, may be largest in southern England.

Climate change adaptation needs to be a material consideration in the design, building and maintenance of NHS infrastructure, as well as in allocation of resources, procurement and training. The Department of Health has produced a Climate Change Plan (2010-2012) which includes a Departmental Adaptation Plan and a Carbon Reduction Delivery Plan providing an analysis of the priorities and needs in the health sector in England in the medium and longer term.

Key links to other CCRA risks / reports

The risks of climate change for the health sector are intrinsically linked to risks in other sectors, such as water, floods, built environment, agriculture, energy, etc. For example, any unmitigated climate-related impacts on food or water quality and availability would have knock-on effects on public health.

Extreme weather events (such as floods and heatwaves) causing disruption in ICT communications, power generation and distribution, or public transport would probably affect NHS services, including access to hospitals, care homes and surgeries. Furthermore, adaptation/mitigation measures in the built environment, transport,

energy, water, agriculture and other sectors will have implications for population health. For example, active travel and reduced car dependency would help reduce obesity as well as greenhouse gas emissions.

Other drivers

Socio-economic drivers of climate change risks in the health sector include the following:

- An ageing population would be expected to be less resilient to changes in climate and associated weather events (such as heatwaves and floods). The ageing of the UK population, which is projected to continue during the 21st century, would be expected to put an additional burden on health and social care services.
- Several socio demographic factors pre-dispose to mental health effects following floods, in particular prior health problems.
- A prolonged global economic crisis could pose budgetary constraints in the health and social care services, which would affect the availability of resources for mitigation/adaptation measures. Increased unemployment and lower living standards due to an economic crisis would affect population health (physical and mental).
- Availability of funding and resources would affect the resilience of the built environment, e.g. availability of cooling measures, including natural ventilation, passive cooling etc in the current and future building stock.
- Effective control of anthropogenic atmospheric emissions (mainly nitrogen oxides and volatile organic compounds) affecting ground-level ozone in the UK would depend on future transport, energy generation, industrial and commercial activity across the northern hemisphere and indeed globally.
- Behavioural patterns would be influenced by the availability of time and resources. A more affluent population would be expected to spend more time in leisure and outdoor activities, potentially involving increased exposure to ground-level ozone and sunlight / UV radiation over the summer.
- The projected changing ethnic mix of the UK, with a relative increase in non-white ethnic groups (particularly the young) (Employers Organisation, 2004[101]), would be anticipated to reduce skin cancer cases and deaths. However, this would be expected to be offset to a degree by a greater increase in population in the south relative to the north, where risk to UVB exposure is greater.
- International tourism, travelling and trade would be expected to increase the risk of UK citizens being infected by vector-borne (e.g. malaria) and water-borne (e.g. diarrhoea) diseases during stays overseas. This trend may increase in the future.
- UK citizens living overseas may repatriate due to climate related or other pressures. This would place an additional burden on the NHS.

Some aspects of globalisation, such as the international nurse and doctor migration, may put pressures on health care services in the UK and abroad.

[101] The Office for National Statistics has not yet produced official population projections for ethnic groups. The data from this study is based on superseded census data; however, the conclusion reached here is unlikely to change based on any updated official figures.

Table 6.1 Scorecard for health and wellbeing

Metric code	Potential risks for health and wellbeing	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE5	Decline in winter mortality due to higher temperatures	M	3	3	3	3	3	3	3	3	3
HE6	Decline in winter morbidity due to higher temperatures	M	3	3	3	3	3	3	3	3	3
BE9	Reduction in energy demand for heating	L	1	2	3	2	3	3	2	3	3
HE10	Effects of floods/storms on mental health	M	3	3	3	3	3	3	3	3	3
FL12a/b	Hospitals and schools at significant risk of flooding	M	2	3	3	3	3	3	3	3	3
HE1	Summer mortality due to higher temperatures	H	2	2	3	2	3	3	3	3	3
HE2	Summer morbidity due to higher temperatures	H	1	2	3	2	3	3	3	3	3
WA3	Reduction in water available for public supply	M	1	2	3	2	3	3	2	3	3
FL2	Vulnerable people at significant risk of flooding	M	2	2	2	2	2	3	2	3	3
BE3	Overheating of buildings	H	1	2	2	2	2	3	2	3	3
MA2a	Decline in marine water quality due to sewer overflows	M	1	2	2	1	2	3	2	3	3
WA5	Public water supply-demand deficits	M	1	1	2	1	3	3	2	3	3
FL1	Number of people at significant risk of flooding	H	2	2	2	2	2	2	2	2	3
WA6	Population affected by water supply-demand pressures	M	1	2	2	1	2	2	2	2	3
HE3	Extreme weather event (flooding and storms) mortality	M	1	2	2	2	2	2	2	2	2
BE5	Effectiveness of green space for cooling	M	1	1	2	1	2	3	2	3	3
WA10	Combined Sewer Overflow spill frequency	L	1	1	1	2	2	2	3	3	3
BD12	Wildfires due to warmer and drier conditions	M	1	1	2	1	2	3	2	2	3
HE9	Sunlight/UV exposure	L	1	1	1	2	2	2	2	2	2
HE7	Extreme weather event (flooding and storms) injuries	M	1	1	1	1	2	2	1	2	2
WA4	Change in household water demand	M	1	1	1	1	1	2	1	1	2
HE4a	Mortality due to summer air pollution (ozone)	M	~	~	~	~	~	~	3	3	3
HE4b	Morbidity due to summer air pollution (ozone)	M	~	~	~	~	~	~	3	3	3
BE1	Urban Heat Island effect	H	Too uncertain*								
MA2b	Risks of human illness due to marine pathogens	L	Too uncertain								
MA1	Risk of Harmful Algal Blooms due to changes in ocean stratification	L	Too uncertain								

**This is because magnitude is site specific*

M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

7 Buildings and Infrastructure

Overview	
• The built environment and national infrastructure have already been identified as priority areas for adaptation (ASC, 2010). This assessment shows that flooding is already a major risk. Overheating of buildings and water scarcity are likely to emerge as significant risks by the 2050s. • Buildings and the main infrastructure sectors (energy, transport, water and information and communications technology (ICT)) are highly interdependent. Vulnerability in one sector can influence others and failure of critical infrastructure components may lead to 'cascade failures' with significant consequences. • Energy policy is a major socio-economic driver affecting not only the energy sector, but all sectors that are dependent on energy, including transport, water ICT, businesses and buildings. As the UK moves towards a low carbon economy, vulnerability to climate change is likely to change presenting both threats and opportunities for buildings and infrastructure. • Decisions in the public and private sector on the location and resilience of new buildings and infrastructure, on refurbishment of existing buildings, and on how we shape and maintain the urban environment and public realm will have a substantial impact on future climate vulnerability. • Examples of threats and opportunities considered in this chapter include the following:	
Threats	**Opportunities**
• Increased flooding may affect a significant proportion of buildings and infrastructure. • Increased summer temperatures may affect conditions in buildings and the urban environment and may lead to heat related damage and/or disruption to energy and transport networks. • The 'Urban Heat Island' effect may become more common and more significant in large cities and may increase demand for cooling. • Changes in water availability, particularly reductions in the summer, without intervention may lead to a need for demand control measures, affecting the public, businesses and industry. • Increased subsidence and landslip in some areas may affect sections of the transport network and buildings.	• Milder winters may reduce demand for heating, reducing costs for businesses and the public, and reducing carbon emissions. • In the long-term, milder winters may reduce cold weather related damage, delays and disruption and associated costs for infrastructure providers, businesses and the public (although the natural variability in the weather will mean that extreme events will still occur). • There may be further opportunities for innovative building services and urban planning in the UK and overseas, for example in the design of sustainable buildings and developments. • UK based infrastructure operators, consultancies and investors may have opportunities to capitalise on global climate change adaptation activity.

Figure 7.1 Summary of buildings and infrastructure impacts with an indication of direction, magnitude and confidence

Note: BE1 is too uncertain to assess UK-wide but has high confidence as the magnitude is site specific

High consequences (positive)
Medium consequences (positive)
Low consequences (positive)
Low consequences (negative)
Medium consequences (negative)
High consequences (negative)

High confidence
Medium confidence
Low confidence

Too uncertain to assess

7.1 Introduction

Buildings and infrastructure are long-term assets that are particularly important in the context of climate change adaptation. Decisions made now will shape the design of homes, cities and major infrastructure developments, which will still be around in fifty years time and in some cases to the end of the century. Action is needed to adapt our cities and make them more robust and resilient to extreme climate conditions.

Buildings and important parts of our transport, energy, water and information and communications technology (ICT) systems are vulnerable to flooding, extreme heat and other climate risks, such as landslides and potential water shortages during major droughts.

- Many towns and cities are located on river and coastal floodplains and the widespread flooding in Summer 2007 and in Cumbria in 2009 demonstrated the vulnerability of buildings, transport, energy and water infrastructure.
- Buildings and roads in our towns and cities store heat in the day time and release it during the night. This effect can contribute to buildings overheating in summer and, in major cities, causes the 'urban heat island' effect with evening temperatures several degrees higher than in the surrounding countryside.
- Extremely hot conditions can cause poor health and fatalities. They may also cause problems for rail systems, energy transmission and increase the demand for water and energy. In 2006 the peak electrical energy demand in the summer in London was greater than the peak winter demand for the first time (Mayor of London, 2010).
- National infrastructure, the design and renovation of buildings and land use planning form three out of the five priority areas identified by the Adaptation Sub-Committee (ASC) for immediate action.[102] The ASC stated that, in these areas, if the UK waits, it will be too late to effectively manage the risks of future climate change (ASC, 2010).

The UK's national infrastructure is defined by Government as 'those facilities, systems, sites and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the UK depends' (Cabinet Office, 2010b).

The Critical Infrastructure Resilience Programme recognises nine infrastructure sectors: energy, food, water, transportation, telecommunications, emergency services, health care, financial services and government. Each of these sectors has critical infrastructure upon which it depends and this was the focus of the first set of sector resilience plans completed in 2009.[103] This is a very wide definition with significant overlap with the other themes of this report, in particular: food is discussed as part of Agriculture & Forestry; emergency services and health care are discussed as part of Health & Wellbeing: and financial services are discussed as part of the Business theme.

For the CCRA infrastructure has been considered as the physical framework for society including transport, energy supply, water supply, drainage and waste water disposal[104] and ICT. In the urban environment, infrastructure has also been used as a term that

[102] The other two priority areas are natural resources and emergency planning.
[103] http://www.cabinetoffice.gov.uk/resource-library/sector-resilience-plan-critical-infrastructure-2010
[104] Waste disposal (with the exception of waste water) was not identified as a priority area as part of this first CCRA. Therefore, is not discussed here.

includes local roads, paths, parks and other green space (often referred to as green infrastructure).

The built environment consists of man-made structures, especially buildings, together with their surroundings, including infrastructure. This is wider than just the urban environment, which is our towns and cities. Therefore, to differentiate between different aspects of the built environment, this chapter focuses on:

- Buildings
- The urban environment
- Energy
- Transport
- Water
- ICT.

This chapter draws on results for all the sector reports and other published work. As part of the introduction the importance of interdependencies and the capacity to be able to adapt are highlighted. This is followed by two sections that focus on risks to buildings and some issues of particular significance in the urban environment. Aspects of infrastructure are then examined. Discussion regarding the consequences of climate change for utility companies and their role within business supply-chains is provided in Chapter 5.

Given the move to a low carbon economy and the implications for power generation, the section on energy also includes a discussion of how such a transition may interact with climate change risks.

Figure 7.1, above, provides a summary of the risks considered as part of the more detailed assessment work in this study and provides an indication of how the magnitude of the Medium emissions scenario, central estimate changes over time. Further detail of the risks relevant to this theme, with more information on how the magnitude of the risks vary under different scenarios is provided in the scorecard at the end of the chapter (see Table 7.2).

7.1.1 Interdependencies

There are significant interdependencies between buildings, infrastructure and the urban environment. Resilience in one sector is dependent on the resilience in another. Examples include (but are not limited to) the following:

- Most modern buildings are reliant on the provision of energy and water;
- Power stations are reliant on the transport infrastructure to deliver fuel;
- Energy is required to run water treatment plants, pumping stations, wastewater treatment works, etc;
- Power stations cooled by freshwater are reliant on water infrastructure;
- Transport is not only reliant on fuel, but also electricity to fuel pumps and to power airports, train stations, etc;
- Transport, water and energy sectors are reliant on ICT for their monitoring and control systems;

- Flood warning systems (for both commercial and domestic users) are reliant on ICT;
- ICT is reliant on energy to power devices and enabling infrastructure;
- Workers in all sectors of infrastructure depend on transport to get to work;
- Access to properties for rescue and limiting damage during or following extreme events (such as flooding) is reliant on the transport network; and
- Emergency services are reliant on the transport network and dependent on such things as adequate water pressure for putting out fires.

These interdependencies are expected to increase in the future. For example, the smart grid[105] will mean that energy systems will become more reliant on ICT and the electrification of transport systems will mean transport will become more reliant on the national grid.

Buildings (or more literally their occupants) not only place demands on infrastructure (most significantly energy and water), but by improving their resilience to future changes in climate (such as providing adequate insulation and shading, recycling water, etc.) they can also impact positively on the infrastructure upon which they depend.

Infrastructure assets are also often located next to each other (above and below ground), which means that extreme weather events, such as flooding, have the potential to affect these assets simultaneously, which could have consequences for functionality at a national scale and can prove particularly problematic for emergency response and recovery.

Box 7.1 Examples of interdependencies of infrastructure for London

Experience in London has highlighted the importance of understanding the interdependencies in infrastructure and the impact that this has on the economic and social wellbeing of London.

Electricity - Electrical supplies are obviously critical to the economic function of London, but should supplies fail or be restricted the knock-on effects to other aspects of infrastructure can be severe. London's underground system is reliant on electricity not only for motive power, but also for lighting, telecommunications and for pumps to control water levels in underground parts of the network. Even if power were available for motive purposes the system could not operate if it lost power to other systems.

ICT - Large portions of London's economic activity are dependent on ICT. If power is lost this activity would be severely disrupted even if individual buildings have their own stand-by/emergency supplies. Similarly, the health and emergency services are also reliant on good quality power supplies to maintain essential operating and telecommunications equipment.

Roads - Disruption to London's road network due to local flooding can also have significant consequences. It is not just the local roads that may be affected, but access to depots and stations may be disrupted resulting in a loss of rail services with drivers not being able to get to their trains.

Assessment of the present and future risks facing UK infrastructure requires a detailed understanding of these interdependencies and safety critical elements (such as parts of fossil fuel or nuclear power stations and some electricity substations). It is not sufficient to measure the risk of individual elements alone, as this high degree of interdependency is liable to lead to 'cascade failures', where failure of one element of infrastructure can lead to other failures. For example, a flooded electricity substation

[105] http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/network/strategy/strategy.aspx

could lead to power cuts affecting the transport system and ICT, which in turn would have consequences for emergency responders and those they are attempting to assist in the surrounding flooded area.

However, this level of 'systems analysis' does not exist yet[106]; the UK Infrastructure Transitions Research Consortium (ITRC) has been recently commissioned to undertake pioneering research to address this issue over the coming five years.[107] Future CCRAs may be able to benefit from this, but in the absence of this level of systems knowledge at present, this assessment has focused on some of the potentially most vulnerable elements of UK infrastructure, in order to 'set the scene'.

7.1.2 Capacity to adapt

The effects of climate change on buildings and infrastructure will not be limited to direct impacts on assets from extreme events or long-term changes. As buildings and infrastructure play such a significant role within the economy, society and the environment, each is affected by and impacts upon the other.

Future use of buildings and infrastructure will be influenced by efforts taken towards climate change mitigation and climate induced changes in behaviour and demographics, including the urban-rural balance, an ageing population and a potential move to more home-working (Engineering the Future, 2011). Examples of future influences on buildings and infrastructure, other than climate change, include the following:

- The economy (within the constraints of legislation/regulation) controls the demand for fossil fuels and overall energy consumption. This can even manifest itself at the individual household scale; it has been widely reported that during recessions carbon emissions drop as people find it more difficult to afford to heat their homes and fuel their cars.[108]
- The net effect of increased home-working on the energy, ICT and transport infrastructure may be significant, but needs further research. The need for a better distributed ICT infrastructure is clear as home workers will need access to systems that rely on fast internet services.
- A low carbon future would have far reaching implications particularly for building design and renovation; transport type and usage; and energy generation and usage. The rising cost of carbon will affect every aspect of buildings and infrastructure. The links between this and climate change adaptation requires further research.
- Future regulations such as those resulting from the Water Framework Directive (WFD) and Bathing Water Directive may require higher levels of wastewater treatment and processing of larger pollutant loads due to higher populations.

In addition, many of the decisions related to buildings and infrastructure have long-term implications because of the design life of many of the structures involved, Box 7.2. This means that decisions being made now need to anticipate relevant consequences of climate change to limit the potential for maladaptation and increase overall system resilience.

[106] See Chapter 2 for more discussion regarding systems analysis
[107] http://www.itrc.org.uk/home/
[108] "Key stories 2009: The Carbon Crunch"
http://www.carbonoffsetsdaily.com/news-channels/top-stories/key-stories-2009-the-carbon-crunch-4294.htm

Box 7.2 Asset life of buildings and infrastructure

Buildings and infrastructure in general have relatively long operational lifetimes.

New homes have design lives of 60 years, but most of these will last well past 2100. Around 85% of today's homes are more than 20 years old. The service life of non-residential buildings is often expected to be shorter (around 30 years), but it could be longer in some cases.

The replacement of building stock is low, typically 1% per year. Therefore, around 70% of the buildings that will be in use in the 2050s have already been built.

Infrastructure also often has a relatively long design life, although individual elements may be replaced or upgraded fairly regularly. For example, many of the power stations built in the 1960s and 1970s are still operational today; and many of the water mains and trunk sewers still in use in the UK's largest cities are over 100 years old.

Changes and additions are continually being made to the UK's buildings and infrastructure, which provides an opportunity to factor climate change into their design. However, such changes form a minor part of the total existing stock. In view of this, the stock of buildings and infrastructure existing in 2050 is unlikely to be significantly different from present day.

This is particularly the case regarding location. The UK is densely occupied in relation to its overall land mass and consequently in its capacity to provide resources such as food, raw materials and energy. The location of buildings and structures is managed through spatial planning. New buildings and structures are developed primarily around existing patterns of settlement and activity, for two main reasons. Firstly, suitable land is generally in short supply, because the major part of land resources are needed for agriculture and resource supply. Secondly, the existing patterns of habitation and activities form a major consideration in decisions on further development.

In consequence, the scope for avoiding risk by replacement construction and use of new areas is in practice seriously limited. However, much of the risk posed to buildings and infrastructure reflects the current form and equipment of these structures and the extent to which they can be adapted. Reuse of structures in any case forms a normal part of development.

Cities include concentrations of people in more deprived areas (Chapter 2) that may be more vulnerable to climate change impacts, including flooding, heatwaves and any disruption or any increase in costs for services. For example, those in poor quality dwellings or workplaces will be least able to adapt these buildings in response to changing climate. Also social groups unable to afford heating or cooling to meet acceptable standards of thermal comfort are more vulnerable to major health impacts.

Should energy, water, transport and ICT providers increase investment in climate adaptation measures, this may have knock-on effects for customers. The costs to service providers of replacing infrastructure or making services more resilient to flooding and droughts, for example, may be passed on to customers. If these costs are large and shared with a small group (e.g. small customer base) over a short time period, there will be pressure for costs/tariffs to rise. Examples include:

- The costs of maintaining water supply and sewerage services in a changing climate, particularly in parts of the UK that are remote, have assets in poor condition or are exposed to higher levels of climate risks;
- The costs of improving the railways to make networks resilient to climate change by replacing assets and in some specific examples, developing new lines away from coastlines at risk of wave overtopping and flooding;
- Developing local flood risk and coastal erosion management measures for communities where cost-benefit ratios will fail to attract full government funding; and

- The costs of improving maritime weather forecasting.

Box 7.3 Adaptation Reporting Powers (ARPs)
The Climate Change Act 2008 gives the Secretary of State the power to direct reporting authorities (bodies with 'functions of a public nature' and 'statutory undertakers') to produce reports on what they are doing to adapt to climate change. It is essential that organisations that are responsible for important services and infrastructure are assessing the risks of climate change and making the necessary plans to respond, as part of their risk management processes. These reports were submitted and reviewed in 2011 and will contribute to the development of the National Adaptation Programme for England and reserved matters. Reporting authorities include (but are not limited to): the Water Companies in England (those in Wales prepared reports voluntarily); electricity generators, transmitters and distributors and gas transporters; Eurotunnel, Network Rail and Transport for London; Strategic Airport Operators; Harbour Authorities; and the Highways Agency (voluntarily). The first CCRA and ARP processes have run in parallel and although the outputs are complementary, the findings from each are not necessarily easily comparable. The CCRA is concerned with identifying risks at the national, strategic level, whereas most of the ARP reports have focused at the local or corporate level. Although some of the earliest ARP reports have been considered in the CCRA, it has not been possible to fully integrate the two evidence streams, primarily due to short timescales available. The outputs of the ARPs will be considered alongside the CCRA as part of the development of the National Adaptation Programme.

7.2 Buildings

Whilst extreme weather events remain the biggest threat to buildings in the near-term, projected higher temperatures and changing rainfall patterns would present other threats to the fabric, structure and performance of buildings in the medium to long-term. However, higher average temperatures would also reduce energy demand for heating in winter with potential benefits of reducing fuel poverty and carbon emissions.

7.2.1 Flooding

The current level of vulnerability of property and people to flooding is deemed to be high. For example:

- Approximately six million UK properties (or one in six of all properties) are currently exposed to some degree of flood risk, with 600,000 properties in areas at significant likelihood of river and tidal flooding in England and Wales alone.[109]
- Present day Expected Annual Damage (EAD) to residential and non-residential properties is of the order of £1.3 billion for the UK as a whole. The EAD is an estimate of the average annual damage to property and contents. The total damage could be much higher if other assets and indirect and intangible losses are included.

[109] Significant likelihood is defined as having an annual chance of flooding (to any depth) greater than 1 in 75.

Many of the properties exposed to a degree of flood risk are in areas with flood defences. However, the current system of flood defences will deteriorate over time and will require significant future investment to maintain, repair and replace if current levels of protection are to be maintained.

About three million properties are at risk of flooding from rivers or the sea and four million from surface water flooding. About one million of the properties at risk of flooding from rivers or the sea are also susceptible to surface water flooding, giving the overall total of six million properties referred to above. Flooding from groundwater also poses a threat in some areas, adding still further to the risk.

Whilst surface water flooding is recognised as a major source of flood risk, it has been difficult to explore the impact of climate change owing to a lack of suitable information on future flooding. Projected increases in rainfall intensity and volume are likely to increase the already considerable risks from surface water flooding.

The nature of flooding from the sea, rivers and surface water is different. Flooding from the sea and large rivers can be very extensive, with deep water and high flow velocities. In contrast, surface water flooding is generally shallow. However urban flood waters are often polluted by sewage leading to additional risks to health, higher repair costs and longer periods of disruption.

The number of properties at significant likelihood of flooding, both from rivers and the sea, is projected to increase throughout the UK based on changes in peak river flows and sea level rise. The frequency of flooding is also projected to increase. For example, the frequency of river flooding may increase by about 2 to 4 times by the 2080s (central estimate) and as much as 3 to eleven times in the more extreme scenarios (Table 3.7).

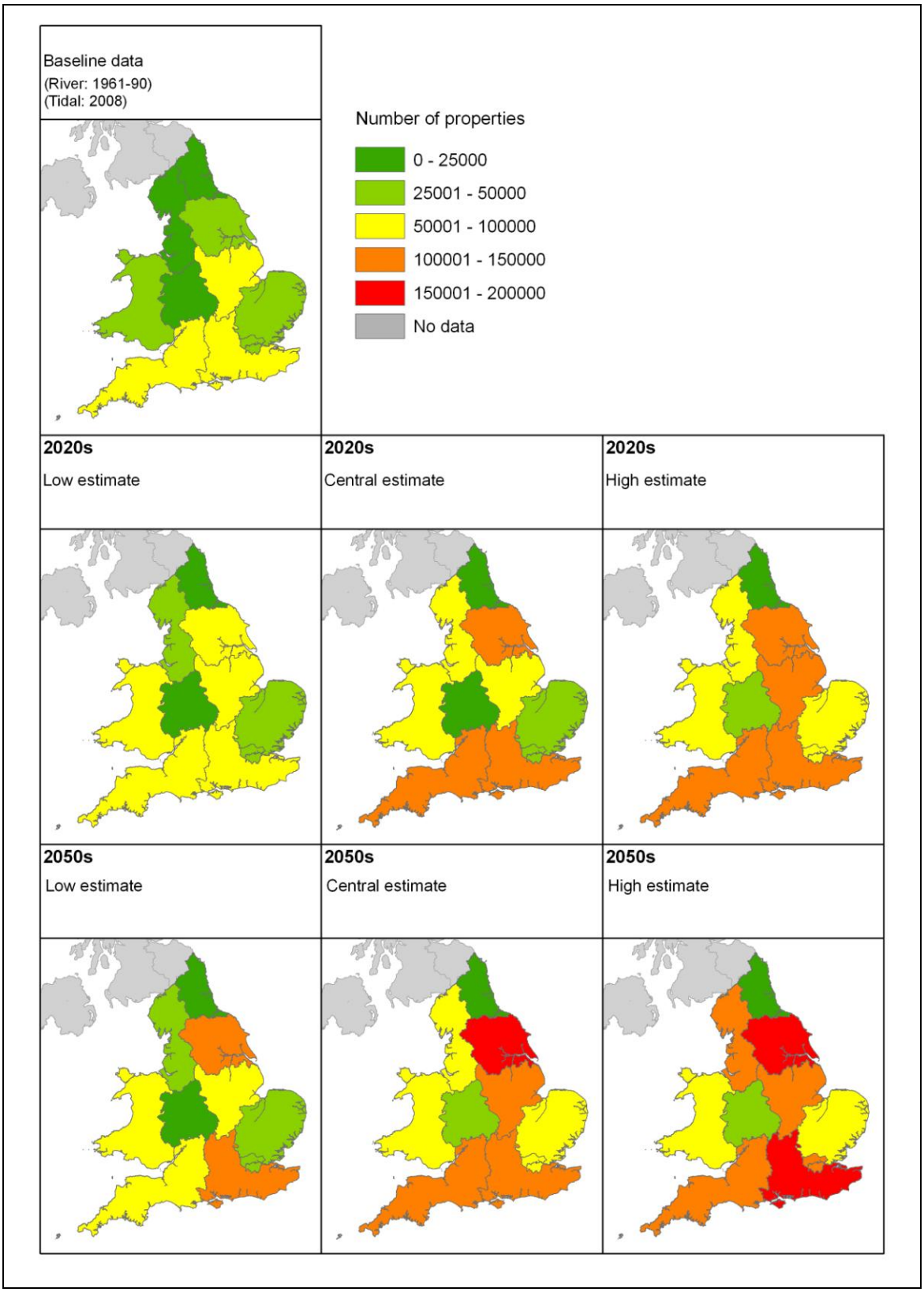
The assessment of flood risk for the CCRA has assumed that there are no changes in the existing flood and coastal erosion risk management measures; the analysis includes the current flood defences and protection against coastal erosion, but does not include any future changes as a result of adaptation policies. This means that the projections given here do not take account of the risk reduction benefits of future measures or the increase in risk that would occur as existing flood defences and other assets deteriorate.

The number of residential properties at significant likelihood of tidal or river flooding (in the absence of any adaptation) in England and Wales[110], based on current population figures, is projected to increase from around 370,000 to almost 900,000 by the 2050s under the Medium emissions scenario, central estimate (with a range of approximately 530,000 to 1 million). Based on the principal population projections, this would rise to 1.1 million (with a range of 690,000 to 1.3 million).	High Confidence

Figure 7.2 shows the number of properties projected to be at significant likelihood of flooding in the near-term (2020s) and medium-term (2050s). The results indicate significant increases in risks for the north-west and Yorkshire and The Humber as well as the West Midlands by the 2050s.

[110] Suitable data was not available for Scotland and Northern Ireland to undertaken similar analysis. Significant likelihood is defined as having an annual chance of flooding (to any depth) greater than 1 in 75.

Figure 7.2 Numbers of residential properties at significant likelihood of flooding (river and tidal) in England and Wales



The present day Expected Annual Damages (EAD) to residential and non-residential properties in England and Wales at risk of flooding from rivers and the sea is estimated at £1.2 billion (£639 million residential and £561 million non-residential). This is an

estimate of the annual damage to property and contents. The total damages could be much higher if indirect and intangible losses are included.

The EAD of residential properties from tidal or river flooding in England and Wales is projected to increase from £640 million at present to over £1.1 billion by the 2020s under the Medium emissions scenario, central estimate (£750 million to £1.6 billion), by the 2050s this would increase to £1.6 billion (£900 million to £2.5 billion) and by the 2080s this would increase to £2.1 billion (£1.1 billion to £3.4 billion). These figures are based on current population figures. Based on the principal population projections, this would rise to £2.1 billion by the 2050s under the Medium emissions scenario, central estimate (a range of approximately £1.1 billion to over £3.2 billion).	High Confidence

The impact of river and tidal flooding in terms of EAD for residential properties in different areas of England and Wales is shown in Figure 7.3 The South East of England currently has the highest EAD for residential properties at risk, followed by the South West of England. The biggest projected increases in the future are in the South West of England, Yorkshire & Humber and the East Midlands.

Projections for non-residential properties (and in particular tourist assets) are discussed in Chapter 5.

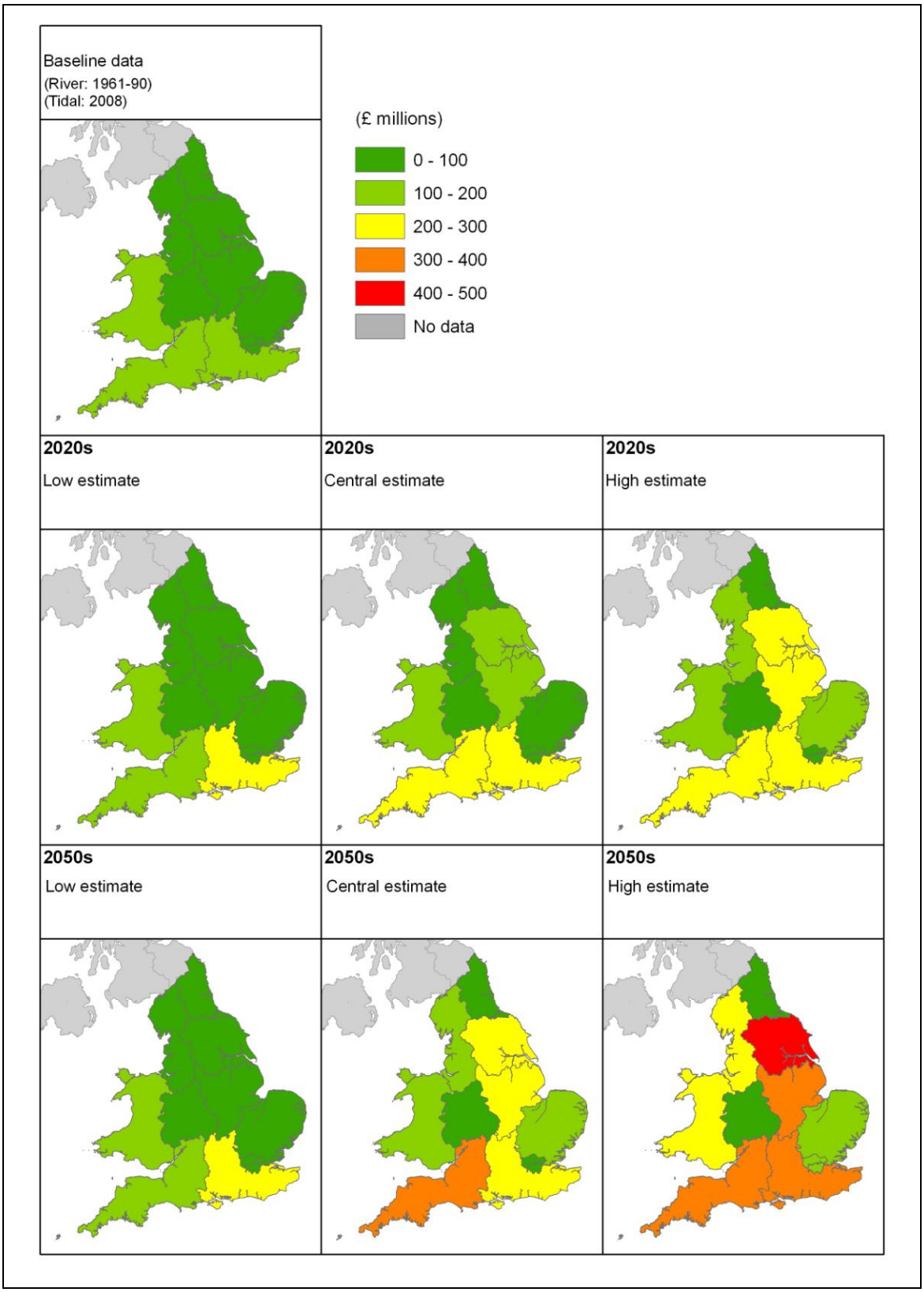
In order to understand some of the potential consequences of flooding of properties, the CCRA analysis also looked at the number of hospitals[111] and schools at significant flood risk. Both hospitals and schools have significant knock-on effects for society and the economy. For example, if staff and facilities are prevented from treating patients, this not only impacts on human health but creates additional business losses due to time off work, etc. If schools are closed this creates childcare problems for parents, which can also create additional business losses with parents having to take time off work. It is estimated that currently 53 hospitals (around 3,500 beds) are in areas at significant likelihood of river or tidal flooding. It is also estimated that currently 776 primary schools (151,000 pupils) and 151 secondary schools (112,000 pupils) are in areas at significant likelihood of river and tidal flooding.

The number of hospitals in England and Wales in areas at significant likelihood of river or tidal flooding is projected to increase from 53 to around 77 by the 2050s based on the Medium emission scenario, central estimate (range from 59 to 89). The number of primary and secondary schools in England and Wales in areas at significant likelihood of river or tidal flooding is projected to increase from 927 (approximately 263,000 pupils) to around 1,400 (approximately 385,000 pupils) by the 2050s for the Medium emissions scenario, central estimate (range 1,019 to 1,654).	Medium Confidence

A further 3 million properties could be susceptible to surface water flooding alone. Flooding from groundwater also poses a threat in some areas, adding still further to the risk (although groundwater is not addressed in the analysis). Whilst surface water flooding is recognised as a major source of flood risk, it has been difficult to explore the impact of climate change owing to a lack of suitable information on future flood risk. Significant increases in rainfall intensity and volume are likely to increase the already considerable economic risks from surface water flooding. In addition, many urban drainage systems are combined sewer systems and urban flood waters are often polluted leading to additional risks to health, higher repair costs and longer periods of disruption.

[111] This does not include health centres, GP practices or flooding of access routes to hospitals.

Figure 7.3 Projected EAD for residential properties at significant likelihood of flooding (river and tidal) in England and Wales



Homes at significant risk in the floodplain may have difficulty getting affordable flood insurance and this in turn could affect mortgage provision. The projected increase in flood insurance claims due to flooding and potential reduction in mortgage value of

properties is discussed in Chapter 5. Certain types of property may be particularly vulnerable to damage and the occupants of these properties may be at greater risk, Box 7.4.

Box 7.4 Vulnerability of buildings and their occupants

Flooding will not affect everyone equally as different parts of the country face different levels of risk. For example, remote locations in the floodplain are often distant from emergency support and are more vulnerable. There is also mounting evidence that deprived communities are both at greater risk and more vulnerable than others to flooding (Walker *et al.*, 2006; Fielding, 2007; Zsamboky *et al.*, 2011).

The type and quality of housing also influences the vulnerability. 'Risks to people' research has shown that serious harm and fatalities are more likely in camping and caravan sites, basement properties, bungalows and single storey buildings, because fewer options for occupants to evacuate or protect themselves are available during a flood (Defra, 2006a). Such properties may also be more difficult to make resistant or resilient to flooding and to dry out following a major flood, although there is still more research needed on the vulnerability and repair costs associated with different types of construction methods.

Buildings are an important part of our cultural heritage and historic buildings and monuments were highlighted by stakeholders as having a significant contribution to the attractiveness of the UK's built environment. Significant numbers of these properties are at risk from flooding. Analysis was undertaken into the flood risk for Scheduled Ancient Monuments (SAMs) to indicate the potential scale of this issue.[112] It is estimated that approximately 7,100 hectares of SAM sites are currently at significant risk of river or tidal flooding in England and Wales.

The area of SAM sites in England and Wales at significant likelihood of river or tidal flooding is projected to increase from 7,100 hectares to around 8,400 hectares by the 2050s (Medium emissions scenario, central estimate), ranging from 7,100 to 9,200 hectares across the range of projection estimates for the 2050s.	High Confidence

7.2.2 Overheating

Historically within the UK, building design (particularly of domestic properties) has been driven by the need for indoor thermal comfort in winter and more recently, by a desire for winter energy efficiency. The risk of summer overheating has not been regarded in the past as a significant problem in the UK.

Overheating depends on a number of climatic factors, primarily external temperature and incident solar radiation, and so there is a geographical variation in the risk; the risk in Central Scotland, for example, is lower than in South East England. Within dense urban areas, the risk of overheating is further exacerbated by the Urban Heat Island effect (see Section 7.3.1).

The risk of overheating also varies from building to building. Nevertheless, there is evidence that some types of building, such as highly insulated lightweight buildings and buildings with heavily glazed facades, are already vulnerable to summer overheating. With increasing temperatures and a higher incidence of summer heatwaves, the risks of overheating is projected to increase for all buildings.

[112] Scheduled Ancient Monuments are 'nationally important' archaeological sites or historic buildings that are protected under the Ancient Monuments and Archaeological Areas Act 1979. These do not include structures that are occupied as dwellings (these are usually designated as listed buildings), used as places of worship or protected under the Protection of Wrecks Act 1973.

An increase in the frequency of maximum daily temperatures exceeding 26°C[113] would increase the risk of overheating in buildings. By the 2050s, a maximum daily temperature of 26°C or above is projected to occur on approximately 50 days a year in London for the Medium emissions scenario, central estimate (a range of 25 to 92 days), compared to 18 days on average at present. For the north of England and Wales a maximum daily temperature of 26°C or above is projected to occur on between 13 and 21 days by the 2050s for the Medium emissions scenario, p50 estimate (a range of 5 to 49 days) compared to between 2 and 7 days at present.	High Confidence

While the precise performance of individual buildings is dependent on a number of factors specific to their design, in broad terms increasing periods of elevated temperatures would increase the risk of impaired productivity. The combination of overheating and warm weather periods has been observed by previous studies to produce two responses in the workforce: increased absenteeism and reduced productivity. The costs to businesses of this impact are discussed in Chapter 5.

It is projected that the number of staff days lost due to high internal building temperatures (based on 26°C[114]) would increase from current levels of around 5.1 million (0.1% of working time) to 7.8 million (0.16% of working time) by the 2020s (range 5.7 million to 10.8 million) and to 14.2 million or 0.28% of working time by the 2050s (range 7.4 million to 35.7 million).	Medium Confidence

The effects of high temperatures on general health and wellbeing are discussed in Chapter 6. However, there may be very specific issues for buildings with different uses, such as hospitals and schools:

- The projected rise in minimum night-time temperatures may particularly affect the performance of hospital buildings; overheating is already a problem for many hospitals, even in new constructions (SHINE, 2010). They differ from commercial buildings as they are occupied and staffed 24 hours a day, with wards often being maintained at warmer temperatures than a domestic bedroom overnight. This means that a rapid night purge[115], such as might be deployed in offices or schools, is not possible. In addition to this, hospitals have very specific requirements regarding air supply and circulation in order to control infection. Because of these unique characteristics, it is not possible to estimate the increase in risk of overheating of hospitals without appropriate evidence and location specific data. The De^{2}RHECC project[116] monitored internal temperatures over the summer 2010 for different buildings on a single campus in England. The results showed that the resilience of different buildings to overheating varied significantly depending on the types of construction used (De^{2}RHECC, 2010).
- The risk of overheating of school buildings varies significantly depending on the age and type of building, in a similar way to other types of buildings. The design of a good teaching environment requires a balance between good natural light, good acoustics and good indoor air quality and thermal comfort throughout the year. There are potential conflicts between these requirements, for example,

[113] Current CIBSE guidance (CIBSE, 2006) outlines an overheating threshold of 28 °C for any building space with the exceptions of bedrooms where the overheating threshold temperature is 26 °C. This threshold should not be exceeded for more than 1% of occupied hours. An external temperature of 26 °C has been used, rather than 28 °C, in order to allow for the effect of solar and internal gains on internal conditions in poorly performing buildings. This is also the temperature at which a reduction in productivity is observed.

[114] Projections based on a threshold of 28°C are also provided in the Business/Industry/Services Sector Report.

[115] The cooling of a building at night once it is no longer occupied, which can take the form of opening windows to allow the cool night air to pass through the building. As the air passes over the internal fabric of the building it removes the heat that has built up during the day.

[116] http://www.robusthospitals.org.uk/

large windows that allow high levels of daylight may lead to excessive solar gain in summer.

The design of buildings has developed over time to meet rising expectations of comfort. Materials and layout have been crucial elements until recent decades, when there has been a growing tendency to regulate conditions through equipment, including cooling, heating and air conditioning. This may have reduced the extent to which improved conditions are achieved through the design of the building itself. Equipment such as air conditioning also uses energy and the demand for energy for cooling is discussed in Section 7.4.3.

7.2.3 Subsidence

In the UK, large numbers of properties are at risk of subsidence. In 2009 there were about 30,000 notified domestic subsidence claims, with a total value of £175m.

In particular, clay soils with high shrink-swell potential underlie much of the densely populated areas of London and the South East of England.[117] Under climate change, changes to the present shrink swell pattern may occur due to higher temperatures and changes in rainfall patterns. However, the range in the projections is wide, reflecting the uncertainty in the projected changes in summer rainfall.

Older buildings and buildings with shallow foundations are at greatest risk. Modern buildings (post-1970) have better foundations and new developments should not increase the number of properties at risk, but given the low replacement rate of properties, a substantial proportion of buildings particularly in the domestic sector would remain at risk.

The average increase in number of households suffering subsidence in areas of England with shrink-swell clay soils is projected to be about 17% by the 2050s (Medium emissions scenario, central estimate). This ranges from a reduction of about 10% to an increase of about 30% for the range for climate change scenarios used in the analysis.	Medium Confidence

Whilst insurers cannot guarantee to maintain cover in all circumstances, regardless of the risk of future subsidence damage, it is considered good practice by the ABI to work with policyholder to identify action that might be taken to manage any ongoing risks, and hence maintain cover, wherever possible. This includes cover subsequent to a claim, if the repair work has been approved, and when the property changes hands.

7.3 Urban environment

Climate change poses several potential risks to the urban environment. As for buildings, this is primarily due to higher temperatures and changing rainfall patterns. The interrelated risks of the Urban Heat Island, building overheating and a reduction in the effectiveness of green spaces could be particularly affected by rising summer temperatures.

[117] Other areas can also be susceptible to subsidence, for example, the Vale of York and the Cheshire Plain. However, regions of the UK that are generally at low risk (North East, North West, West Midlands, Scotland, Wales and Northern Ireland) have not been analysed as part of this first CCRA.

7.3.1 Urban heat island

The temperature at the centre of a large city can be several degrees higher than in the surrounding rural areas, which is known as the Urban Heat Island (UHI) effect. Several factors contribute to the development of this urban microclimate. There is greater absorption and storage of short-wave solar radiation by the urban fabric during the day. This energy is then re-emitted at night as long-wave radiation. Surface water is typically drained away and is therefore not available for evaporative cooling. Anthropogenic heat emissions, such as exhaust air from air-conditioning systems, also act to increase the local air temperature. The magnitude of the UHI effect is dependent upon the interplay of local conditions including land coverage, built form, wind regimes, cloud cover and relative humidity (see Chapter 3).

In the case of London, the UHI effect on night time temperatures has been recorded to be up to 9 °C. In Manchester night time temperatures have been recorded to be between 5 and 10 °C higher than surrounding areas and in Birmingham a 5 °C difference has been recorded.

UKCP09 projections for the mean average summer night-time temperature would see an increase of the order of 2°C to 3°C in the 2050s (Medium emissions scenario, central estimate) across the UK; this would increase to between 3°C and 4 °C in the 2080s (Medium emissions scenario, central estimate). The spatial scale in the UKCP09 regional climate change models is too large for urban heat islands to be represented explicitly.

Modelling of UHI effects across the UK is currently being undertaken by the Met Office Hadley Centre. This is still at an early stage, but early indications suggest that there may be a major UHI effect in the Greater London and Greater Manchester areas by the 2050s (further information is provided in the Built Environment Sector Report). Other research is also currently underway as part of the Adaptation and Resilience in a Changing Climate (ARCC) projects.[118]

A precise relationship between elevated night time temperatures during heatwave events and the magnitude of consequences for human health and comfort is unclear and has not been assessed as part of this first CCRA. However, night time temperature thresholds for heatwave action may be exceeded more frequently by the 2050s.

7.3.2 Effectiveness of green space

Green and blue infrastructure (such as parks, open spaces, rivers and water bodies) has a dual function in combating the Urban Heat Island effect. Firstly, it provides an inherent cooling effect and, in the case of green infrastructure, shading capacity reduces the heat vulnerability of the surrounding area. Secondly, it provides valuable climate refuges, to which local residents can go for temporary respite from extreme heat.

Green infrastructure can take many forms from large open spaces such as parks to smaller scale features such as domestic gardens and street trees. In recent hot summers, drying out of green space has been observed, for example the parched grassland in Hyde Park in 2006. Under prolonged hot, dry conditions, evapo-transpiration of the green space slows down, eventually shutting down if the vegetation becomes completely parched. Consequently, the cooling effect of the green space is effectively switched off. Without adaptation, this could become an ever more frequent

[118] http://www.ukcip-arcc.org.uk/content/view/605/519/

occurrence as summers become hotter and drier. Clearly this also has consequences for the Urban Heat Island and overheating.

The CCRA analysis categorised green space as all types of open space from woodland and farmland to parks and grassed verges, but excludes domestic gardens.[119] The effect of climate change on the cooling benefit of urban green space was represented in the CCRA by a reduction in the 'effective area' of green space. This analysis only provides a very general guide to the connection between the reduced effectiveness of urban green space and more prolonged dry, warm periods. It does not take into account urban microclimates and, therefore, does not account for any UHI effects.

It is projected that the reduction in the 'effective area' of green space could be about 15% by the 2050s, (Medium emissions scenario, central estimate) with a range of 0 to 40% rising to over 30% by the 2080s, (Medium emissions scenario, central estimate) with a range of 2% to 72%.	Medium Confidence

Nonetheless, future adaptation proposals should encompass all scales of green infrastructure. The effectiveness of green space is linked to wider urban planning considerations, for example the creation of green corridors and the adoption of green roofs. Particular consideration should also be given to vulnerable locations, such as hospitals and care homes and socially disadvantaged areas. The latter typically have less access to urban green space.

Green space is also a key component of Sustainable Drainage Systems (SUDS). It is therefore also important in improving flood resilience. Further discussion of flooding is provided below.

Summer air quality (specifically ground level ozone) is discussed in Chapter 6.

7.3.3 Interdependencies

Our current climate will continue to cause problems for buildings in the short-term through extreme weather events, such as flooding and storm damage. Based on future climate projections, extreme weather events will continue to cause problems in the future. But more endemic problems would arise in the medium (by the 2050s) to long-term (by the 2080s), due to the increased likelihood of hotter summers and changes in rainfall, increasing the risks of overheating, including the Urban Heat Island effect (particularly in London and other large conurbations), and subsidence.

It is essential to consider buildings within their immediate and wider environment and across all potential climate impacts. For example, external temperatures are higher within the Urban Heat Island, increasing the risk of building overheating. However, green and blue infrastructure can help cool urban areas. Thus, the UHI effect is closely linked to both building overheating and to the availability and effectiveness of urban green (and blue) space. This means that resilient building design needs to be carried out in conjunction with effective land use planning, so that buildings can benefit from suitable locations within the built environment, for example, to help maximise water and energy conservation and to minimise flood risk.

The UHI effect, overheating of buildings and the effectiveness of green space all relate to thermal comfort (both indoor and outdoor) and, therefore, to heat-related health problems. Heat related mortality and morbidity are discussed in Chapter 6.

[119] Although gardens were excluded from the analysis, domestic gardens also play an important and similar role in the urban environment.

These summer heat issues also have clear interdependencies with the business and tourism sectors. For example, productivity is affected by overheating in buildings. However, warmer summers may also have positive consequences, for example, increased tourism and leisure activities. This is discussed further in Chapter 5.

There is also a dependency between the expected reduction in heating demand and the increased energy demand for cooling (see Section 7.4.3).

7.4 Energy

The energy industry occupies an unusual position with respect to climate change. The sector is traditionally seen as a driver of climate change, through its greenhouse gas emissions; in the UK, the Government's pledges on emissions cuts will exert pressure on energy companies in this regard. However, the sensitivity of key aspects of the energy industry to weather reveals that energy generation, transmission, supply and demand are also likely to be impacted by climate change.

This first CCRA has focused on electricity generation/production, transmission and distribution and supply/demand, as these processes were identified as being particularly vulnerable and most closely related to other infrastructure sectors, and hence the risk of cascade failure was considered high.

The CCRA analysis did not look at climate change impacts on primary energy sources (oil, gas, coal, nuclear). The impacts of climate change on renewable sites were only included in the analysis for flooding (hence only for England and Wales) and, as such, have been categorised as generating sites. The impacts of future renewable sites on the natural environment are discussed in Chapter 8.

7.4.1 Generation

There are over 2,500 electricity generating stations in the UK[120], with the majority of the generating capacity being fuelled by coal, gas and nuclear energy (URS, 2010).

The main climate change impacts for electricity generation are considered to relate to flooding of power stations and need for water for cooling. Other issues such as electricity turbine efficiency are discussed as part of the sector analysis, which can be found in the Energy Sector Report.

It is estimated that 19 power stations[121] in England and Wales[122] are currently in areas at significant likelihood[123] of tidal or river flooding. The actual flood risk to each power station depends on the standard of protection provided by local flood defences, which may differ from (generally being much higher than) the general standards of protection assumed for the CCRA analysis. Due to connection to the National Grid there is considerable flexibility in the system even if parts of the generation capacity are disabled.

[120] There are around 100 large electricity generating stations and 2,400 small stations.
[121] The power stations included in the analysis include operational and decommissioned nuclear power stations.
[122] Suitable data was not available for Scotland or Northern Ireland to undertake similar analysis.
[123] Significant likelihood is defined as having an annual chance of flooding (to any depth) greater than 1 in 75.

It is projected that the number of power stations in England and Wales in areas at significant likelihood of river and tidal flooding and requiring at least local defences may increase from the present day figure of 19 (with a generating capacity of about 10 GW or 15% of total generating capacity) to 26 (16 GW) by the 2020s for the Medium emissions scenario, central estimate (range 11 to 16 GW). This number is projected to rise to 34 (19 GW) by the 2050s for the Medium emissions scenario, central estimate (range 15 to 22 GW) and 38 (22 GW) by the 2080s for the Medium emissions scenario, central estimate (range 19 to 25 GW), assuming that the locations and number of sites do not change.	Medium Confidence

The assessment projected the following potential risks to nuclear sites in the UK by the 2080s:

- Of the total of nineteen sites with existing or future nuclear facilities, six would have a high risk of flooding if adequate protection was not provided. Four of these sites and one other site would also have a high risk of coastal erosion.
- Five of the eight sites for new nuclear power stations would have a high risk of flooding if adequate protection was not provided. Three of these sites would also have a high risk of coastal erosion.
- Five of the twelve sites used for radioactive waste storage would have a high risk of flooding if adequate protection was not provided. Four of these sites and one other site would also have a high risk of coastal erosion.
- Five of the sixteen decommissioning sites would have a high risk of flooding if adequate protection is not provided. Four of these sites and one other site would also have a high risk of coastal erosion.

All of the high risk sites are on the coast or estuaries. They may, therefore, be exposed to sea level rise and coastal erosion. **All sites have a high level of protection**, but projected sea level rise would gradually reduce the standard of protection unless defences were raised. Similarly, coastal erosion protection may require upgrading over time depending on changes at each site.

If temperatures rise in the future, the amount of water required for power station cooling would change as the water becomes warmer. More water would be needed to achieve the same amount of cooling. If water quantities were not increased, there would be a reduction in generation capacity. Where power stations use river water, this could have consequences for the aquatic environment and the water sector (both with regard to the sustainability of abstractions and water temperature due to the used water being returned to the water body). Based on analysis for England and Wales only, the Severn, Thames and Humber river basin regions are projected to be most affected in terms of changes in sustainable abstractions. Further information can be found in the Energy Sector Report. All currently operating and future planned nuclear sites in the UK are cooled using water from the sea or estuaries, which eliminates any problem of water availability and reduces the likelihood of water temperature issues.[124]

Increased carbon capture and storage in the future may increase water use requirements for fossil fuel based power generation.

[124] http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/nuclear/nuclear.aspx

7.4.2 Transmission and distribution

The UK's transmission system transfers electricity from individual generation plants to distribution substations (or directly to major energy users). The distribution system then delivers electricity from the substations to end users.

Electricity transmission and distribution networks are susceptible to faults caused by weather-related phenomena. The resilience of the network to faults is very important for the continuity of service to customers, which in turn affects the Networks companies' performance as monitored by the energy regulation body OFGEM (the Office of the Gas and Electricity Markets).

Transmission and distribution is dependent on infrastructure such as pylons, underground cables, poles, overhead conductors, insulators and transformers. These structures are particularly vulnerable to extreme weather (e.g. wind gusts, lightning, snow and ice) and/or to flooding (whether this results from waves/surges at coastal sites, localised extreme rainfall, or from periods of prolonged rainfall causing rivers to burst their banks). Additionally, the efficiency of underground cables, overhead conductors[125] and transformers is strongly influenced by temperature. Vegetation can also damage power line infrastructure in various ways (e.g. trees falling on power lines during high winds[126], excessive water extraction by roots undermining pylon/pole foundations, etc.), but is managed as part of routine maintenance, according to the local vegetation types and growing seasons.

Gas transmission and distribution is also at risk from present-day climate conditions. The main issue for gas is the possibility of failure of gas mains in cold conditions, although metal gas mains in the UK are gradually being replaced with plastic mains, which are more durable and can have a lifetime of up to 80 years underground if left undisturbed.[127] However, this was not included in the CCRA analysis.

Electricity substations[128], of which there are around 340 in the UK (URS, 2010) and 271 in England and Wales (National Grid 2009 data), are often located on 'brownfield' sites on floodplains or near coasts. During the summer 2007 floods, inundation was only narrowly avoided at Walham substation in Gloucestershire, which provides power to hundreds of thousands of homes and the Government Communications Headquarters (GCHQ). It is estimated that 46 substations are currently in areas at significant likelihood of river and tidal flooding[129] in England and Wales, although action is already being taken by the industry to address this.

The number of substations in England and Wales in areas identified has having significant likelihood of river and tidal flooding is projected to increase from 46 at present to 64 by the 2050s for the Medium emissions scenario, central estimate (range of 51 to 73), increasing to 68 by the 2080s (range of 57 to 79), assuming that the locations and number of sites do not change.	High Confidence

Different methods of transmission and distribution are used in rural and urban areas. Overhead conductors are used in rural areas. They are hung between poles or pylons, and higher temperatures can cause the conductors to expand and sag. To keep lines a safe distance from the ground during hot spells they are 'derated', i.e. the amount of current passed through them is reduced.

[125] The term "cable" is generally used to denote a power line which is buried underground, either directly or in a duct. The term "conductor" is generally used to denote a power line which is carried overhead, by pylons or poles.
[126] The risk to overhead lines from trees falling onto the lines is less than other forms of wind damage such as wind borne debris and conductors clashing with each other.
[127] http://www.nationalgrid.com/uk/Gas/Pipelines/Streetworks/Pipeline+Replacement/; http://www.nationalgrid.com/uk/Gas/Pipelines/Streetworks/news/09.06.08.htm
[128] Electricity substation function is to transform the voltage of electricity so that it can be carried between the transmission and distribution networks.
[129] Significant likelihood is defined as having an annual chance of flooding (to any depth) greater than 1 in 75.

In urban areas, power cables are often buried beneath the ground surface, the efficiency of these cables is therefore dependent on soil conditions (temperature and moisture content) in addition to air temperature. The moisture content can also affect the earthing potential of soils; long, dry periods may cause issues of safety and supply where current installations provide a marginal earthing scenario (Rawlins *et al.*, 2010).

Additionally, the effect of temperature on transformers could be a particular problem in urban regions where the urban heat island effect may cause operating thresholds to be exceeded more frequently. Power transformers at 11kV are at greater risk of de-rating than those at higher voltage.

Capacity losses in overhead conductors for the distribution network are projected to range from between 1 and 19% by the 2080s. Capacity losses in overhead conductors for the transmission network are projected to range from between 1 and 5% by the 2080s. Capacity losses in underground cables are projected to range from between 1 and 11% by the 2080s. Capacity losses in 11kV power transformers are projected to range from between 1 and 12% by the 2080s, depending on location in the UK, although this does not take into consideration urban heat island effects.	High Confidence

It is not possible to calculate projections of future absolute losses in current over the entire network, since its composition in terms of the different types of equipment is not known. However, the above results of projected capacity losses per equipment type can be considered in context of historical load growth to provide an indication of their relative magnitude. The networks have been subject to a load growth of approximately 1.5% to 2% per annum. Therefore dealing with changes in capacity on the transmission and distribution network is not a new problem. The impact of de-rating is not dissimilar to recent demand growth, which is taken into account within design standards.

7.4.3 Demand

The UK's temperate present-day climate means that energy demand is typically highest during the winter months, the main reason for this being increased use of heating, although illumination is also a factor as the hours of daylight are fewer in winter. While some countries experience a high demand for energy in the warmer months, as a result of increased use of air conditioning, this is generally not a major issue in the UK, except for (i) the occasional occurrence of heatwave conditions (e.g. during the summers of 2003 and 2006) and (ii) the urban heat island (UHI) effect in large urban areas (i.e. that they are typically warmer than their rural surroundings), particularly in the southeast of England.

Projected seasonal changes in the UK's climate may lead to changes in the seasonal pattern of demand. Warmer winters would result in reduced demand for natural gas for central heating, whilst hotter summers could lead to increased electricity demand for air conditioning, particularly in large urban areas. At present approximately two-thirds of the energy used domestically is natural gas, with electricity making up approximately one quarter (DECC, 2010b). A reduction in carbon emissions from heating is important for the UK to meet its greenhouse gas (GHG) emissions target of at least an 80% reduction by 2050s. However, it is too simplistic to look at the potential impact of climate change on future carbon emissions based on the present day energy mix (see Section 7.4.5). This is not only the case for heating demand, but is also true of cooling demand.

With projected temperature rises, the demand for energy (mainly electricity) to provide cooling (for air conditioning of homes, offices, factories, ICT, etc.) could increase. However, actual future cooling demand is likely to be highly dependent on a number of other factors, including the extent of future uptake of cooling systems and changes in building design (although the scale of this is limited by the turnover in building stock). In turn, these factors will be influenced by the measures taken to achieve a low carbon future and economic growth.[130]

Cooling of buildings currently accounts for around 4% of the total electricity demand in the UK (approximately 15TWh) and this demand is increasing with the growth of air-conditioning sales by 5% per year (Day *et al.*, 2009).

Day *et al.* (2009) estimate that energy demand for cooling in London could rise from approximately 1.6TWh in 2004 to between 2.2TWh and 2.5 TWh by 2030 under a low or high climate change scenario respectively.

The cost of an increase in cooling demand for the UK is estimated to be high; between £100 and £1000 million by the 2050s and in excess of £1000 million by the 2080s. These costs do not take account of any urban heat island effects or the additional investment costs associated with installation of air conditioning units. Therefore, this could be an underestimation of the total cost. Conversely, these costs do not take into consideration potential future energy efficiencies and should also be considered in light of the benefit of less energy being used for winter heating (discussed later).

Cooling degree days[131] (CDD) are projected to increase across the UK, but with much greater impacts in Southern England. In Southern England the number of CDDs currently ranges from between 25 and 50 and this is projected to increase to between 125 and 175 degree days in the 2080s. The projected increase in CDDs is reduced with increasing latitude, such that the increases by the 2080s over northern England and Scotland are much smaller (25 – 50). This is discussed in more detail in Chapter 3.

Analysing future projections of CDD provides a means to assess how cooling demand may change in the future based on climatic factors alone. However, relating CDD to energy demand should ideally take into consideration non-climate factors, such as building stock and uptake of air-conditioning, and this type of detailed information is not readily available at the UK scale. Further discussion of this is provided in the Energy Sector Report.

Higher summer loadings can generally create two issues for network operators.

- Firstly, energy generators and providers use the reduced demand period as an opportunity to take equipment out of service for maintenance. Increased cooling demand in the future may shorten these “outage windows”. However, this issue is a reflection of existing energy demand and energy mix, which may change as the UK moves towards a low carbon future. For example, there may be a greater demand for electricity in the future to provide winter heating (such as an increased use of heat pumps)[132], which may offset extra summer demand for cooling.
- Secondly transformers have a significant thermal inertia that is exploited by allowing them to heat up during the day, knowing that they will get an opportunity to cool again overnight. The “urban heat island” effect means that there may be less of a cooling opportunity over night in densely populated areas and additional cooling may be required. Other factors in the future could also

[130] Issac and van Vuuren (2009) looked at a number of regions throughout the globe and found that besides climate change, cooling demand increase is mainly due to income growth in regions with a high potential cooling demand.
[131] The day-by-day sum of the mean number of degrees by which the air temperature is more than a value of 22 °C.
[132] Even if the total energy demand reduces.

reduce cooling opportunity, such as increased usage of electric cars that would be charged overnight.

Further risks posed by increased demand for cooling would be (a) the potential for increased GHG emissions if the increased demand is met by increased fossil fuel consumption (see Section 7.4.5 for discussion regarding the UK's low carbon future and changing energy mix) and (b) the potential for increased contribution of waste heat exacerbating the urban heat island effect and reducing the efficiency of cooling systems (see Section 7.7.3 for discussion of how this is affects the ICT sector).

Impacts on society could be significant if demand for cooling is not met. This is discussed further in Chapters 5 and 6.

Impacts on the economy could be negative or positive. Failure to meet cooling demand could reduce workplace productivity (discussed earlier). However meeting the demand could provide opportunities for those responsible for cooling infrastructure and electricity supply.

Currently the total demand for electricity is much higher in the winter than the summer due to heating and lighting requirements. Based on analysis for Great Britain, results indicated that winter demand would continue to be higher than summer demand, but this does not take into consideration any future improvements in energy efficiency.

Projections of future total energy demand for domestic space heating in Great Britain[133] indicate a reduction in consumption of approximately 27% by the 2050s (Medium emissions scenario, central estimate), ranging between 20% and 30% depending on the area of Great Britain. This is based on current population figures. If the principal population projections are applied, this reduction is only 6% (Medium emissions scenario, central estimate), ranging between 3 and 12%.	Medium Confidence

Heating degree days[134] (HDD) provide an indication of winter energy demands and are projected to decrease across the UK. Heating degree days are projected to decrease in step with changes in winter temperature with immediate impacts in the short term. In the long term (2080s) HDD in Southern England are projected to be 50% lower than the 1961-1990 period and 30% lower in Scotland. This is discussed in more detail in Chapter 3.

There are other factors that may also affect demand for energy, for example, as well as having a growing population, that population is ageing and, therefore may use less or more energy at different times of day or during the year. Warmer summers may lead to lifestyle changes, including working patterns, for example, longer lunch breaks during the hottest part of the day. But how these factors might alter energy demands has not been considered as part of the CCRA.

It is important to note that energy demand is a function of many parameters, only some of which are weather-related. The Government's energy policy of moving towards a low carbon future is expected to have a more significant effect on future energy demand than direct climate change impacts. A low carbon economy would in all likelihood be a combination of improved energy efficiency and increased diversity of energy sources. This is discussed more fully in Section 7.4.5.

[133] Data was not available for Northern Ireland.
[134] The day-by-day sum of the mean number of degrees by which the air temperature is less than a value of 15.5 °C.

7.4.4 International dimension

Since 2004 the UK has been a net importer of fuels and this makes the UK highly reliant on international energy transportation infrastructure. In 2009, the UK imported 27% of its energy; this is projected to increase to between 46% and 58% by 2020 (DECC 2010c).

The international energy market is changing as reserves (such as those in the North Sea) are being depleted and greater reliance is being put onto a smaller number of large reserves. This is resulting in longer supply chains and the longer the supply chain, the greater the vulnerability of that supply chain to disruption and associated cost implications (either derived from increased operational costs or market forces). The following gives an indication of potential impacts and consequences of climate change that may affect UK energy prices and security of supply. However, these may be relatively minor in comparison to non-climate drivers as discussed in Section 7.4.5.

Extraction of fossil fuels – Increases in extreme weather and decreasing water availability would impact upon the extraction of petroleum and gas. For example, changes in ocean swell height or storm surges may have negative consequences for oil rigs and associated infrastructure across the world by the 2040s. The projected decrease in water availability for mid and semi-low latitudes could constrain the activities of oil and gas industries (which have very high water requirements[135]) in these regions by the 2040s (Foresight, 2011a).

Imports and processing - Large-scale goods ports are likely to adapt to sea-level rise. However, temporary disruption to the infrastructure that provide energy supplies (such as oil refineries, natural gas terminals, and the physical infrastructure in port facilities that service them) is a possibility as rising sea-levels increase the consequences of extreme events, assuming defences are not upgraded.

Transboundary infrastructure – Some of the most strategically-important oil and gas pipelines are located in areas of the world with the potential to be adversely affected by climate change. For example, many pipelines in Russia are built on permafrost and melting of this permafrost due to increasing temperatures would threaten the integrity of the pipeline infrastructure. There are gas interconnectors between Great Britain and Northern Ireland, the Republic of Ireland, Belgium and the Netherlands. Northern Ireland has electricity interconnectors with the Republic of Ireland and there is also an electricity interconnector between the British transmission system and France, with other being proposed.

International trade - The energy sector is also dependent on the international energy market. Climate change may disrupt existing agreements between countries or regions, if energy requirements were to change within a region and, therefore, would affect how much energy is available to trade. For example, the price and security of supply of UK electricity imports from France and elsewhere in Europe may be adversely affected by increases in mean and extreme temperatures and increased drought frequency. Political tensions between countries can also impact on energy security and these may occur or be exacerbated by climate change.

International markets – Past experience has demonstrated that extreme events, such as hurricanes in the Gulf of Mexico, can have dramatic effects on the global energy markets, causing price volatility.

Further discussion regarding the factors that could influence the UK's energy security can be found in Foresight (2011a).

[135] Alternative sources of fossil fuel also have very high water requirements. For example, estimates indicate that between 2 and 4.5 barrels of water are extracted from Canada's Athabasca River to produce one barrel of synthetic crude oil from oil sands (Canada National Energy Board, 2006).

7.4.5 A low carbon future

The UK's energy policy is influenced by the need to ensure long term energy security and the climate change agenda. The UK Government already has short and long-term policy commitments towards an 80% reduction in GHGs for the UK by 2050 relative to 1990 levels, as set out in the Climate Change Act 2008.

Transport, ICT and water[136] are all heavy energy users. For example, in 2009, transport accounted for 22% of the UK's GHG emissions (DECC, 2011). Based on the current energy mix, these sectors are, therefore, carbon intensive and need to look at cutting demand and changing to low carbon energy supplies.

The global emission projections used in the UKCP09 climate projections (and hence used for the CCRA) are based on future scenarios developed by the IPCC Special Report on Emission Scenarios (SRES), which do not include climate emission mitigation initiatives, although sub-divisions of these scenarios do represent different combinations of fuel sources.

It is common practice in risk assessments to match up the socio-economic scenarios and climate scenarios to ensure consistency between the future scenario and its input assumptions. Coupled with this, currently available socio-economic data sets for the UK are only based on future scenarios without mitigation. Therefore, the climate projections and corresponding socio-economic data sets used in this first CCRA do not explicitly include climate mitigation and do not fully represent a 'low carbon future'.

The future energy mix will be a major factor in determining vulnerabilities at all levels within the energy sector (e.g. individual consumers, communities, businesses, industry, etc.) However, it is not possible to predict this accurately. Nor is it possible to predict which low carbon technologies will prove successful or how consumer behaviours and infrastructure will change in the future in response to an increasingly low carbon economy. Despite this, it is important to understand potential alternative futures and where possible plan for these now.

The 2050 Pathways Analysis (DECC, 2010a) looked at a range of different potential pathways to delivering an 80% reduction in GHG by 2050 relative to 1990 levels. No preferred route was suggested, but there were a number of common themes that emerged. These are listed in Table 7.1, along with relevant comments on projected climate change impacts and consequences. Although not comprehensive, this gives an indication of (a) how a low carbon future may alter future climate change vulnerability and (b) how targets for reducing GHG emissions may be met in the future with a changing climate.

The relationship between the climate change mitigation strategy and adaptation strategy is complex. Future climate change risk assessments should aim to look more closely at alternative future pathways for delivering a low carbon economy and how these may be affected by climate change.

Recent work on behalf of the Climate Change Committee (Forster *et al.,* 2011) has also identified how future climate change may influence elements of the climate change mitigation strategy and conclusions were drawn that were similar to those presented in Table 7.1. Forster *et al.* (2011) also looked how this may affect the cost of delivering the carbon budgets. It was concluded that the climate change mitigation strategy for the UK should explicitly take into account the threats and opportunities posed by future climate change to the delivery of the carbon budgets. The study also concluded that where opportunities exist to build resilience to climate change into the mitigation planning they should be maximised. Examples include climate change resilience

[136] According to stakeholders at the Northern Ireland workshop, Northern Ireland Water is the largest electricity consumer in Northern Ireland and is dependent on an uninterrupted supply.

planning for new energy infrastructure; embedding resilience into new building regulations (e.g. for cooling); and energy efficiency of products for reducing internal gains within buildings.

Table 7.1 Common themes across different 2050 pathways

Common themes across different 2050 pathways	Examples of projected climate change impacts and consequences that may affect or be affected by these common themes
Ambitious per capita energy demand reduction is needed. Total energy demand reduction by 2050 may need to be as high as 40% compared to 2007 levels, depending on which illustrative pathway is considered.	The projected reduction in winter demand for heating due to climate change may contribute to the reduction in energy demand. Building modifications (such as home insulation) may also help to offset the projected increase in demand for cooling in the summer due to climate change (see Section 7.4.3), although air tightness and loss of thermal mass may have the opposite effect. More efficient electrical appliances may play an important role in reducing energy demand. These produce less waste heat, which may have benefits in reducing the need for air conditioning during hot weather. However, this waste heat is sometimes useful in maintaining comfortable indoor temperatures. Transport demand/usage may change in the future, which would directly affect energy demands. This may be partly the result of climate change, but it is likely to be more heavily influenced by energy policy (see Section 7.5.6).
A substantial level of electrification of heating, transport and industry is needed.	An increase in electrification may require a larger and 'smarter' distribution network. Coupled with a bigger and more sophisticated transmission grid to allow for renewable generation sites, this may increase vulnerability to (a) damage or disruption due to flooding and (b) transmission and distribution losses due to high air temperatures (see Section 7.4.2). The increased sophistication of transmission and distribution networks would lead to greater reliance on ICT (see Section 7.7). The variability in renewable supplies may need managing by increasing the number of interconnections with foreign suppliers, which may increase vulnerability to climate change impacts overseas (see Section 7.4.4). The CCRA has not assessed the impacts of climate change on current or future renewable generation sites, as these were not considered to be significant enough to be selected for the Tier 2 analysis. Projections regarding wind and storminess are too uncertain to determine whether there may be threats or opportunities in the future for offshore and onshore wind generation.
Electricity supply may need to double, as a result of the need to electrify large parts of the heat and transport sectors. This electricity would need to be almost exclusively from low carbon sources.	
A growing level of variable renewable generation increases the challenge of balancing the electricity grid.	

Common themes across different 2050 pathways	Examples of projected climate change impacts and consequences that may affect or be affected by these common themes
Sustainable bioenergy is a vital part of the low carbon energy system in sectors where electrification is unlikely to be practical, such as long haul freight transport and aviation and some industrial high-grade heating processes. Depending on the pathway considered, up to 10% of UK land would need to be used for energy crops.	Warmer temperatures and increased CO_2 fertilisation may increase yields for current biofuel crops, such as wheat and sugar beet, as long as sufficient nutrients and water are available. There may also be opportunities to grow a wider range of energy crops, as the geographical range of existing crops may increase and conditions, particularly in southern England, may become suitable for new crops (see Section 4.2.3).
Emissions from agriculture, waste, industrial processes and international transport (aviation and shipping) make up a small proportion of emissions today, but by 2050, if no action were taken, emissions from these sectors alone would exceed the maximum level of emissions for the whole economy.	Future emissions from agriculture (in particular management of wastes and bi-products from livestock systems) may be influenced by climate change and this may lead to a decrease in the effectiveness or viability of certain practices, such as manure spreading. Future emissions may also increase as a result of an increase in livestock production, should this occur as a consequence of the projected increase in grass yields (see Section4.2.1). Other forms of waste were not looked at in detail as part of the CCRA analysis. Agriculture practices are also closely linked to land management practices, which in turn can influence the storage of carbon in soils (particularly peat lands). There is considerable uncertainty surrounding the potential impact of climate change on soil organic carbon, which means it is not possible to state with any certainty whether this will result in an increased or decreased carbon store (see Section 8.4.2). Industrial processes may have greater demand for energy for cooling, but this was not looked at in detail as part of the CCRA analysis. International transport has not been projected to be significantly affected by climate change within the UK context (see Sections 7.5.3 and 7.5.4). However, the potential opening of the North West Passage, due to the melting of the Arctic ice, may provide opportunities for shorter routes for sea freight, which may reduce emissions.
There will be an ongoing need for fossil fuels in our energy mix, although their precise long term role will depend on a range of issues such as the development of carbon capture and storage.	Existing fossil fuel power stations may be at increased risk of flooding in the future due to climate change and may also be affected by water availability for cooling (see Section 7.4.1). Increased use carbon capture and storage may increase water use requirements for fossil fuel based power generation (see Section 7.4.1). Gas transmission and distribution are not considered as being at greater risk in the future from direct climate change impacts (see Section 7.4.2).

7.5 Transport

Currently, operation and maintenance of the UK's transport networks is strongly affected by the weather, with the greatest risks for all modes of transport posed by extreme weather events (such as flooding, heatwaves, snow and gales). Disruption caused by extreme winter conditions may become less frequent, but threats from heat and flooding may increase.

Box 7.5 Pattern of transport infrastructure and use in the UK

Transport plays a vital role in economic and social activities in the UK, providing access for people to services and movement of materials and goods. Because the sector is so diverse in the provision of infrastructure and services and in user patterns, there is a wide range of opportunities and threats possible from climate change impacts.

The scale of movement has continually increased over time, broadly in line with growth in economic activities. Today travel patterns are dominated by road vehicle movement. The increase in private car ownership and use has enabled a good proportion of the population to live their lives beyond the immediate locality. Road carriage has taken over a high proportion of goods movement, serving increasingly complex patterns of commerce and manufacture; 88% of inland freight transport, measured in tonne-kilometres, is carried by road transport in the UK, and 93 out of every 100 passenger kilometres are travelled by road. But public transport, especially the railway system, remains important for certain activities (such as workers commuting to and from large cities).

As an island nation, the UK also makes substantial use of air and sea movement. For example, in 2010 there were 21.9 million international ferry passengers travelling to and from the UK[137]; a total of 512 million tonnes of freight traffic passed through UK ports[138]; and there were over 2 million flights to and from UK airports (including over 2.3 million tonnes of freight).[139] Around 95% of the UK's trade by weight is carried by sea, with the volume of shipping increasing in many areas. Ships are getting larger and many more ships are confined to deeper water in restricted channels.

Not surprisingly, UK society has become far more dependent on having secure transport networks available at all times. Operation and maintenance of the transport networks has always been affected by the weather. Problems can be caused by the day to day variations in weather patterns. However, extreme weather events can cause severe disruption: snow and ice, flooding, gales, storms at sea and extreme heat all have particular impacts and consequences.

Cold weather, seen in terms of snow and ice, can cause widespread stoppage across whole regions, delaying movement on all modes.

Flooding incidents, caused by very high rainfall, or by thawing of previous fallen snow, are more likely to damage a section of road or railway at a specific point, sometimes very local. However, it can cause much wider impacts if this breaks a key network link or node: e.g. a railway or trunk road junction.

The UK Coastguard is responding to increasing numbers of incidents at sea, due to busier seas (with increased recreational activities and commercial shipping) and due more frequent and more intense storms that have been experienced in recent years.

Excessively high temperatures can lead to deformation of road and rail surfaces and to very unpleasant travelling conditions. While replacing buckled rails or a deformed road surface may not cost a great deal, transport providers can be faced with significant financial penalties

[137] According to the Department for Transport Sea Passenger Statistics.
[138] According to the Department for Transport Port Freight Statistics.
[139] According to the Department for Transport Air Transport Movement Statistics

when this causes disruption to their services. These incidents can also have serious effects for economic and social activity patterns, through preventing access to services and supply of materials and goods.

Transport systems in other parts of the world already cope with weather conditions far more severe than those likely to be encountered in the future in the UK and useful practical lessons can be learned from overseas. In the current UK climate, disruption due to cold, wind, rain, snow and ice is more frequently experienced than disruption due to heat

As the climate changes, disruption caused by cold, snow and ice may occur less frequently, whereas there may be an increased risk posed by both heat and by flooding. Extremes of weather can be accommodated in the design of transport elements and infrastructure; the variability of the climate from year to year and the unpredictable nature of that variability can often be more difficult to accommodate.

Gradual changes in the climate affect the design criteria that should be applied to vehicles and transport infrastructure. Infrastructure that has been designed in the past may not have the capability to accommodate present and future changes in climate. Increases in temperature and associated heatwaves, for example, may lead to conditions that exceed the design limits of existing infrastructure (e.g. rail buckling).

Thus the risks to transport can be classified as:

- Damage to transport infrastructure and the associated disruption caused by extreme events.
- Disruption to transport vehicles (road vehicles, trains, aircraft and ships) caused by extreme events. This can range from precautionary closures of roads and rail/air/ship services to catastrophic damage.
- Disruption to transport caused by gradual changes in the climate, such as increases in temperature and sea level rise.

The CCRA analysis suggests that the greatest overall risk is in England, due to the greater length of the transport networks and higher volumes of traffic. However, the Devolved Administrations have a higher proportion of communities that are vulnerable to being cut off as a result of extreme events, due to having very limited transport links, which means that the consequences for these communities can be very serious.

7.5.1 Roads

There are over 8,000 km of strategic network (motorways and major trunk roads) and over 250,000 km of other public roads (local road network) in the UK (URS, 2010).

Most road vehicles are expected to perform in all weather conditions, but remain sensitive to extremes of heat and cold, damp, wet or icy road conditions and road blockages or closures due to flooding, snow or fog, although modern road design aims to minimise some of these problems.

Flooding

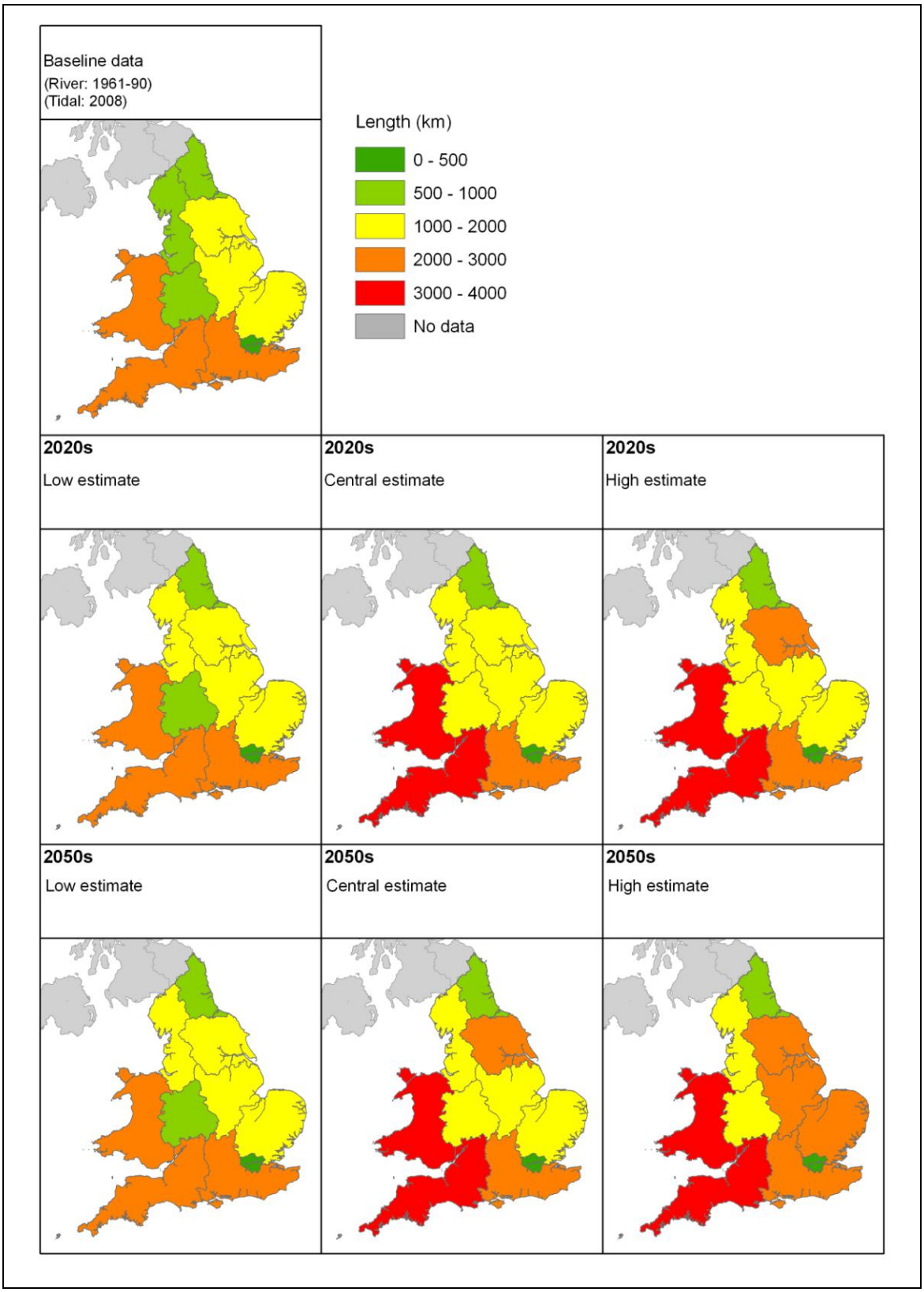
Flooding is anticipated to be the most significant impact on the road network in the future. Flooding of roads and the associated disruption is projected to increase. Not only does this affect some of the main roads including motorways, but many rural communities can be cut off if their access roads flood.

Currently it is estimated that about 12,000 km of roads (motorway, A roads, B roads and minor roads) are at significant likelihood of river or tidal flooding in England and Wales[140]. This figure includes 3,400 km of motorway and A roads. It is projected that these figures would gradually increase as flood risk increases, with an overall increase of about 40% by the 2080s if adaptation measures are not implemented before then.

The distribution of road and rail at risk in England and Wales is shown in Figure 7.4. Currently, Wales, the South West and South East of England have the greatest length of roads and railways at significant likelihood of river and tidal flooding. It is projected that in the near future (2020s) there would a significant increase in both Wales and the South West of England.

[140] Significant likelihood of flooding is defined as having an annual chance of flooding (to any depth) greater than 1 in 75. Suitable data was not available for Scotland and Northern Ireland to undertake the analysis.

Figure 7.4 Projected length of roads and railways at significant likelihood of flooding (river and tidal) in England and Wales



The length of road at significant risk of river or tidal flooding in England and Wales is projected to increase from around 12,000 km[141] at present to 14,000 km in the near-term (2020s) for the Medium emissions scenario, central estimate (ranging from 13,000 to 16,000 km). This is projected to rise to 17,000 km for the Medium emissions scenario, central estimate by the 2080s (ranging from 14,000 to 19,000 km).	High Confidence

Disruption and delay to road and rail traffic and the associated consequences for society and business are likely to increase if flooding increases. The widespread flooding of major and minor roads in 2007 gives a very useful guide to the scale and costs of the risks involved. It has been estimated that the cost of disruption was of the order of £100m and the probability of this type of event may increase with climate change. The CCRA analysis suggests that the cost of delays and disruption from floods is projected to remain relatively low to the 2050s with the potential to increase to the levels experienced during the 2007 event on an almost annual basis by the 2080s.

The cost of delays and disruption of road traffic in England due to flooding is projected to increase to between £10 million and £100 million per year by the 2080s (Medium emissions scenario, central estimate). The baseline for this projection is the estimated total costs relating to delays and disruption to road users during the 2007 floods, which was estimated as being around £100m (with a wide range of between £22 million to £174 million).	Low Confidence

The annual frequency of occurrence of the 2007 flood varies from location to location, but was about 0.5% (1 in 200 year return period) on the River Severn at Gloucester. An equivalent flood of this magnitude might have an annual probability of 1.3% (1 in 75 year return period) or greater by the 2080s.

Bridge scour

Bridge scour[142] is often associated with flooding due to high river flows. Both road and rail bridges built with footings in rivers and estuaries are at risk of scour occurring around these foundations. If the development of scour at these foundations becomes significant, then the stability of the foundations may be threatened and there is associated danger of structural damage or failure. In the last 10 years there have been at least 7 road or rail bridge failures in the UK and one fatality.[143]

The rate of increase in scour in the future would be dependent on local conditions, namely the construction of the bridge, the hydrodynamics of the flowing water and characteristics of the river bed. Gravel beds present a greater risk than sand beds. Sufficient data is not available to provide projections regarding the number of bridge failures in the future, but the estimated increase in the occurrence of scour suggests that the number would increase above the present baseline of about one failure per year.

Bridge scour on the road and rail network may increase by the 2080s. Depending on the local conditions, scour depths may increase by between 5% and 50%.	Medium Confidence

[141] 9,200 km at risk from fluvial flooding and 3,200 km at risk from tidal flooding.
[142] Scour is the term used to describe the movement of riverbed sediment as a response to the shear forces associated with flowing water in the presence of a hydraulic structure, such as a bridge. Where sediment is moved irrespective of a man-made structure this is usually termed erosion.
[143] Older bridges (especially pre 20th century) tend to be more vulnerable to scour; major modern bridges are rarely vulnerable due to advances in structural design and understanding of scour.

It should be noted that bridge failure due to flooding may not necessarily be scour related. Structural failure can also be caused by the bridge being hit by floating debris such as vehicles; the washout of masonry and fill material due to poor maintenance; or through a combination of these.

Slope stability and subsidence

The length of roads currently under some kind of threat from landslides in the UK is in excess of 1,000 km. However, the length of road at risk is projected to remain similar to current levels until the 2050s (Medium emissions scenario, central estimate), with some increase in risk beyond this period. However, these estimates are based on the detrimental effect of increased rainfall on slope stability alone and should only be considered as indicative. Land management practices can also have a significant effect on slope stability in many locations.

The incidence of landslides may increase with up to double the number of roads in England (around 1,500 km) being at risk by the 2080s (central estimate for all emissions scenarios). For Scotland[144] and Northern Ireland[145] an increase in risk is only projected for the p90 or 'wet' scenarios.	Medium Confidence

Road subsidence has not been considered as a significant issue by the CCRA. It is generally managed effectively as part of existing road maintenance programmes. Therefore, subsidence or low level ground movement is not quantified or reported separately from general road condition. Hence, data is not readily available to undertake analysis.

Thermal loading

Warm and dry weather can be beneficial for construction activities owing to a lack of weather interference. However, thermal loading may have an impact on the life of the bituminous surfacing of roads, with deformation increasing as road surface temperatures increase during warmer summers, which would result in higher maintenance costs. The hot weather of July 2003 caused asphalt roads to 'bleed' and stone dust had to be spread to prevent the surface breaking up. There is also the potential for an increase in disruption of construction or repair activities at temperatures above 35°C when surfacing of some roads has to be suspended as the asphalt will not cool sufficiently quickly.

The CCRA analysis indicates that the cost of carriageway repairs as a result of increased thermal loading is likely to be less significant than those due to flood risk. However, the analysis was based on seasonal average temperatures and the costs incurred in the 2003 heatwave suggest a greater risk and that this may therefore be an underestimate of the level of change. Also, the analysis undertaken by the CCRA did not cover the associated disruption to transport arising from road damage and repairs.

[144] Projections for Scotland are based on trunk roads only.
[145] Data for Wales was not available to undertake the analysis.

The annual cost of carriageway repairs in England[146] incurred as a result of thermal loading is projected to be between £1 million and £10 million by the 2080s for the Medium emissions scenario, central estimate (range £1 million to £100 million). Currently, annual carriageway repair costs due to thermal loading are less than £1 million.	Medium Confidence

7.5.2 Rail

The rail network[147], like the road network, is also affected by weather conditions. For instance, heavy rain or snow can cause track blockages, particularly in cuttings, and cold weather affects many activities, particularly when accompanied by snow. Strong winds can also be a hazard and can bring down overhead cables, particularly if trees are blown onto them.

Railway engines are powered by either electricity or diesel and both are designed to operate in UK conditions. These can be sensitive to cold and hot weather conditions and under a changing climate there is likely to be a need to continue to refine designs and retrofit measures to cope with the changing conditions.

Climatic design should ensure that the track will not buckle in hot weather, at the one extreme, and that points will not freeze at the other. However, extremes of temperature indicate that this is not always the case. At present, there are about 50 rail buckles per year in Great Britain[148] at a cost of nearly £1 million. In the hot summer of 2003 there were 137 rail buckles at a cost of about £2.5 million for repairs and delays.

The mean number of rail buckles in Great Britain is projected to increase from 50 per year (based on1995 to 2009 figures) to 185 by the 2080s (Medium emissions scenario, central estimate). Based on current costs, this would result in costs to the rail network provider of around £3.5 million per year (with a range of £2.5 million to £4.5 million).	High Confidence

Considerable work is underway to make the rail system more resilient to climate effects. To date this has been primarily addressed to the effects of extreme rainfall on drainage systems, embankment stability, extreme river flows on the stability of bridges and coastal defences.

Currently it is estimated that about 2,000 km of railway line are at significant risk[149] of river or tidal flooding in England and Wales[150]. Calculations of the costs of the 2007 floods also lead to an estimated £25.6 million in rail user delays and a further £10.5 million for rail infrastructure costs (Transport Sector Report).

The length of railway line at significant risk of flooding in England and Wales may increase from about 2,000 km to 2,300 km in the near-term (2020s) for the Medium emissions scenario, central estimate. This may rise to 2,700 km (range of 2,200km to 3,000km) by the 2080s.	High Confidence

Underground infrastructure is prone to rising water tables and pluvial flooding[151]. The lack of heating and ventilation on the London Underground means temperatures can

[146] Data was only available for England and Northern Ireland for undertaking the analysis. The results of the analysis for Northern Ireland indicate that costs would be less than £1 million per year (Medium emissions projection, central estimate for the 2080s).
[147] There are over 20,000 km of rail track in the UK (URS 2010).
[148] Data was not available to undertake a similar analysis for Northern Ireland.
[149] Significant risk is defined as exposure to a flood frequency (to any depth) greater than 1 in 75 years
[150] Suitable data was not available for Scotland and Northern Ireland to undertake the analysis.
[151] Flooding caused by runoff. See definition of surface water flooding in section 7.6.3.

exceed thermal comfort thresholds. All of these issues are likely to be exacerbated as the climate changes.

7.5.3 Ports and shipping

To date very little work has been carried out to assess the impacts of climate change on ports and shipping. Confidence in wind and storm projections from GCMs and RCMs is relatively low, with some models suggesting that the UK may experience fewer storms in the future and other models suggesting an increase. Should wind speeds and storm frequencies change in the future, the height of waves around the UK could also change with potential consequences for maritime safety. Although there have not been any clear trends over the twentieth century, the wave climate seems to have roughened appreciably between the 1960s and 1990s. This is likely to be a consequence of the change in strength of the North Atlantic Oscillation (JERICHO, 1999).

Vessels have varying abilities to cope with extremes of weather and this, in general, determines their range of use. For commercial shipping this is carefully controlled through vessel certification and so can be managed to take account of changes in climate (e.g. the distance offshore that a particular size of vessel is allowed to operate). Hence for vessels at sea the main changes are likely to be driven by requirements to reduce emissions, reduce energy usage and control discharges.

Within ports the main sensitivities are to wind, tide and wave conditions, all of which influence the initial choice of port location to maximise the shelter they offer and hence the operational efficiency of the port. The latest projections of climate change suggest minimal change to these conditions (see Annex A). Therefore, climate change risks are not considered by the ports industry to be substantial in the near to medium term. Sea level rise may be more critical in the long-term, because quays have a fixed elevation and as water levels rise, there is a greater risk of flooding and for some ports lifting equipment may need to be modified. However, the existing freeboard at most ports means that this is not of immediate concern and where issues such as flooding are a problem they are already being addressed (e.g. additional defences around the quays in the port of Hull). However, there may be some additional risk of damage to cargo and for those ports that choose not to protect the dock estate from flooding, there may be an increased risk to the surrounding neighbourhood.

A number of studies have attempted to assess the potential impact of future climate change on the operation of roll-on-roll-off ferries throughout Europe, including an assessment of the sensitivity of ferry services to the Western Isles of Scotland due to changes in wave climate (Woolf *et al.,* 2004; Weisse *et al.,* 2009), but these do not go as far as providing projections of future disruption. If the wave climate around the UK in winter did roughen appreciably (although this is too uncertain at present), this would cause more frequent disruption to ferry services of northwest Scotland, South West England and across the Irish Sea. Further information can be found in the Marine & Fisheries Sector Report.

There are also gaps in understanding regarding:

- The potential scale of the knock-on effects of port disruption (even if this is considered as having a low likelihood); and
- The indirect consequences for ports as commercial businesses[152] in a future economy affected by climate change. This includes the international dimension regarding climate change impacts on transportation hubs in other parts of the

[152] There are 120 commercial ports in the UK (URS 2010).

world and subsequent trading routes, in particular sea freight. This could offer up opportunities as well as threaten business in the UK (Foresight, 2011a).

The melting of the Arctic ice and the opening up of the North West and North East passages to the Pacific Ocean may lead to a shift in the importance of UK ports from the South to the North West or North East of the British Isles. The Far East is more than 3000 km shorter via the North East passage (also referred to as the Northern Sea Route) than via Suez Canal. The impact of this on exports and imports and supply chains is discussed in the Business Theme.

Projections of ice cover for the Arctic provided by the Met Office show that the Northern (Arctic) sea routes may become open in the near future and remain open for longer period during the Arctic summer. The projections suggest that there will be ice free Arctic summers by the 2080s. For example, results showed that the north east passage could be open for up to 120 days by the 2050s and 180 days by the 2080s. These projections are based on a single projection for each time-slice (2020s, 2050s and 2080s) using the HadCM3 model.	Medium Confidence

7.5.4 Air transport

Today, aircraft and helicopters are designed to operate virtually anywhere in the world and, as such, the climatic design is advanced.

Airports are designed to be kept open every day of the year in all weather conditions. For example, all airports in the UK[153] have provision for 'round the clock' snow and ice control, both for clearing runways and aircraft. However, the need for such services is intermittent and is likely to continue to be so in the future. Therefore, as now, the challenges will be for (a) good forecasts to operators and (b) operators to maintain appropriate contingency plans.

Specific impacts on airports and aircraft have not been analysed as part of this first CCRA. However, it is important to take into consideration the role that air transport plays in the transport network as a whole. For example, passengers and cargo are transferred to and from airports via rail and road networks.

7.5.5 Winter conditions

Milder winters may benefit the transport sector in the long-term, as disruption and delay caused by snow and ice may reduce. However, the natural variability in the weather will mean that extreme events will still occur and any benefit is unlikely to be experienced in the near-term.

During November and December 2010, heavy snow and freezing conditions led to considerable disruption on road, rail and at airports. The winter weather disruption cost Heathrow £24 million. In recent years the total cost to delayed journeys to both businesses and individuals due to severe winter weather has been estimated to be around £280 million per day in England alone (in 2010 prices) (DfT, 2011).

Whilst the incidence and intensity of heavy snowfall is projected to decrease in the UK overall (Brown *et al.*, 2010), there would remain issues associated with repeated freezing and thawing, which would have implications for maintenance. It only requires about a quarter of the amount of de-icing chemical to prevent ice formation than to melt ice, owing to the extra energy required to melt ice. Hence accurate forecast of the likely formation and timing of ice are important and enable pre-salting to be carried out.

[153] There are 36 commercial airports in the UK (URS 2010).

7.5.6 Transport Demand/Usage

As 90% of transport needs are provided by roads in the UK, most of the CCRA analysis has concentrated on road transport. The mix of road/rail/air and water transport is likely to change in the future, partly due to legislation/regulation and partly due to changes in driver and passenger behaviour patterns. For example, road usage may increase due to economic growth or a growth in domestic tourism and outdoor activities; it may decrease due to fuel prices and the low carbon agenda. The current impact and risk of climate change on transport could be vastly affected if vehicle emissions are reduced by 80% by 2050. Fossil fuels may no longer be in widespread use and electric and hybrid cars might become the dominant form of transport in the UK. These developments would have major implications for the transport networks and infrastructure. There are already increasing numbers of passengers using rail travel and this may lead to more weather and climate related train delays in the future as more services are provided on a fixed infrastructure. There is also the possibility that there may be a decline in domestic demand for air travel as the climate becomes more favourable in the UK.

7.5.7 Interdependencies

Transport networks in the UK are closely linked; a disruption in one mode of transport can have knock on effects on other modes of transport, as users switch from one to another. This particularly applies between road and rail transport at various levels: e.g. inter-urban rail travel is complemented by local road travel.

The transport networks play a vital role in business supply chains, including getting the workforce to and from the workplace, the supply of materials and goods, as well as supporting social and leisure activities (see Chapter 5). They also play a vital role in evacuation and rescue activities associated with extreme events (see Chapter 6).

Changes in technology could change the nature of climate risks in the future. If, for example, a large proportion of transport is electrified in the future, then this would change both the risks themselves (as new technologies might have different vulnerabilities) but also the nature and extent of interdependencies with other sectors. In this case the interdependencies with the energy sector and ICT would be affected.

Transport infrastructure also affects the landscape and biodiversity. Roads and railways can present barriers to (and conduits for) movement for species and to a lesser degree vehicle pollution also impacts on biodiversity and hence agriculture and forestry. Conversely, wildfires can have consequences for transport where the fire or smoke encroaches on the network.

The canal and inland waterway is mainly used for leisure activities, although there has been an increase in commercial traffic in recent years and parts of the network are also used for the movement of grey water for industrial use. In winter parts of the network freeze over preventing vessel movement and increasing the damage to vessels and infrastructure and this may be reduced in a warmer climate. However, the greater risk is the availability of water to maintain water depths in the network. As discussed in Section 7.6.2, there is likely to be an increasing gap between water supply and demand, which is likely to put increasing pressure on the use of water storage and reservoirs that are currently maintained for the canal system.

Transport usage is also affected by changes in behaviour of users, for example, changes in holiday patterns. Tourism is discussed further in Chapter 5.

7.6 Water

One of the most significant issues for the water industry in the future will be pressures on the availability of water, which will have consequences for all water users (domestic, industrial, commercial, agriculture, etc.) and the natural environment.

For the purposes of this first CCRA, focus on the UK's water infrastructure has been limited to the infrastructure owned and operated by the regulated water industry, such as water supply network, sewerage network, water treatment works and wastewater treatment works. Out of these, water supply and sewerage performance were identified as being most vulnerable to climate change and have been the focus of the CCRA analysis.

Water infrastructure can actually refer to much more than this and can include (but is not limited to) land and road drainage systems, inland waterways, port and harbour water assets, private reservoirs, flood defence management schemes, etc. (Engineering the Future, 2011).

As well as climate factors, water availability and quality is affected by land use change and a range of social and economic drivers. These drivers include changes in population needs and/or demands, the distribution of wealth, global stability and government decision-making. Population growth represents one of the biggest pressures in parts of the UK, as this increases the demand for water and may also increase pollution pressures, due to both point source pollution from sewer discharges and diffuse pollution from more urbanised environments. Discussion of the water environment is provided in Chapter 8.

7.6.1 Availability

Water availability in the summer is projected to reduce as a result of rising temperatures and reduced precipitation. Whilst little change is projected in overall annual precipitation, in combination with projected increases in temperature and demand (as a result of increases in aridity and population), this would mean that the overall availability of water would reduce.

Large reductions in summer flows could have significant consequences for different users including public water supply, agriculture, industry and the environment. However, some of the consequences for water supplies may be offset by making use of surplus winter flows that are expected to increase under most scenarios. Whilst measures will be taken in the future to adapt to changing water availability, drought is considered to be a major potential risk in the future. This is supported by the aridity projections (see Chapter 3).

The overall impact of climate change on water supplies in the future will be strongly affected by adaptation measures (for example, increased water storage) and changes in regulation (which may come about, for example, as a result of the Water Framework Directive or as part of adaptation) and water use. Future adaptation and regulation measures have not been taken into consideration as part of this analysis.

The current deployable output (i.e. the amount of water that can be pumped from a water company's sources, constrained by licence, hydrology or hydrogeological factors and works capacity) for the UK is 19,500 Ml/day.

Deployable output for the UK is projected to decrease from present day output of 19,500 Ml/day by around 750 Ml/day by the 2020s for the Medium emissions scenario, central estimate (ranging from an increase of 1,200 Ml/day to a decrease of 2,900 Ml/day) and decrease by 3,600 Ml/day by the 2050s (ranging from a decrease of 280 to 6,600 Ml/day).	Medium confidence

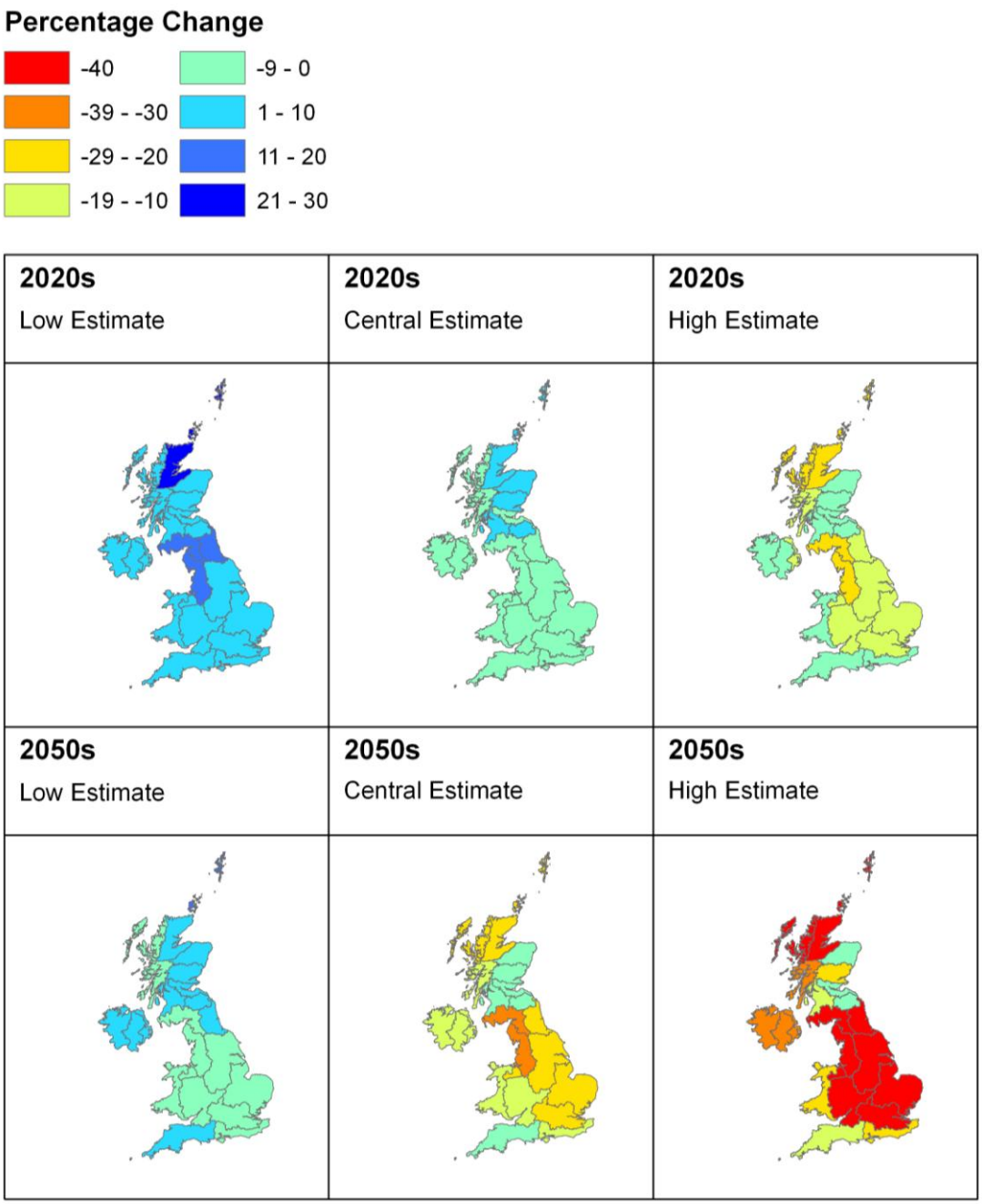
Water shortages are generally considered as only affecting non-essential supplies if the reduction in water availability is in the order of 5 to 10%; a reduction greater than this becomes a threat to essential supplies, although exact figures vary between water companies.

Figure 7.5 shows the projected changes in deployable outputs for different parts of the UK. This shows that there is a projected increase in deployable output for the 2020s p10 or 'wet' scenario, but there is a projected decrease for all other scenarios. This figure also shows that the North West England and Solway river basins are projected to have a significant decrease by the 2050s Medium emissions scenario, central estimate, with the majority of river basins in England and several in northern Scotland having a severe decrease by the 2050s based on the High emissions scenario, high (dry) estimate.

Overall the results for the 2020s are similar to those presented in water company plans. At present the water companies are planning for deficits that lie between the central estimate in Figure 7.5 and the 'dry' estimate for High emissions scenario for the period up to 2035. It is up to individual water companies to consider what level of climate change risk to plan for and if investment is needed they need to present a robust case, using the latest climate change science, to the regulators.

There is also a need to consider how to balance environmental water requirements with demands for water in a changing climate. The UK Government will be required to protect environmental flows under the Water Framework Directive (WFD), yet water may become less available due to climate change and the needs of the many diverse users may increase (e.g. due to increasing population, or the demand for irrigated crops). Abstractors may need to consider new ways of securing water supplies, for example through options for sharing resources (both within and across sectors), forming abstractor groups or developing sites in areas with available water.

Figure 7.5 Projected percentage changes in Deployable Outputs



7.6.2 Water supply

Across the UK the water industry collects, treats and supplies around 18 billion litres of water to domestic and commercial customers on a daily basis. The total amount of water used in the UK is greater than this due to direct industrial, agricultural and domestic abstractions.

Household demand for water is projected to increase in the UK by around 4% by the 2050s for the Medium emissions scenario, central estimate (range 2% to 5%).	Medium

In the near term (2020s), the majority of the UK population will be living in areas with increased pressure on water resources, but the current water resources planning framework is likely to maintain water supplies. In the longer term (2050s), water users may be affected by more frequent restrictions and changing levels of service, unless a wider range of supply and demand measures are taken to close the supply-demand balance. Recent work by the Environment Agency on future water resources suggests that maintaining water supplies in the 2050s will be particularly challenging in the south-east of England and the Midlands, where water availability is most limited. Water resources planning may benefit from taking a longer term view of the potential impacts to support the development of flexible and robust investment plans.

Box 7.6 The Environment Agency's Case for Change

In the Environment Agency's Case for Change (Environment Agency, 2011) analysis is presented on the possible impacts of future pressures on water availability in the 2050s. This was based on a number of scenarios that include a range of projected futures, taking climate change, population growth, demand changes and environmental requirements into account.

The results of the Environment Agency's analysis have been compared with the CCRA results. Because the studies consider different scenarios, data sets and assumptions there are differences in the specific findings. There is complete agreement, however, over the high level findings. In particular:

- Summer river flows are projected to reduce significantly – although there is a large variability in the projections.
- Large reductions in summer flows could have significant consequences for different users including public water supply, agriculture, industry and the environment.
- In the future, the majority of the UK population is projected to be living in areas with increased pressure on water resources.
- It may be necessary to review conservation thresholds as habitats change in character in response to climate change.

Both sets of analysis project water deficits across England and Wales. The Environment Agency's analysis highlights specific deficits for the Thames, Severn and Dee river basins. The CCRA projects similar average supply-demand deficits across large basins in the North West and the Trent and Humber river basins. However, it does not provide the detailed analysis to understand the spatial variations of deficits across or within these basins or northern England. Projections from both studies show that the Thames river basin faces the biggest challenge by the 2050s.

Whilst climate change could affect the access of industrial plants and other businesses to water, industrial demand is a relatively small proportion of overall water demand. It is more likely that adaptive measures or regulation will have a greater impact on water supplies for industry. A particular concern is the need for increased cooling requirements for industrial machinery. Increasing demands for water for business is discussed in Chapter 5 and for agriculture in Chapter 4.

Overall, it is projected that the supply demand balance in the UK may reduce from a surplus of about 1,200 Ml/day (approximately 7%) at present to a surplus of about 240 Ml/day (approximately 1%) by the 2020s (Medium emissions scenario, central estimate) based on present day population (with the range being a surplus of 2,300 Ml/day to deficit of 2,000 Ml/day). However, this assumes that all river basins with surpluses can share that surplus with river basins in deficit. Major water transfers are very expensive, have high energy costs for pumping and also have to be permissible within environmental constraints. Therefore, if river basins with a surplus are

discounted, there would be a deficit of around 380 Ml/day (approximately 2%) by the 2020s (Medium emissions scenario, central estimate), based on present day population (with the range being between zero deficit and a deficit of 2,300 Ml/day). This analysis, however, does not take into consideration future resource development by water companies (for example the building of new reservoirs).

The current water supply surplus in the UK of around 1,200 Ml/day is projected to turn into a water supply deficit of around 5,500 Ml/day[154] (30%) by the 2050s (Medium emissions scenario, central estimate), if it is assumed that there is no transfer of water between river basins and based on projected principal population and no change in consumption rates (with the range being between a deficit of 2,200 and 8,700 Ml/day).	Medium Confidence

The distribution of the supply-demand deficit across the UK is shown on Figure 7.6, assuming no sharing of water between river basins. This shows that the Thames and Humber basins are most likely to be affected in the near term (2020s), with the Anglian, Severn, North West England and Solway basins being significantly affected by the 2050s. The time of greatest water stress is expected to be in the summer, when there would be a reduction in the availability of water. This would lead to more frequent restrictions for use (such as hosepipe bans).

The UK population living in areas affected by a supply-demand deficit is projected to be around 37 million (approximately 60% of the population) by the 2020s for the Medium emissions scenario, central estimate based on existing population figures[155], or 55 million (approximately 80% of the population) based on the principal population projections. By the 2050s, these figures are projected to increase to 54 million (27 million to 59 million) and 74 million (69 million to 76 million) respectively.	Medium Confidence

As well as households, public services such as schools and hospitals are large users of water from both public water supply and their own groundwater abstraction licences.[156] Any disruption of supply for essential services would have significant consequences and maintaining these supplies is a priority in water company drought plans and emergency plans. As discussed in the previous section, a reduction in water availability of over 10% would start to impact upon essential supplies.

There are specific concerns about vulnerable groups and the affordability of water, Box 7.7. At present, water utility bills are highest in the South West of England. In Northern Ireland they have traditionally been included in rates, rather than as a separate tariff.

There is also a spatial dimension to how climate change effects and population growth interact to determine future risks. The CCRA analysis indicates that deficits may develop across England by the 2050s due to climate change alone; these would be exacerbated by population growth, particularly in the Thames and Trent and Humber basins that reflects growing populations in London and Birmingham. After anticipated adaptation, the risks are greatest in the Thames basin and still significant across large areas of the UK.

[154] This is roughly double the water supply requirements for London.
[155] 2008 population estimates
[156] Data on hospital water use is available http://www.hefs.ic.nhs.uk/

Box 7.7 Affordability of public water supply

The future affordability of public water supply was addressed in the Walker Review on Charging and Metering for Water and Sewerage Services (Defra, 2009b). The highest water prices in the UK are in the South West of England where new block tariffs are being trialled with different prices for essential water use, a standard 'block' for water that may be needed for essential use and a premium block of more expensive water for households that consume water for non-essential uses (e.g. for pools, jet sprayers etc). Benzie *et al.* (2011) argued that the lowest income groups may struggle to pay and that some may not be able to reduce water use because they are tenants or can't afford water efficient products. Water companies, however, already operate schemes to protect the most vulnerable. With increasing water scarcity, innovative demand side measures are needed to reduce water use for all customers; particular attention to affordability of essential water resources is important for future policy.

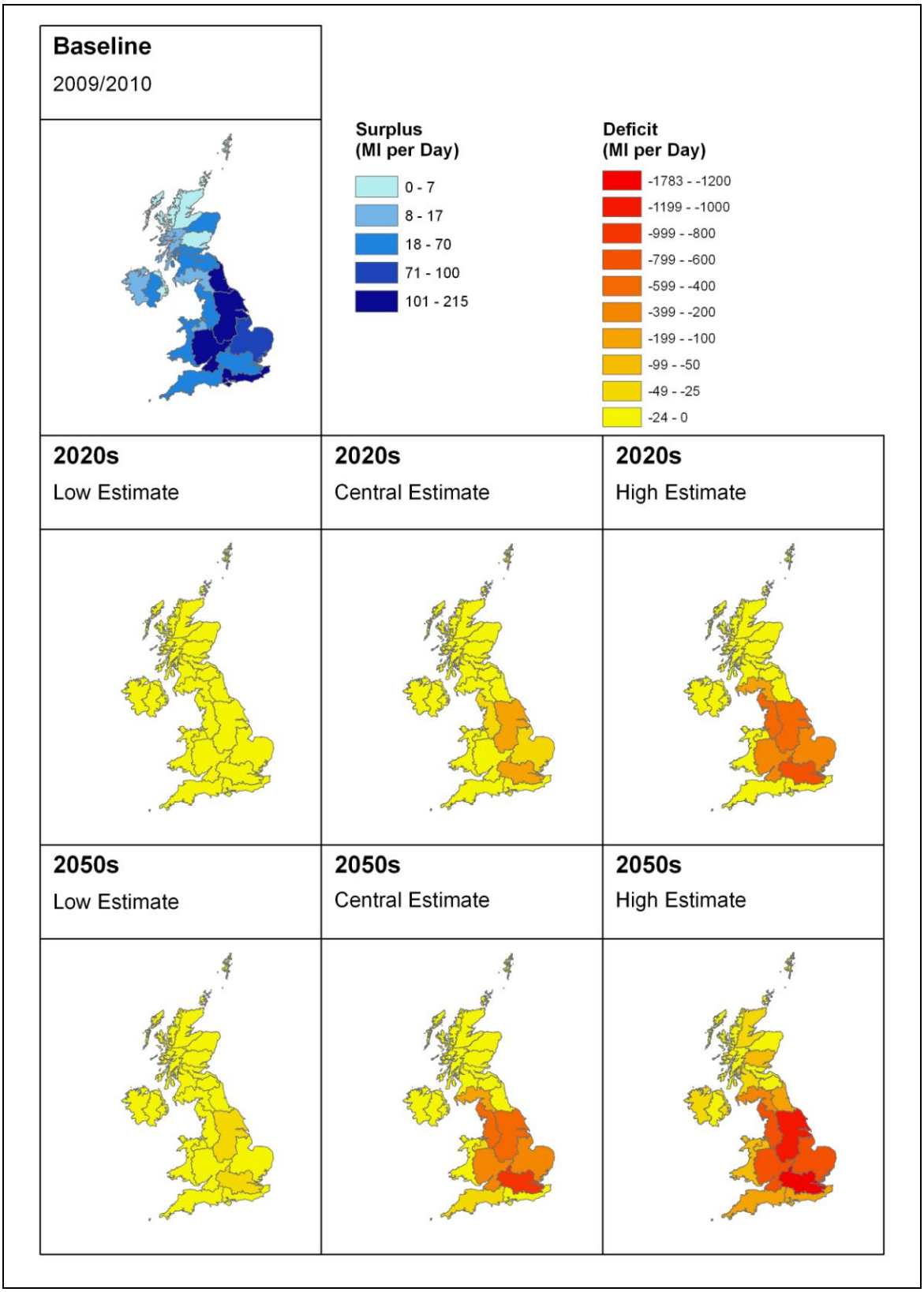
The Government's Water White Paper (Defra, 2011b) sets out measures which enable water companies to take action to reduce the affordability problems households are facing now.

- In October 2011, the Government published draft guidance for both water companies and Ofwat on water company social tariffs.[157] Final guidance to companies will be published in 2012. This will enable water companies to offer more support to customers at risk of affordability problems by introducing their own social tariffs.

- As households in the South West of England face the highest water bills in the country, the Government will fund South West Water to enable it to cut bills by £50 per year for all household customers until at leas the end of the next spending review period.

[157] http://www.defra.gov.uk/consult/2011/10/26/social-tariffs/

Figure 7.6 Projected changes in supply-demand deficit assuming no sharing of water across regions by UKCP09 river basin region



An indication of the likely future stress on water supplies is the number of river abstraction sites with sustainable abstraction.

The number of sites with sustainable abstraction in England and Wales, based on water availability in the local catchment only, is projected to reduce by around 30% by the 2020s for the Medium emissions scenario, central estimate (range being between an increase of 10% and a reduction of 44%) and 46% by the 2050s for the Medium emissions scenario, central estimate (range being between a 19% and 52% reduction). If consideration of downstream catchments is included, then the number of sites reduces by 17% by the 2020s for the Medium emissions scenario, central estimate (range being between an increase of 8% and a reduction of 26%) and 27% by the 2050s for the Medium emissions scenario, central estimate (range being between an 11% and 32% reduction).	Medium Confidence

These figures suggest a significant challenge ahead related to the sustainable management of water resources. There is an urgent need to consider how to continue to maintain public water supply without causing environmental damage as demands for water increase due to climate and socio-economic change. Water could potentially become scarcer as demands rise (e.g. due to increasing population or the demand for irrigated crops) at a time when the UK Government will be required to protect water ecosystems under the Water Framework Directive (WFD). The overall impact of climate change on water supplies will be strongly affected by adaptation measures and changes in regulation and water use.

The CCRA has considered the effects of some demand reductions due to water efficiency, but further adaptation measures and changes in regulation may be needed. The cost effectiveness of different adaptation policies will be considered further as part of the Economic of Climate Resilience study and National Adaptation programme.

Power stations that use freshwater in large quantities will need to invest in water efficiency, particularly if they are located in basins that are likely to experience high water stress.

There is likely to be an increasing risk of drought in future if the summers become warmer and drier. Whilst measures may be taken in the future to adapt to changing water availability, it is expected that drought would remain a major future risk. This is supported by aridity projections, which indicate that the dry summer of 2003 may become a typical summer by the 2050s.

Water supply infrastructure may become increasingly vulnerable to flooding as flood risk increases. This in turn would affect water supplies and potentially lead to failures of supplies, as occurred in England during the July 2007 floods. This has not been quantified in the CCRA analysis owing to a lack of suitable data, but is considered to be an important potential impact of climate change.

The potential consequences of deterioration in raw water quality are also important for the water industry and other abstractors, including increased GHG emissions and costs associated with water treatment (borne by the water companies and ultimately their customers). Raw water quality is discussed in Chapter 8, but the knock-on effects for abstractors have not been analysed as part of this first CCRA.

7.6.3 Wastewater collection

Over 16 billion litres of wastewater is collected and treated every day by the water industry (URS, 2010).

Many wastewater collection systems (also known as urban drainage systems) are combined sewer systems that drain surface water as well as wastewater. When these combined sewer systems are full, excess water is either discharged via Combined Sewer Overflows (CSOs) or in extreme events flooding can occur out of manholes. Surface water flooding in urban areas can be either pluvial (i.e. direct runoff from rainfall) or sewer flooding or a combination of both. Flooding contaminated with sewage has additional risks to health and results in higher repair costs for affected properties and longer periods of disruption.

Surface water flooding

There are national data available on present day flood risk for surface water flooding, although this only includes a simple (and approximate) allowance for sewer flooding. This provides estimates of present day flood risk for 0.5% (1:200) annual probability using flood depth categories of <0.3m, 0.3 – 1.0m and >1.0m. However, data are not available for other flood frequencies or future projections of surface water flooding resulting from climate change. It was, therefore, not possible to provide projections for future surface water flood risk as part of the CCRA analysis.

Sewer flooding

Sewer flooding was not analysed as part of this first CCRA, but in subsequent cycles it may be possible to do so by building on some recently completed modelling work. One study, commissioned by Ofwat, looked at the impacts on sewer systems in England and Wales up to the 2040s (Ofwat, 2011). It considered not only the impacts that may result from climate change, but also those that arise from changes in population and housing growth, and urban creep (increasing drained area). Looking at population growth and urban creep provides a potential useful perspective in terms of considering the relative influence of socio-economic factors on sewer flooding.

The study concluded that climate change 'has the potential to bring a significant increase in sewer flooding' (Ofwat, 2011). Results from the analysis showed a 27% increase in sewer flooding due to climate change by the 2040s (based on the Medium emissions scenario, central estimate). Taking into consideration population and property creep, this figure increases to 51%.

While it was not an aspect considered in detail, the report also concluded that sewer overflow spill frequency and volume would increase, with the changes largely in proportion to increases in flood volume.

CSO spills

The discharge from CSOs (also known as spills) can be used as an indicator of how frequently sewerage systems would fill in the future. An estimate has been made of the frequency of heavy rainfall events that may cause CSO spills. The results suggest that CSO spill frequency would increase in the future, based on rainfall projections, but the confidence in these results is considered low.

This risk is currently being considered in greater detail by the UK Water Industry including estimates of the future investments that may be required to manage increases in CSO volume, whether this is at source using sustainable drainage systems (SUDS) or 'end of pipe' solutions (UKWIR, 2011a forthcoming). The Flood and Water Management Act when implemented will increase the uptake of SUDS in new

developments and re-developments in England and Wales, helping to reduce flooding and sewer capacity problems.

CSOs intermittently discharge dilute, untreated sewage into rivers. An increase in CSO spill frequency and duration could lead to a reduction in water quality depending on the nature of the discharge and the receiving water. For example, discharges from CSOs following intense summer rainfall when flows in the receiving water may be low would offer less dilution. Sensitive waters, such as bathing waters, are likely to be more vulnerable to possible pollution from CSOs and action may be required if there is a deterioration in water quality to maintain health protection and tourism status (see Chapter 6).

Emergency overflows at pumping stations can also discharge into watercourses. These are designed to prevent flooding in the upstream system if the pumps fail. If power is not available for any reason to operate the pumps, this would trigger these additional spills to watercourses. This is an example of a potential infrastructure 'cascade failure'.

7.6.4 Interdependencies

The water sector is a highly integrated system, with water and wastewater infrastructure being dependent on multiple elements within the sector.

The following represent some of the interdependencies with other infrastructure sectors considered as most critical by stakeholders. Further examples of interdependencies can be found in the Engineering the Future report (2011).

- The Water Industry is a very large electricity consumer and only has limited capacity to continue operations if the supply is interrupted. Therefore, any disruption or failure of the energy supply has severe consequences for water supply.
- Any increase in demand in energy from the water sector would have consequences for the energy sector. Certain impacts of climate change, for example on water quality and treatment processes, may lead to the use of more energy to maintain compliance with standards. In their ARP reports, many water companies recognised their dependence on energy supplies and the importance of energy efficiency and carbon management as an aspect of their business. Overall changes in the water balance, costs of energy and commitments to enhance the environment could create increasing pressures on the costs of water.
- The energy sector is also reliant on water for power station cooling. Therefore, there can be competing demands on the water resource (in the case of non-coastal power stations) between sectors.
- ICT is very important for the monitoring and control systems for both the networks and treatment works.
- Transport is often required for disposal of waste offsite. When sewers flood the water is often conveyed along roads causing traffic disruption.

The water sector also has important interdependencies with the other themes in this report. These include:

- Agriculture and Forestry: the demand for water for agriculture; soil erosion and sediment loads and water quality of rivers; and the runoff of pollutants from agricultural land deteriorating water quality.

- Natural Environment: changes in water availability, water quality and water temperature may have implications for habitats and species in aquatic and marine environments and, therefore, ecosystem services; while an increase in certain invasive non-native species may affect water quality and water industry assets.
- Business: changes in water availability could restrict industrial abstractions, potentially disrupting certain processes; and in extreme cases affect businesses reliant on the public water supply.
- Health and Wellbeing: an increase in outbreaks of water-borne diseases would have health implications; while supply-demand deficits may lead to disruptions in water supply to homes potentially affecting the elderly, the very young, the ill and the disadvantaged.

7.7 ICT

Information and Communications Technology (ICT) networks are vulnerable to extreme weather events and these events will continue in the future and may increase in severity or frequency. The UK's infrastructure is heavily reliant on ICT networks. Therefore, any disruption to ICT service provision can have knock-on effects and in extreme cases has the potential to result in 'cascade failures' across infrastructure sectors.

7.7.1 Infrastructure

Horrocks *et al.* (2010) concluded that the majority of devices (computers, mobile phones, etc.) typically used in the UK already have operating tolerances that will accommodate the projected temperature changes, provided they are installed and maintained appropriately. It is the enabling infrastructure (both below and above ground) that is vulnerable to the weather conditions surrounding it, which can have consequences for service provision. ICT infrastructure is already vulnerable to extreme weather damage or disruption and increasing temperatures (particularly heatwaves) and more frequent flooding are the main areas of concern for the future.

The ICT industry is of the general view that the broader ICT infrastructure is relatively resilient to disruption, because the telecommunications grid is much more distributed (than, for instance the energy grid) as a variety of technologies are being used. Very few impacts would be expected to affect the entire national ICT network. The majority of impacts would cause disruption at the level of individual organisations or local geographical areas. Some of the more remote parts of the UK may be particularly vulnerable, where the network is limited.

However, the national ICT network is only part of the international network, upon which UK users are becoming increasingly reliant. The sector has links to many parts of the world that may experience significant impacts from climate change, such as India, China, South America and Siberia (Horrocks *et al.,* 2010). Therefore, resilience of ICT infrastructure overseas, including the one million kilometres of submarine fibre-optic cable, is also very important. However, the scale of this vulnerability has not been assessed.

7.7.2 Demand

It is estimated that about 80% of businesses are 'heavily dependent' on ICT, and therefore any disruption to ICT provision would have immediate effects. It has not been possible to provide an estimate of the number of days that might be lost due to disruption to ICT owing to a lack of suitable data. However, the risk of major ICT disruption due to climate change is considered to be relatively low for large businesses, as they are often based in large urban centres and have flexibility in managing their ICT systems. Smaller companies (including SMEs) and remote workers, on the other hand, are much more vulnerable to ICT disruption and the knock-on effects are far greater. This is because they are often dependent on a single link which, if it fails, causes a complete loss of service.

An increased dependence on ICT services during extreme events, such as people either choosing or forced to work at home (as experienced during the winters of 2009 to 2011), would also add to the difficulties for the industry in providing a high quality, uninterrupted and reliable service.

The likelihood of decreased productivity and revenues for UK businesses due to ICT loss/disruption is discussed in Chapter 5.

7.7.3 Interdependencies

According to recent studies (Horrocks *et al.,* 2010; URS, 2010), the UK, including its infrastructure, is heavily reliant on the effective functioning of ICT and this dependency is likely to grow.

ICT (both the devices and infrastructure) is also dependent on energy supplies (data centres are particularly heavy electricity users) and any disruption in energy supply would have direct consequences for ICT systems. In addition, energy demands for ICT would increase with increased air temperatures, for example, cooling requirements of data centres, which would mean that operating costs would increase.

Increasing pressures on energy usage (whether climate driven or not) would mean that the ICT industry would need to adapt. For example, Horrocks *et al.* (2010) suggest that in some instances there may be a commercial interest in developing devices and components with higher temperature operating regimes. Alternatively, the siting of data centres in the UK may become increasingly dependent on access to cool air for 'free air cooling systems'[158]. This may present opportunities for the cooler regions of the UK, especially as part of the transition to a low carbon economy, although at present there is still a mindset in businesses for having data centres on site or nearby. With perhaps the exception of the financial sector, which relies on extremely fast data transfer, most businesses would notice no difference in speed of transfer if the data centre was located remotely.

Cloud computing[159] and the use of overseas data centres is predicted to grow dramatically over the next few years (Foresight, 2011a). The relatively high costs of construction, land and electricity currently make the UK a less attractive location for data centres than other parts of the world. However, some of these overseas locations may be more vulnerable to climate change (both extreme events and long-term gradual change), which may result in damage locally, but disruption internationally. Data centres in warmer climates may also become less attractive in future should average

[158] Free-air cooling of data centres can be either direct (where external air is used to cool the facility) or indirect (where air from within the facility is passed through a heat exchanger against external air). Use of free-air cooling reduces the need for conventional air-conditioning, but is reliant on relatively cool external temperatures.
[159] A general term for anything that involves delivering hosted services (e.g. business applications such as office suites, online gaming, etc.) over the internet.

air temperatures increase and the resultant increased costs of cooling outweigh other cost savings.

Data centres also release large amounts of heat into the surrounding environment, which can exacerbate the urban heat island effect.[160] Opportunities may exist to utilise the waste heat in district heating schemes (e.g. an office block or housing estate nearby), but this is of greater benefit in the cooler months. Therefore, a move away from the urban centres may have secondary benefits for the urban environment.

7.8 Evidence gaps

A common theme across buildings and infrastructure is the evidence gaps associated with extreme events. Many of the weather and climate related threats facing buildings and infrastructure in the UK relate to extreme events. Providing projections of future changes to extreme events is a developing area of science that is particularly challenging due to the limitations in the current generation of climate models. This is discussed further in Chapter 9.

7.8.1 Buildings and the urban environment

Examples of areas where further work could underpin more robust projections and adaptation strategies for the built environment sector include:

Heat related issues

- It is unclear from the UKCP09 projections how extremes are likely to change relative to mean temperatures, yet it is during heatwaves that heat related impacts and consequences may be most significant.
- Future cycles of the CCRA should aim to exploit more recent research into UHI effects, which were unavailable when the CCRA analysis was being undertaken.
- Further research to relate specific building types to indoor thermal comfort would provide a much better understanding of the thermal performance of buildings. Coupled with this, further research into what constitutes overheating would also be beneficial.[161]
- More research is needed to improve understanding of the mechanisms by which vegetation cools the surrounding environment.

Water

- Improved understanding of the effectiveness of water efficiency and technology and behavioural change due to water scarcity.

Flooding

- The analysis for this first CCRA focuses on river and tidal flooding in England and Wales, as comparable data are not yet available for surface water flooding. There is an urgent need to further develop projections of future surface water flood risk in England and Wales and for all types of flooding in Scotland and Northern Ireland for the next CCRA.

[160] An average data centre can release around thirty times more heat than an equivalent sized office (personal communication with industry expert).
[161] This research need has already been identified by DCLG.

- Further analysis is needed to understand the correlation between estimated annual damages to properties from flooding compared to insurance claims and how this may change in the future.

Subsidence

- Access to high-resolution soil data was a significant limitation of the analysis undertaken.
- It would also be beneficial to explore the correlation between stock replacement rates and soil types.

Energy demands

- Understanding the influences of population growth and increasing numbers of properties in the future and how these may offset the projected reduction in heating demand, would lead to a better understanding of future winter energy demands.
- Data on energy demand for cooling for both domestic and non-domestic properties would increase confidence in the projections of cooling energy demand.

Further information can be found in the Built Environment Sector Report.

7.8.2 Energy

Key areas where more clarity is needed about the effects of climate change on the energy sector include:

- Site-specific flood risks to individual locations where energy infrastructure is located.
- Relating CDD to energy demand taking into consideration non-climate factors (such as building stock and uptake of air-conditioning).
- Positive and negative impacts of warmer temperatures on electricity demand and supply and the interdependence between these impacts.
- Climate projections for other parts of the world relevant to the UK energy sector (e.g. the Middle East).
- The particular vulnerability of cities to climate change.
- The impact of climate change on the UK's wind energy resource.
- Timescales within which different adaptation approaches need to be implemented in order to be successful.

More broadly, future climate change risk assessments should aim to look more closely at alternative future pathways for delivering a low carbon economy (in particular regarding the future energy mix) and how these may be affected by climate change.

There are also areas where gaps in data could also be filled. For example, data are not available to assess the vulnerability of gas infrastructure to permanent inundation by sea level rise.

7.8.3 Transport

The underlying issue for this sector is a lack of coherent data across the UK, resulting in a predominantly qualitative assessment with a significant amount of uncertainty in the outcomes. Improved record keeping is required across all modes of transport, for example delay times, if the analysis that has been undertaken as part of this CCRA is to be built upon for future assessments.

Many impacts on the transport sector could not be analysed due to lack of knowledge regarding trigger mechanisms and thresholds. For example, impacts such as flooding and bridge scour are location specific and the trigger mechanism will vary from location to location. A detailed inventory of all hard infrastructure and past climate events is required to complete a detailed analysis of such impacts.

A specific gap in knowledge relates to railway embankment stability. Work is in progress to evaluate the potential risks to railway embankments from climate change, which may be suitable for use in the next CCRA (Loveridge *et al*., 2010). Academic research is also ongoing in this area, including the CLIFFS[162] and BIONICS[163] projects.

Further uncertainties relate to the climate change drivers; the majority of analysis for this CCRA has focused on UKCP09 temperature and precipitation data. Other impacts would need projections for climate variables that are not available yet, such as wind and visibility projections. As stated earlier, projections for extreme events would also be an important step forward. The uncertainty surrounding offshore wind and storm projections is a major limitation with attempting to assess future risks for shipping and offshore renewable energy.

The transport sector is integral to the smooth running of society and the economy and further work is required to help meet the challenge of establishing reliable and relevant climate change impact projections and adaptation strategies. Technological innovation should be considered alongside other socio-economic factors and Government policy, such as a low carbon future (see Section 7.4.5). Ongoing research, such as the TRACCA project (Tomorrow's Railways and Climate Change Adaptation), will be a first step to providing more knowledge in some areas.

7.8.4 Water

Despite the extensive work already undertaken in this sector, there are a number of areas where additional research would either strengthen the evidence base on which climate change impact projections can be made, or inform decision-making on potential adaptation measures. They include:

- The potential impact of climate change on water quality.
- The environmental impacts of drought (and climate modelling of droughts lasting more than one season).
- Incentives and mechanisms that could encourage water trading between water companies.
- Mechanisms for encouraging increased efficiency in water use.
- Methods for increasing energy efficiency/decrease energy use in water and wastewater treatment.
- The impacts of changes in water demand on river flows.

[162] http://cliffs.lboro.ac.uk/
[163] http://research.ncl.ac.uk/bionics/

- Techniques enabling early detection/attribution of manmade climate-related impacts on the water sector.
- Development of tools and techniques for scaling up local case studies to UK level.

Any future changes in drought magnitude and frequency are likely to have the greatest impact on water resources, and therefore a key area where more research is required. At present this is an area where different views exist. For example, some recent papers have suggested an increase in rainfall droughts (Vidal and Wade, 2009) but others, including recent Met Office Hadley Centre research, have concluded that while there is a tendency for increased drought, it is not yet possible to robustly project changes in UK meteorological droughts arising from increased greenhouse gases (Burke *et al.,* 2010). Therefore, new research on future droughts is likely to improve evidence in this area prior to the next CCRA.

7.8.5 ICT

There is a limited evidence base regarding climate change impacts for the ICT sector. This makes forward planning difficult and is compounded by the short-term business models applied by industry.

ICT within the context of our future climate are important due to the interdependencies described in earlier sections of this chapter. Further research and awareness-raising is needed regarding the resilience of ICT systems. It is particularly important that the role of ICT systems in potential cascade failures is understood more fully, especially in light of the growing usage of ICT systems and the sharing of ICT infrastructure within the UK and abroad.

7.9 Summary

Buildings and infrastructure (and the built environment as a whole) are affected by both extreme events and long-term gradual climate change.

Flooding is the most significant risk in the near-term (at present and by the 2020s) and is projected to continue to be one of the most important threats in the medium (2050s) and long-term (2080s). Water availability and overheating of buildings are projected to become significant in the medium-term (by the 2050s) most notably in England.

Buildings, energy, transport, water and ICT are highly interdependent and these interdependencies may increase in the future, due to socio-economic changes. These interdependencies mean that the vulnerability of one sector can influence the vulnerability of the other sectors and failure of one element can lead to other ‘cascade failures’.

Energy policy is a major socio-economic driver affecting not only the energy sector, but all sectors that are dependent on energy, including transport, water, ICT, businesses and buildings. As the UK moves towards a low carbon economy, vulnerability to climate change is likely to change, presenting both threats and opportunities for buildings, infrastructure and the built environment as a whole.

Spatial planning also has a key role influencing climate change vulnerability and particularly maximising the benefits for those living and working in our towns and cities. The long life of buildings and infrastructure assets means that future changes in vulnerability need to be planned and designed for now. Not only does climate change need to be factored into new buildings and infrastructure, but programmes need to be put in place for improving the resilience of existing buildings and infrastructure.

This chapter has provided an overview of the risks posed to buildings and infrastructure as a result of climate change, drawing on the risk metrics that have been developed as part of this assessment as listed in Table 7.2.

Decisions made now in the design of new buildings, for instance, will determine how resilient they are to future warmer temperatures, increased flood risks and pressures on water resources, and how easily they can be adapted in future refurbishments as climate risks become clearer. Similarly, infrastructure needs to be maintained and upgraded to ensure it can cope with rising temperatures; it is resilient to extreme weather events, such as floods and droughts; and it can take account of changing patterns of consumer demand (with regards to energy, water, travel and ICT).

The potentially most significant extreme events in the future will be flooding. The CCRA analysis has highlighted that a sizeable proportion of infrastructure and public services are already in flood risk areas and this would increase in the future, based on current climate projections. Widespread floods can cause serious indirect impacts, including damage to important energy, water, ICT and transport infrastructure. They can also interfere with basic public services such as schools and hospitals. The likelihood of flooding of buildings (both residential and non-residential) is also projected to increase, which would have consequences for businesses including the insurance industry (as discussed in Chapter 5) and the health and wellbeing of the UK's population (as discussed in Chapter 6).

Extreme events that have happened in the past have helped to highlight the critical interdependencies between different sectors of infrastructure, buildings and the built environment in general and where they have led to 'cascade failures'. Extreme events will continue to be a characteristic of the UK's future climate, with or without the effects of climate change. Therefore, understanding the consequences of these events, in particular with respect to cascade failures, is very important in order to maintain and improve the resilience of the UK's infrastructure, buildings and communities. Analysis of these cascade failures has not been undertaken as part of this first CCRA. Therefore, any estimates regarding the potential scale of these failures would be pure supposition. However, the CCRA analysis has helped to highlight where significant vulnerabilities exist that may trigger cascade failures.

The most significant long-term gradual climate change impacts on buildings and infrastructure (for which there is greatest confidence in the projections) relate to overheating and water availability.

The overheating of buildings, and in particular the Urban Heat Island effect in some of England's largest cities, would become a significant problem by the 2080s, based on current climate change projections. The effectiveness of green space would diminish and increased demands for cooling may lead to mal-adaptation, exacerbating the UHI effect. However, this would be less of an issue in the Devolved Administrations.

There are significant pressures on water availability in the UK that could increase due to drier conditions and rising demands. These pressures affect the north and west as well as the south east of England; North and south Wales, parts of Scotland and Northern Ireland. In the near term (2020s) the current water resources framework is likely to maintain water supplies but in the longer term (2050s, 2080s) further measures and potentially a step change in our approach will be required to manage water sustainably.

Resilience in the built environment will depend on widely dispersed decision-making in the public and private sectors and, therefore, poses a particular capacity challenge, which potentially extends beyond the established levers of spatial planning, building regulation and industry best practice.

Opportunities resulting from direct physical climate change impacts are limited, but a decrease in demand of heating is projected with a high degree of confidence.

Otherwise, the main opportunities for the building and infrastructure industries (as highlighted under Business above) arise from the move to a low carbon economy and delivery of adaptation measures.

Energy policy is a major socio-economic driver affecting not only the energy sector, but all sectors that are dependent on energy, including transport, water ICT, businesses and buildings. As the UK moves towards a low carbon economy, vulnerability to climate change is likely to change presenting both threats and opportunities for infrastructure and the built environment.

Table 7.2 Scorecard for Buildings and Infrastructure

Metric code	Potential risks for buildings and infrastructure	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
BE9	Reduction in energy demand for heating	L	1	2	3	2	3	3	2	3	3
MA5	Opening of Arctic shipping routes due to ice melt	M	1	2	2	2	2	3	2	3	3
EN1	Energy infrastructure at significant risk of flooding	H	2	3	3	2	3	3	3	3	3
FL11b	Sub-stations at significant risk of flooding	H	2	3	3	2	3	3	3	3	3
FL12a/b	Hospitals and schools at significant risk of flooding	M	2	3	3	3	3	3	3	3	3
FL13	Ability to obtain flood insurance for residential properties	M	3	3	3	3	3	3	3	3	3
FL7a	Non-residential properties at significant risk of flooding	H	1	3	3	2	3	3	2	3	3
FL7b	Expected Annual Damage (EAD) to non-residential property due to flooding	H	2	3	3	3	3	3	3	3	3
FL6b	Expected Annual Damage (EAD) to residential property due to flooding	H	3	3	3	3	3	3	3	3	3
FL6a	Residential properties at significant risk of flooding	H	2	2	2	2	3	3	2	3	3
FL15	Flood risk for Scheduled Ancient Monument sites	H	1	2	2	2	3	3	2	3	3
WA3	Reduction in water available for public supply	M	1	2	3	2	3	3	2	3	3
BE3	Overheating of buildings	H	1	2	2	2	2	3	2	3	3
EN2	Energy demand for cooling	H	2	2	2	2	2	3	2	3	3
FL11a	Power stations at significant risk of flooding	M	2	2	2	2	2	3	2	3	3
WA8	Number of unsustainable water abstractions (total)	M	1	2	2	2	2	3	2	3	3
FL8a	Roads at significant risk of flooding	H	2	2	2	2	2	3	2	3	3
FL8b	Railways at significant risk of flooding	H	2	2	2	2	2	3	2	3	3
WA5	Public water supply-demand deficits	M	1	1	2	1	3	3	2	3	3
WA6	Population affected by water supply-demand pressures	M	1	2	2	1	2	2	2	2	3
BU10	Loss of staff hours due to high internal building temperatures	M	1	2	2	1	2	3	1	2	3
WA10	Combined Sewer Overflow spill frequency	L	1	1	1	2	2	2	3	3	3
BU2	Monetary losses due to tourist assets at risk from flooding	M	1	1	2	2	2	3	2	3	3
BE5	Effectiveness of green space for cooling	M	1	1	2	1	2	3	2	3	3
TR6	Scouring of road and rail bridges	M	1	1	2	1	2	3	1	2	3
BE2	Increased subsidence risk due to rainfall changes	M	1	1	2	1	2	2	1	2	2
MA7	Potential disruption to shipping due to rough seas	L	~	1	~	~	2	~	~	2	~
EN10	Energy transmission efficiency capacity losses due to heat - over ground	H	1	1	1	1	1	3	1	2	3
TR1	Disruption to road traffic due to flooding	M	1	1	1	1	1	2	1	2	3
TR2	Landslide risks on the road network	M	1	1	1	1	1	2	1	2	2
EN3	Heat related damage/disruption to energy infrastructure	L	1	1	1	1	1	1	1	1	1
WA4	Change in household water demand	M	1	1	1	1	1	2	1	1	2
TR5	Rail buckling risk	H	1	1	1	1	1	1	1	1	1
EN4	Risk of restrictions in water abstraction for energy generation	M	1	1	2	1	1	2	1	1	2
TR4	Cost of carriageway repairs due to high summer temperatures	M	1	1	1	1	1	1	1	1	1
BE1	Urban Heat Island effect	H	Too uncertain*								
BU5	Loss of productivity due to ICT disruption	L	Too uncertain								

**This is because magnitude is site specific*

M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

8 Natural Environment

Overview	
• Recent changes in the natural environment have been driven principally by land use change and management. Climate change is expected to play a bigger part in driving change in the natural environment, impacting biodiversity and ecosystem services more in the future. The magnitude of climate change impacts may be mediated by management and use of land and the natural environment. • Due to the inherent complexity of ecosystems and non-linearity of many of the responses to climate parameters, it is difficult to assess the magnitude of future risks to biodiversity with any certainty. A particular climate driver may give rise to multiple threats and opportunities, affecting individual species or habitats differently; the responses of species and/or habitats are also location and scale dependent. However, the direction of change and trends are apparent in many cases. • There is high uncertainty for a number of impacts in this theme where the potential impacts may also be large, particularly over the long-term e.g. ocean acidification.	
Threats	**Opportunities**
• Coastal change, water availability and quality changes and species' inability to follow range shifts: Coastal zones, uplands, semi-natural grasslands, wetlands and freshwater are particularly vulnerable. • Changes in soils, invasive non-native species, pests and diseases become increasing pressures to biodiversity and ecosystem services. • New conditions may favour generalist species, pests, diseases and invasive non-native species, leading to a reduction in biodiversity and disrupting ecosystem services. • Phenological mismatch may lead to disruption of food species and put species and ecosystem services at risk.	• Better conditions for some flora and fauna, although this will tend to favour generalist species that are more adaptable over the specialists that are more specific in their habitat requirements. • Increased productivity in forests and woodlands due to increased temperatures where drought, pests, pathogens and other pressures are not limiting factors.
Threats & Opportunities	
• Climate mitigation and adaptation strategies have the potential to endanger or to enhance biodiversity. • Changes in species' ranges may present primarily threats, but also some opportunities, for wider biodiversity and ecosystem services. • New fish species, changes in marine community composition and increased levels of human activity present both opportunities and challenges for marine management.	

Figure 8.1 Summary of natural environment impacts with an indication of direction, magnitude and confidence

8.1 Introduction

The natural environment is the complex of the biological and physical environment, crucial to human wellbeing and sustainable development. Changes in climate are expected to have a range of direct and indirect impacts on the natural environment. The impacts on the natural environment are linked to the changes in biological and physical processes describing the interactions between atmosphere, land and water. The ecosystem services (products of the natural environment) underpin many of the other themes in the CCRA, including timber production in Agriculture and Forestry, hazard regulation in Business, control of pests and diseases in Health and water supply and quality under the Buildings and Infrastructure theme.

The current threats to biodiversity within the natural environment as a consequence of land use changes and other pressures have been widely reported (Lawton et al., 2010). Climate change is an additional pressure on biodiversity and the ecosystem services provided for human use and wellbeing. In some cases, opportunities will be created, in others the changes will have a neutral effect, but in many cases further pressure will damage the services we receive. The direction of change, magnitude of the impacts and association with other drivers of change, such as land use change, are often uncertain. Vulnerability to climate change varies from species to species and the adaptive capacity of the natural environment it greatly dependent upon the way in which the landscape in the UK is managed.

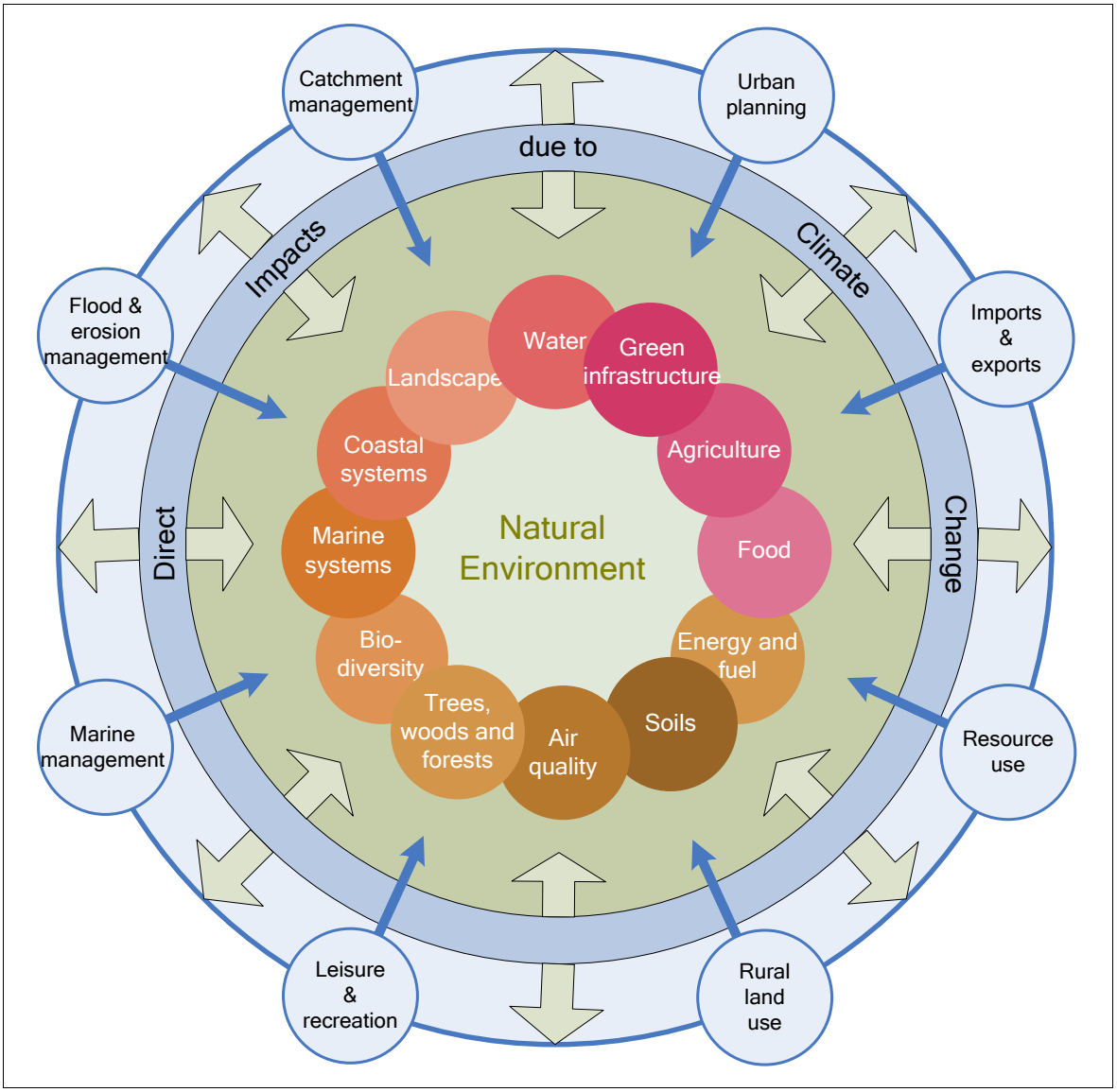
"*The natural environment underpins all aspects of our lives. It will be affected by climate change, and yet we will be increasingly reliant on it to help us manage the impacts that a changing climate will bring"* (Defra, 2010f).

The natural environment encompasses a range of elements that broadly characterise the physical and biological world including plants, animals and landscape. One view of the constituent parts of the natural environment is summarised in the descriptions given around the central ring of Figure 8.2 (landscape, water, etc, based on Defra, 2010f), this guides the discussion on the natural environment in this chapter. The terrestrial, freshwater and marine environments in the UK cover a range of habitats including agricultural, woodland, open water, wetland, coastal and marine habitats. Collectively these host the UK's biodiversity (i.e. diversity at the genetic, species and ecosystem level). The biophysical processes occurring within the natural environment, including the daily functioning of ecosystems and the occurrence of extreme events such as flooding and coastal erosion, are an intrinsic part of the natural environment.

A variety of services, or outputs, from ecosystems provide benefits for people, broadly classified as supporting, provisioning, regulating and cultural services. For example, food, energy and fuel are provisioning services provided by nature. Green and blue infrastructure is a strategically planned network of high quality green spaces, waterways and natural environmental features that draw on ecosystem services for society (Defra, 2010f). The natural environment thus covers a range of ecosystems,

habitats, biodiversity, biophysical processes, services and managed features (summarised in the centre of Figure 8.2).

Figure 8.2 An illustration of the constituent parts of the natural environment and the direct and indirect impacts of climate change
(Adapted from Defra, 2010f)



The inner circle describes the range of features that make up the natural environment. The thick blue circle surrounding these represents direct impacts on the natural environment e.g. sea-level rise. Direct impacts drive changes in the natural environment itself and impact the indirect impacts (shown in the outer-most circles) which in turn also drive changes in the natural environment. Furthermore, adaptation actions may influence both the inner circle of features that make up the natural environment as well as the direct and indirect drivers, e.g. resource use, catchment management etc. It is important to note that these divisions are made for descriptive purposes and that direct and indirect drivers often interact to affect a particular consequence in the natural environment.

In the following sections some initial background on the Natural Environment theme is followed by more detailed consideration of:

- The direct impacts of climate change and the implications for habitat and species distribution, ecosystem function and community composition; and
- The indirect consequences due to changes in land use and management, which may need to be adapted in response to climate change, with resultant knock-on effects on the natural environment.

Figure 8.1, at the beginning of this chapter, provides a summary of the risks considered as part of the more detailed assessment work in this study and provides an indication of how the magnitude of risks arising from the Medium emissions scenario, central estimate changes over time. Further detail of the risks relevant to this theme, with more information on how the magnitude of the risks vary under different scenarios is provided in the scorecard at the end of the chapter, Table 8.8.

Note that there are overlaps between the content of this chapter and Chapter 3 on bio-physical impacts and similarly on agriculture and forestry impacts as discussed in Chapter 4. However, this chapter draws out the consequences of these impacts in the context of the natural environment; biodiversity and ecosystem services.

8.1.1 Direct and indirect climate change impacts

Climate change can bring about direct and indirect impacts on the natural environment. Direct impacts are those that directly bring about a change in species, habitats, biodiversity and ecosystems. Indirect impacts are caused by societal responses to climate change rather than by climate change itself. The main direct and indirect impacts on the natural environment are summarised in Table 8.1 (after Mitchell *et al.*, 2007).

Table 8.1 Direct and indirect impacts

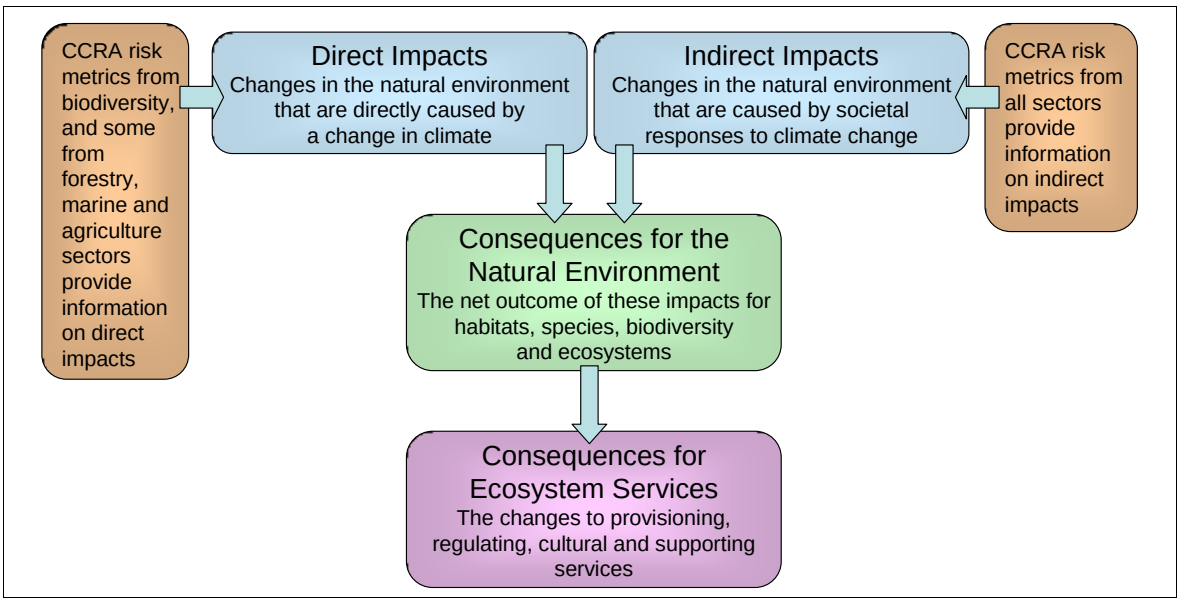
Direct impacts	Indirect impacts
• Changes in climate space[164] leading to shifts in species distribution and ranges. • Loss of physical space along coastlines due to sea level rise and coastal erosion and at altitudinal limits due to temperature increases. • Changes in phenology (seasonal timing of life cycle events). • Phenological mismatch. Changes in phenology may lead to misalignment between species that depend on others for survival. • Arrival of non-native species. • Changes in community composition. • Change in inter-species competition. • Changes in ecosystem function and processes, including areas such as water quality, as modified by climate and exposure to extreme events such as drought, floods and storms.	• Changes in socio-economic drivers; including social values, working practices, policies and resource use. • Changes in land management including crop types, management for carbon sequestration, production of biomass, creation of ecological networks. • Catchment management approaches to water resource and quality issues, flood and erosion control and hydropower. • Management of the marine environment; including fisheries policy and renewable energy development. • Planning and development of rural and urban areas, which affects energy use and the inclusion of natural features and biodiversity within the built environment. • Land used for leisure and recreation. • International effects; imports and exports e.g. of food.

[164] The term "climate space" refers to the geographical area that is suitable for a particular species, based on the climate parameters within which the species can survive and reproduce. Climate space does not take into account other factors, such as topography, food or water availability that might impact upon the species actual geographical range (realised range).

These broad direct and indirect impacts are generally cross-cutting issues across more than one, if not all, elements of the natural environment. This is illustrated schematically in Figure 8.2, which shows the direct impacts on the constituent parts of the natural environment (shown in the ring in the centre). Direct impacts are driven by changes in temperature, rainfall, storms, sea level, etc., and the biological responses to these changes. The same changes in climate can also influence other societal responses. A selection of the most relevant societal responses is captured in the outer ring in Figure 8.2. These then also have an indirect impact on aspects of the natural environment.

This risk assessment has considered a range of climate change risks across a number of sectors. Each of these risks has either a direct or indirect impact on the natural environment. Figure 8.3 illustrates the relationship between the risks examined in this study (the CCRA risk metrics) and the impacts and consequences for both the natural environment and ecosystem services that it provides.

Figure 8.3 Relationship between CCRA risk metrics, climate change impacts and consequences for the natural environment and ecosystem services



The current state of the natural environment in the UK has already been changed from its character in past years, decades and centuries due to a number of drivers including climate change. The discussion that follows focuses on potential future impacts of climate change to the 2020s and 2050s from the 2010 baseline. The changes in the natural environment that occurred before 2010 are not covered here as they have been investigated in the UK National Ecosystem Assessment (see Box 8.1).

Box 8.1 National Ecosystem Assessment (UK NEA, 2011)

The NEA provided a comprehensive overview of ecosystem services in the UK, including their current status and trends, together with a future outlook. It explores the drivers of change impacting on ecosystems (see Figure 8.4), and the services which flow from them to deliver a range of goods that we value individually and as a society. Broad habitats were used to provide a high-level framework through which ecosystems were characterised.

The NEA acknowledges that there are currently many knowledge gaps and uncertainties. In particular, it was not possible to comprehensively quantify relationships between biodiversity and ecosystem services because of differences in knowledge across taxonomic groups relative to the functions and services they provide. Some services were also better characterised than others in the NEA, depending on data availability. Cultural services were particularly challenging which was attributed to the complex inter-relationships between biodiversity, culture and human wellbeing.

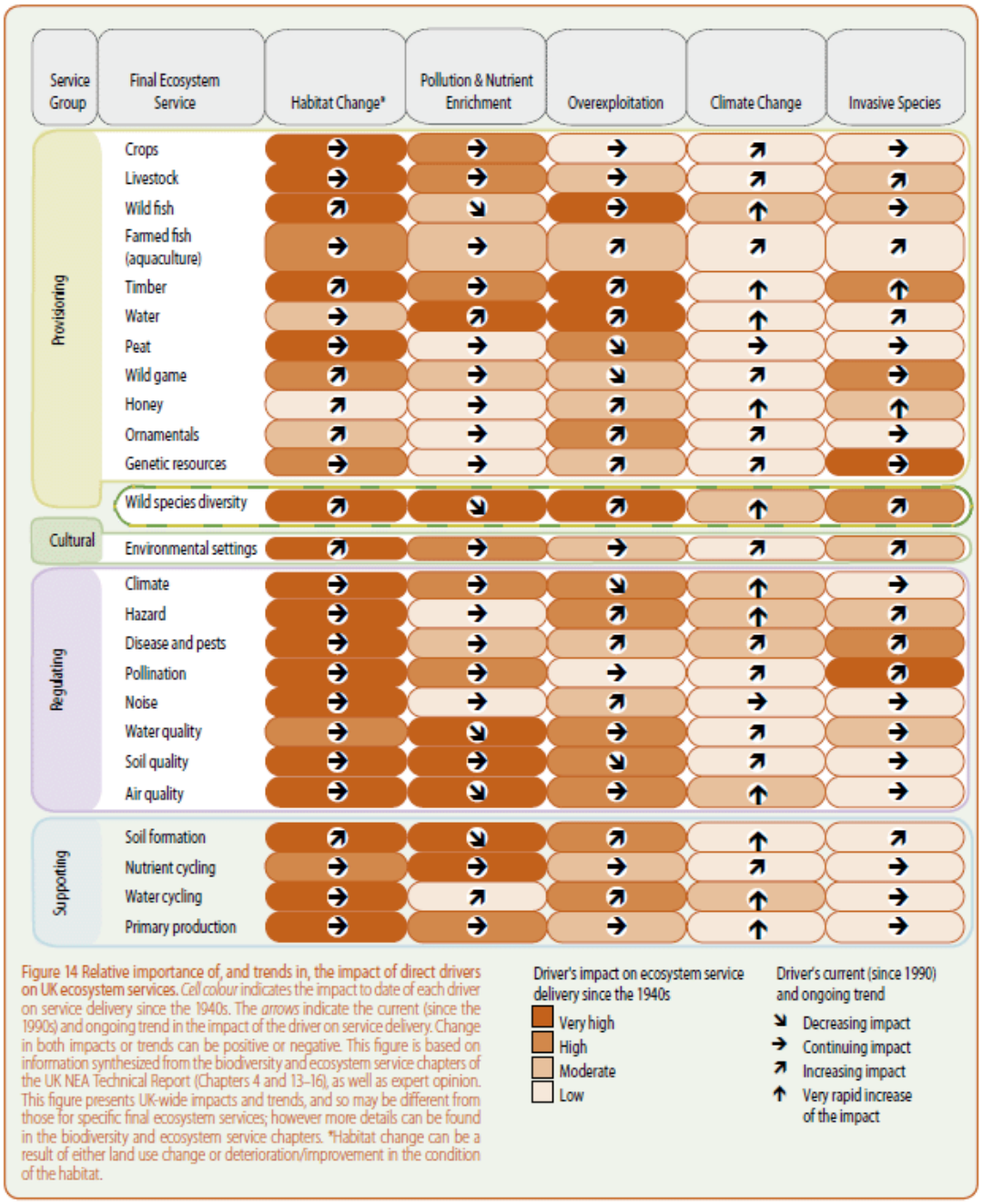
Nevertheless, the NEA developed an economic framework to provide indicative values for ecosystem services, and complemented this with non-monetary values for health and shared social benefits to represent their broader value to human wellbeing. The NEA found that over 30% of services are in decline, often due to long-term declines in habitat extent or condition.

The emphasis of this chapter is on the direct impacts to the natural environment, with less emphasis on indirect impacts and ecosystem services. Risks related to both indirect impacts and ecosystem services are also covered under the other themes, although not necessarily using "ecosystem services" terminology. The types of ecosystem services important to the other themes are summarised here in Table 8.2.

Table 8.2 Relationship between ecosystem services and other themes

	Agriculture & Forestry (Ch. 4)	**Business** (Ch.5)	**Health & Wellbeing** (Ch.6)	**Buildings & Infrastructure** (Ch.7)
Supporting	Soil formation, nutrient cycling, water cycling, primary production (Ch. 3)			
Provisioning	° Timber & biomass production ° Crop production ° Animal products ° Water supply ° Wild species diversity	° Fisheries & aquaculture ° Water supply ° Crop production ° Animal products ° Renewable energy	° Crop production ° Animal products ° Water supply ° Wild species diversity	° Water supply ° Renewable energy ° Building materials
Regulating	° Climate regulation ° Pest and disease regulation ° Water, soil & air quality ° Hazard regulation ° Pollination	° Water supply ° Water quality ° Hazard regulation	° Water, soil & air quality ° Hazard regulation ° Erosion control ° Pest and disease regulation ° Climate regulation	° Hazard regulation ° Erosion control ° Pest and disease regulation ° Regulation of local climate
Cultural	° Recreation ° Wild species diversity	° Recreation & tourism ° Historic & spiritual services ° Wild species diversity	° Recreation (conservation sites) ° Historic & spiritual services ° Wild species diversity	° Historic & spiritual services ° Recreation (green space)
Key	Underpinning and/or indirect		Direct	

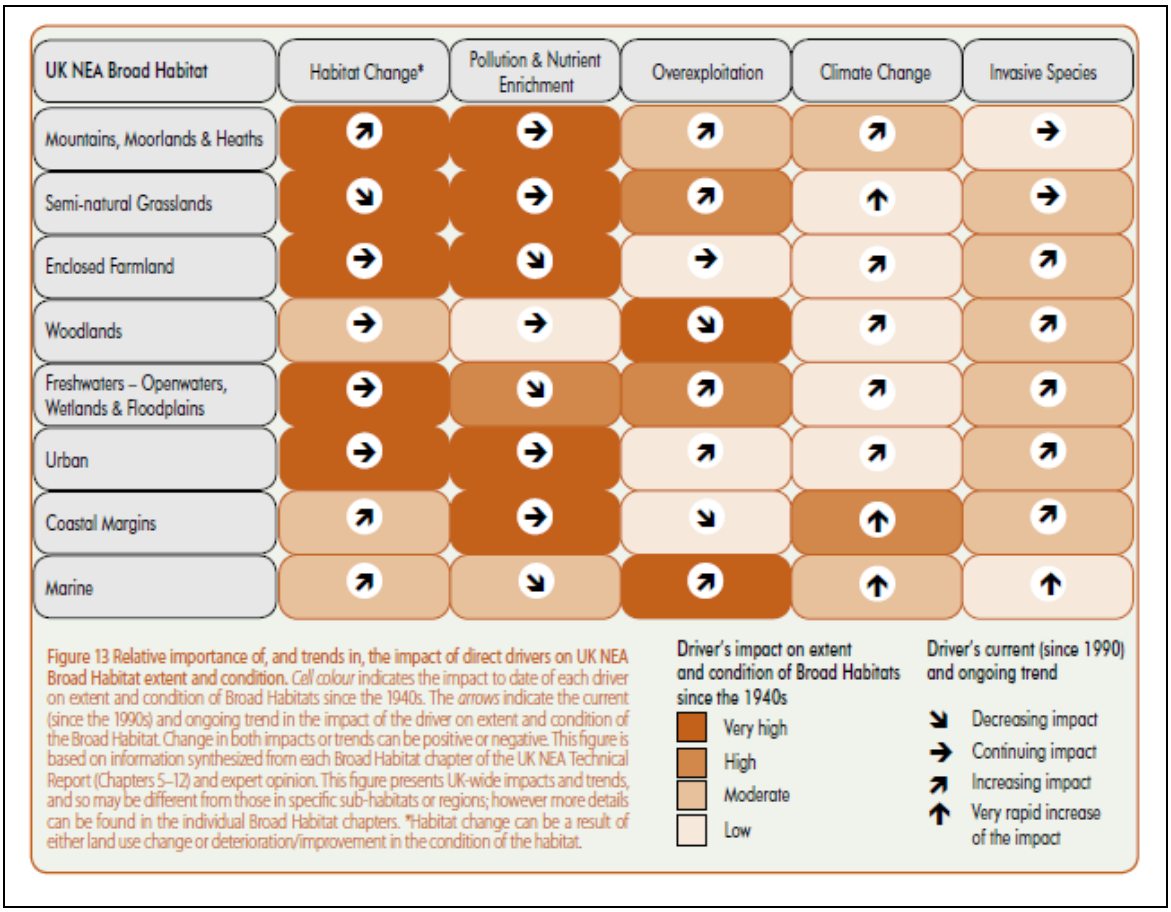
Figure 8.4 Influence and trend of different drivers on ecosystem services
(Source: UK NEA, 2011)



8.1.2 Drivers of change in the natural environment

Climate change is one of a number of drivers of change in the natural environment (Lawton *et al.*, 2010; Watson and Albon, 2010), including future changes in demographics, economic growth, technologies, policy and regulation and societal preferences. For some of the climate change impacts examined in this study and other assessments, non-climate related drivers may be most important in determining outcomes (see Figure 8.5). The potential increase of forest extent affected by pests and pathogens, for example, may be influenced more by the control of trade and imports than by a change in climate.

Figure 8.5 Relative importance of, and trend in, the impact of direct drivers on UK NEA Broad Habitat extent and condition
(Source: UK NEA, 2011)



The changes in the natural environment that climate change and other drivers will bring about will be both positive as well as negative; for example, England's southern species may be able to increase their range by expanding north (Lawton *et al.*, 2010), whilst those in the north may struggle to retain suitable niches[165]. The consequences of negative impacts are likely to outweigh the positive impacts if no action is taken now to allow species to adapt to climate change. A species ability to increase its range also depends on other factors, such as the availability of suitable habitat and its own ability to disperse; some species may simply not be able to keep pace with the changes (Travis, 2003). A number of broad principles and ideas around how to manage adaptation of the natural environment to climate change have been established (Defra, 2010f; Hopkins *et al.*, 2007; Smithers *et al.*, 2008; Mitchell *et al.*, 2007). This report focuses on the potential consequences of climate change for the natural environment and does not explore the range of managed adaptation strategies that are needed.

Climate, principally temperature and precipitation, is a key factor in influencing the overall distribution of terrestrial ecosystems, habitats and species; a natural process that has occurred for millions of years. Similarly, water temperature is the key factor for marine ecosystems, habitats and species. Biodiversity is sensitive to rapid climate change (as already experienced) because it is already under pressure from a range of other factors, such as land use change. Areas of good quality habitat that do remain,

[165] The term "Ecological niche" refers to the position of a species within an ecosystem, comprising its individual species habitat requirements including all the physical, chemical and biological conditions required by that species for survival, growth and reproduction.

such as in protected sites, are often too fragmented, too small or lack the diversity needed to allow species to adapt on a UK scale.

8.1.3 Vulnerability

Current vulnerability to change is generally greatest for uplands, coasts and wetlands and habitats and species at either the southern end or lower altitudinal limit of their climate range. The inherent vulnerability of a species or habitat is very important when trying to assess the potential impacts of climate or other environmental change. Certain physiological and life cycle traits may make species inherently vulnerable or resilient to disturbance, including climate-related disturbance, see Table 8.3.

Table 8.3 Physiological and life history traits that may make a species more or less vulnerable or resilient to climate-related disturbances
(Adapted from Steffen *et al*., 2009)

Species at least risk	**Species at most risk**
• Physiological tolerance to a broad range of factors such as temperatures, drought and flooding • High degree of phenotypic plasticity (ability to change observable characteristic or trait) • High degree of genetic variability • Short generation time (i.e. life cycle) and short time to sexual maturity • High fecundity (reproductive ability) • 'Generalist' requirements for food, nesting sites, etc. • Good dispersal capability • Broad geographic range	• Narrow range of physiological tolerance to factors such as temperature, drought and flooding. • Low genetic variability • Long generation times and long time to sexual maturity • Specialised requirements for other species (e.g. for a disperser, prey species or pollinator) or for a particular habitat that may itself be restricted (e.g. a particular soil type) • Poor dispersers • Narrow geographic ranges

An example of how inherent species traits affect vulnerability can be found in Northern Ireland, where species such as Wood Crane's-bill (*Geranium sylvaticum)* has a very restricted range and is currently in decline (DOENI, 2005); whereas, bracken (*Pteridium aquilinum*), which produces spores in copious amounts, particularly in wet environments (Conway, 1957), is increasing in range.

Habitats and species can also exhibit rather different responses to change depending on their local context. The BICCO-Net project assessed the impact of climate change on UK biodiversity by analysing long-term monitoring data on eight terrestrial taxa. The results show complex responses of populations. The project included a broad range of research on the influence of climate on birds and the findings highlight that changes in climate can bring about significant constraints on bird populations as well as benefits for some selected species. Different species have varying sensitivities to weather patterns, but the impacts of temperature changes can be distinguished whilst precipitation changes are often more complex. This can make management of the UK protected site network for the benefit of these species and habitats very challenging. Whilst data on specific species groups, such as birds and butterflies, is well established and recorded in the UK, more systematic UK-level collation and interpretation of site monitoring and other available data (e.g. phenology), against inter-annual patterns of

climate variability and trends of long-term change, tends not to be as good[166]. This is particularly the case at the habitat and ecosystem level. At a local scale, some sites may be very well monitored. However, using data collected from one site to inform the management of another site may not lead to the most optimum outcome due to local differences in species responses.

Vulnerability may be increased or decreased by the way in which the landscape is managed. The presence of man-made fixed defences on coastal and river floodplains, and zones of erosion, separate active and non-active areas of the coast or fluvial zone. Such defences disrupt the natural process of erosion and deposition, which acts to the detriment of many habitats. By reducing the ability of ecosystems to respond to change, there is an increased likelihood of non-linear step changes that can cause a major decline in biodiversity. Large declines in biodiversity can negatively impact upon the delivery of key ecosystem services that support human wellbeing such as freshwater provision and soil formation. The role of ecosystem services is not well recognised in all sectors. This may lead to these services being vulnerable to climate change adaptation responses and mitigation efforts that focus only on potential impacts on one sector rather than also considering the associated consequences for ecosystem services. Constructing larger flood defences as an adaptation response to climate change, for example, may result in a decline in the delivery of ecosystem services, if such adaptation is not managed with due attention to ecosystem services.

The potential biophysical impacts arising from climate change are discussed in Chapter 3. This chapter focuses on what the potential changes in biophysical processes mean for the natural environment. The impacts on the natural environment are considered in terms of the impacts on nature itself as well as the consequences these impacts have for the resources and services provided to society by the natural environment.

8.1.4 Adaptive capacity

Consideration of adaptive capacity in the CCRA primarily focussed on the adaptive capacity in human, as opposed to natural, systems. In the natural environment, both the inherent adaptive capacity of natural systems plus the socio-economic factors determining the ability to implement planned adaptation measures (Lindner *et al.*, 2010) is vital to understanding the level of risk. Socio-economic factors that determine adaptive capacity to climate change include economic development, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital (McCarthy *et al.*, 2001).

All species are expected to be able to adapt to changes in their environment to an extent. The response they can make to changes in climate depends on a number of factors that can be classified as either ecological or evolutionary adaptive responses.

Evolutionary adaptive responses refer to the ability of a species as a whole to adapt through natural selection (genetic adaptation) to changes in its natural environment. Those species with higher genetic variation within their population are more likely to be able to adapt over time, than those with lower genetic variation. Indirectly, population size and the rate of environmental change also affect a species' ability to adapt in evolutionary terms, to its natural environment, with large population sizes and slower rates of change being more favourable. More specialist species are likely to be more vulnerable, as their specialism at a genetic level is also often low and, therefore, their evolutionary responses more limited. Increases in success of generalist species over specialist species will be at the expense of diversity and, in the long-term, the adaptive

[166] For example, upscaling of sensitivity data from freshwater ecosystems for regional and national-scale assessments to understand the interactions between water temperature, water quality and water quantity on priority habitats and species is currently only available at site level (Biodiversity & Ecosystem Services Sector Report).

capacity of the system. Capacity for evolutionary adaptation is very difficult to quantify across many species and this was not undertaken for this cycle of the CCRA. Theoretically, evolutionary shifts may also be preceded by reductions in population sizes, putting species at increased risk from other effects of climate change such as phenological mismatch, habitat type and extent changes, predator and disease pressure and changing prey base (Williams *et al*. 2008).

Ecological adaptive responses refer to the physiological and/or behavioural plasticity of a species. It is thought that in most cases, ecological responses are going to be more important than evolutionary responses in adapting to changes that occur quickly. This is because ecological plasticity can occur within one generation, but evolutionary adaptation occurs over multiple generations. This will of course vary between species, not least because generation times will differ. Ecological responses include (Williams *et al*. 2008):

- Shifts in distribution, following changes in "climate space";[167]
- Contraction of range into areas that remain suitable (refugia);[168]
- Changes in phenology (seasonal timing of life-cycle events);
- Acclimatisation to the new climate;
- Changes in the type of habitat or micro-habitat used; and
- Changes in interactions with other species.

The ability of a particular species to adapt using these mechanisms will be constrained by the factors described in Table 8.3.

The extent to which a species is required to adapt to changes in climate will also depend on its exposure to those changes. The degree of exposure may be mitigated by the actual degree of climate change that occurs in the area in question, buffered by local microhabitats and the extent to which behavioural responses can reduce exposure e.g. seeking shade during the middle of the day (Williams *et al*., 2008).

Ecosystems as a whole also exhibit natural adaptive capacity; in part, this derives from the natural adaptive capacity of the species within those ecosystems, but capacity is also related to the diversity within and across the species within the ecosystem, the ecological niches and habitat availability, and ultimately to the structure and functioning of an ecosystem. The ability of species within communities to respond to a changing environment allows ecosystems to cope with, modify and buffer changes while still providing a range of ecosystem functions. This resilience is important when trying to understand the level of risk posed by environment change, including climate change. Unfortunately, whilst complexity has been recognised as a vital component of the adaptive capacity of ecosystems, there is still a lot to learn about the application of these principles (van de Koppel *et al*. 2005).

The way in which the landscape is managed is very important, as different ways of managing the landscape may either help or prevent natural adaptive responses and the species and ecosystem level to take place. Natural adaptive capacity needs to be facilitated by human organisational adaptive capacity, as many habitats are currently maintained by human interventions. Therefore, it follows that maximum adaptive

[167] The term "climate space" refers to the geographical area which is suitable for a particular species, based on the climate parameters within which the species can survive and reproduce. Climate space does not take into account other factors, such as topography, food or water availability that might impact upon the species actual geographical range (realised range).

[168] Species range contraction into areas that remain suitable for their climate requirements may lead to small groups of individuals becoming isolated from the rest of their species and is thought to increase their risk of localised extinction.

capacity will be realised when organisational adaptive capacity acts to enhance the natural adaptive capacity already present within an ecosystem.

8.2 Direct impacts

Climate change may change the geographical ranges of species, leading to local extinctions and new compositions of species within UK habitats. Changes in climate space, water availability and coastal change would test the UK's protected sites network in its support of UK biodiversity and maintenance of ecosystem services. Areas outside protected areas would be required to support species to maintain the adaptive capacity of the natural environment to the pressures that climate change may add. Phenological change puts some species at risk of local extinction and subsequent disruption to food webs may prove even more serious. Pests, diseases and invasive non-native species may benefit from a changing climate. Warmer winters may allow over-winter survival, supporting their populations and increasing associated problems. Species specific responses have the potential to lead to changes in the composition of species seen in the natural environment. The vulnerability of some more specialist species may lead to the overall reduction in biodiversity at a UK scale, having knock-on consequences for ecosystem services, such as pollination.

Primary productivity, nutrient and water cycling and soil formation underpin many of the goods and services that humans obtain from the natural environment. Regulation of soil, water and air quality, hazards, carbon and erosion creates the stable environment upon which we draw on important ecosystem goods. Yet our knowledge of this area and the magnitude of the impacts that climate change will have in future is limited. The complexity of ecosystems means it is difficult to project future risks with certainty. The evidence suggests that changes are inevitable, but rates of change are less certain. This unpredictability has very important implications for the many services we obtain from the natural environment.

This section outlines the implications of the direct impacts of climate change on the natural environment, loosely following the list given in Table 8.1.

8.2.1 Changes in species distribution and range

The geographical range that a species occupies is driven by a number of factors. Depending upon the geographical scale, different drivers of range will have different levels of influence over the actual range realised by a species. At the regional level,

climate influences a number of the environmental conditions that determine the prevalence of species of flora and fauna. Temperature and water availability in particular may determine the spatial extent and distribution of species. As conditions change with a change in climate, so too may the distribution and ranges of species. At a smaller scale, topography, soil types, nutrient availability, pollution, disturbances such as fire or land-use change and habitat fragmentation begins to have a large influence over the realised range of a species. At a smaller scale still, local patches of habitat, interactions between species and micro-environmental characteristics, such as amount of shade and aspect with respect to the sun, also influence species' distribution (Whittaker, Willis and Field, 2001).

The geographical extent of suitable climate parameters for a particular species is known as its climate space. A change in climate will change where the climate space for a particular species is found. This varies from species to species and must not be confused with the actual geographic area in which the species in question is found. Whilst temperature is a key climate parameter for analysing climate space, water availability is also very important and affects the total range and distribution within that range that a species can tolerate. Physical disturbance, such as coastal erosion and flooding, also impacts upon the distribution of species and habitats. Changes in the frequency, severity or duration of such disturbance influence the ability of a given species to survive. Tolerances to disturbance vary between species.

The geographical extent realised by a species has implications for the network of conservation sites within the UK. As a general rule, the larger the protected site, the greater its resilience to changes in climate. However, it is the connectivity of these sites and the suitability of the areas outside of the protected sites that is thought to affect species abilities to adapt to changes in climate.

Changes in Climate Space

The term "climate space" refers to the geographical area that is suitable for a particular species, based on the climate parameters within which the species can survive and reproduce. The evaluation of climate space does not take into account other factors, such as topography, food or water availability that might impact upon a species' actual geographical range.

Detailed analysis of changes in climate space across a range of species has been carried out by the MONARCH and BRANCH projects using UKCIP02 climate projections. The MONARCH3 analysis (Harrison *et al.*, 2001; Berry *et al.*, 2007; Walmsley *et al.*, 2007) categorised 32 UK Biodiversity Action Plan (BAP) priority species using four categories; Gain, Loss, No Change and Shift. Species that gain climate space include birds, such as the stone-curlew and turtle dove, species of butterfly, some bats and some plants also may potentially gain climate space within the UK. Priority species such as the capercaillie, black grouse and skylarks may loose climate space in the UK and species such as the tree sparrow, stag beetle and barbastelle bat present either no projected changes or a northward shift of their climate space. This must be interpreted with caution as these represent the geographical area these species may survive in based on climate parameters only and do not include factors such as the availability of suitable habitat that may affect the realised range of the species in question and their total population size. The realised actual ranges of these species may differ from the projections, but the exercise does highlight those species that may be under more pressure than others from climate change.

The BRANCH project modelled 386 species, primarily plants. Table 8.4 presents an assessment of the likelihood, based on climate space alone, of species expanding in range within, or moving into, the UK (Berry, 2007). A third of the species in Table 8.4

are not native to the UK, which could have important implications for the management of the ecological network; this may challenge the definition of native species and change the species and/or communities for which a number of sites are designated and/or managed.

Table 8.4 The likelihood of European species gaining over 50% new potentially suitable climate space from 2020s to 2080s (UKCIP02 High emissions scenarios)
(Source: Berry, 2007)

Likelihood of expansion over 50%	Common name
Exceptionally unlikely	Wild service tree, Turtle dove
Very unlikely	Silver-studded blue, Dormouse, Whitebeam, Chalk milkwort, Wood spurge
Unlikely	Yellow-bellied toad, Grey-headed woodpecker, Mastic tree, Valonia oak, Narrow-mouthed whorl snail, Marsh gentian, Lady's mantle
As likely as not	Southern damselfly, Shrubby seablite, Red-tipped cudweed, Narrow-leafed ash, Oleander, Aleppo pine, Stone curlew, Flowering ash, Olive, Wheatear, Portuguese oak
Likely	Hop hornbeam, Spiny broom
Virtually certain	Bristle bent, Midwife toad, Purple emperor, Creeping marshwort, Box, Nightjar, Dwarf sedge, Chequered skipper, Cetti's warbler, European fan palm, Steppe grasshopper, Zitting cisticola, Western whip snake, Lily of the valley, Stinking hawks beard, Middle spotted woodpecker, Black woodpecker, Little egret, Reed bunting, Herb Robert, Silver-spotted skipper, Icterine warbler, Wryneck, Sand lizard, Wood white, Wood lark, Large copper butterfly, Adonis blue, Chalkhill blue, Marbled white, Granville fritillary, Heath fritillary, European bee-eater, Common vole, Swallowtail, Herb Paris, Wall lizard, Oxlip, Downy oak, Agile frog, Pool Frog, Greater horseshoe bat, Lesser horseshoe bat, Shore dock, Fire salamander

A further assessment of likelihood of extinction is provided in Table 8.5 based upon those species that are projected to lose 90% or more of their climate space in the UK and for which the future climate space area is not projected to overlap with the current area of suitable climate space (Berry, 2007). The inability of some species to disperse and track their changing climate space is likely to lead to the loss of biodiversity.

Table 8.5 The likelihood of extinction of species based upon loss of climate space from 2020s to 2080s (UKCIP02 High emissions scenarios)
(Source: Berry, 2007)

Likelihood of extinction	Common name
Virtually certain	Hawkweeds, Shetland pondweed, Woolly willow, Whorl snail
Likely	Bittern, Red-tipped cudweed, Slender naiad
As likely as not	Meadow pipit, Twite, Pied flycatcher, Narrow-headed ant, Dune gentian, Wryneck, Red-backed shrike, Twinflower, Fen orchid, Small cow-wheat, Wheatear, Grey partridge, Narrow-mouthed whorl snail, Oblong woodsia
Unlikely	Yellow-necked mouse, Stiff sedge, Prickly Sedge, Scottish scurvy-grass, Scottish wood ant, Black-backed meadow ant, Wood crane's-bill, Sea pea, Lax-flowered sea-lavender, Red-necked phalarope, Roseate tern, Capercaillie, Round-mouthed whorl snail
Very unlikely	Water vole, Reed bunting, Southern wood ant, Common scoter, Bird cherry, Yellow marsh saxifrage
Exceptionally unlikely	Bullfinch

The potential risk is that the persistence of the existing climate in upland and montane locations will be reduced and ultimately lost as they become warmer and the existing climate space is pushed from its altitudinal limit. Upland and montane habitats and species, of which there are only small areas at their southern limits in England and which are more abundant in Scotland and North Wales, are therefore the most vulnerable to climate change (Mitchell *et al.*, 2007). Species such as dwarf willow (*Salix herbacea*) and trailing azalea (*Loiseleuria procumbends*) are projected to lose all of their climate space from upland areas such as the Pennines, Lake District and North York Moors, where they currently occur, by the 2050s (Harrison *et al.,* 2001). There is a particular threat to rare, isolated, specialist species, which may be lost to the UK, for example the mountain ringlet (*Erebia epiphron*) (Harrison *et al.*, 2001). There are also opportunities for some species and habitats (Hopkins *et al.*, 2007), which may increase in distribution and extent as higher altitudes become within their tolerated temperature range and assuming that their existing lower altitudes do not warm beyond their tolerance, for example lowland meadows.

Box 8.2 Topography and altitudinal gradients

Topography is a key influence on local climate patterns and their spatial variability. Hence in mountainous areas (notably Scotland, Wales, Northern England), an altitudinal gradient can be important in determining a species' typical range because average temperatures reduce with altitude (Berry *et al.*, 2005, Mitchell *et al.*, 2007, Hopkins *et al.*, 2007). With regard to climate change, this can produce local-scale variations to the more general latitudinal (i.e. south-north) shifts in climate space. As a broad generalisation, species will respond to a warming climate by moving up an altitudinal gradient, either retreating from stressful warm conditions (including increased competition) or expanding up into areas that were once too cold for their survival. Work by Franco (2006) indicates that local climate warming has been of comparable importance to habitat loss in driving local extinctions of northern species of butterflies in Britain over the past few decades. Future modelling in the MONARCH project indicated that for 7 out of 12 of the species investigated, their climate space would move with altitude and their abundance would shift up-slope, especially under the High emissions scenarios (see Biodiversity & Ecosystem Services Sector Report).

However, the degree of change in the range of species does not just follow a temperature gradient. Another climatic variable may be more important than temperature for some species: for example, Crimmins *et al.* (2011) have highlighted observations in North America of species moving downhill in response to climate change, due to the changing water balance being the dominant influence rather than the rising temperatures. Aspect can modify temperature gradients, as south-facing slopes intercept more solar radiation than north-facing slopes. Wind exposure can also provide a major restriction on the upward expansion of some species. Alternatively, recent changes may not be due entirely to climatic warming: Britton *et al.* (2009) found that lichen species richness declined in the alpine zone of Scotland, but that this response was probably due to the effects of nitrogen pollution. At the downhill edge of a species range, biotic interactions may become the driving force, rather than the physiological stress imposed by temperature (Brooker, 2006).

Marine species may also experience similar pressure to move in range; warm-water marine species have been shown to expand their ranges in a pole-ward direction (i.e. northwards in the northern hemisphere) and into deeper, cooler waters. Analysis conducted by Burrows *et al*. (2009) on inter-tidal invertebrate species suggests that of the 44 species of algae, sponge, anemone, worm, crustacean and mollusc assessed, 16 species were projected to expand their range in the British Isles, 4 were projected to experience a contraction in range and 16 would experience no change. Analysis conducted by Huntley *et al*., (2007) suggests that by the end of the 21st century, as a result of changes in climate, species such as the great skua and Arctic skua may no longer breed in the UK and the range of black guillemot, common gull and Arctic tern may all shrink significantly to the extent that breeding colonies would only persist in Shetland and the most northerly tips of mainland Scotland, whereas they currently exist further south. These projections seem sensible given that these species, particularly the skuas, are confined to colder parts of the northern hemisphere (Furness, 1988) and that their food is not necessarily confined to such areas. The projected extinctions of both skua species are of conservation concern, given that Arctic skua numbers in the UK have declined rapidly in recent years (JNCC, 2009) and the UK holds 60% of the world breeding population of great skuas (Furness and Ratcliffe, 2004). Huntley *et al.*, (2007) also projected that by the end of the 21st century many other species would no longer be breeding in south eastern England, but it is uncertain whether the total numbers of these animals would decrease substantially, given that only a small proportion of the UK's population breed there. Often research into changes in the marine environment of this type focuses on fish species of commercial importance. Changes in fish distribution would not only impact fishermen and dependent coastal communities, but such changes would also have important consequences for other components of the ecosystem. For example, some species of toothed whales and

dolphins are showing shifts in distribution around the UK, which may be linked to increasing sea temperatures and changing prey availability (Evans *et al*., 2010).

Species most likely to be affected by changes in their climate space are those where the climate effect is compounded by biotic factors, i.e. those that have limited dispersal ability or barriers to dispersal, limited genetic adaptability, and occupy specialised ecological niches.

Water availability

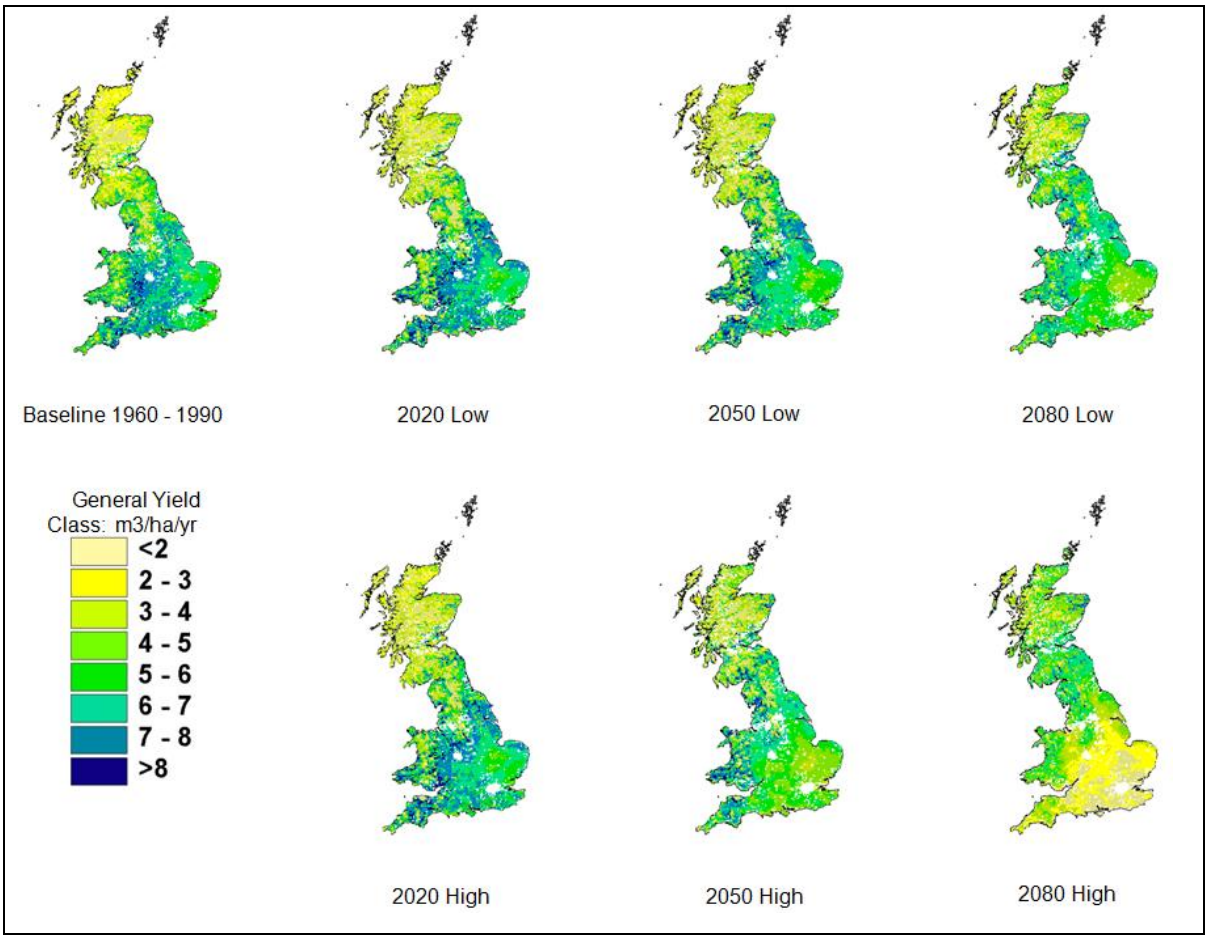
Beech woodland

The European beech (*Fagus sylvatica* L.) is usually the dominant species within two priority habitats identified by Annex 1 of the EU Habitats Directive: *Asperulo-Fagetum* beech forests, which occur on neutral or calcareous soils (notable examples include the beech hangers of the Chilterns, Cotswolds and East Hampshire); and Atlantic acidophilous beech forests, which occur on acid soils (notable examples exist in Epping Forest and the New Forest). These beech woodland habitats are typically associated with thin soils that have a relatively low available water capacity (AWC) that increases their vulnerability to drought.

Future projections of climate suitability for beech suggest that lowland beech woodland habitat may decline as it loses climate space in the south and east of England, where it currently prevails (Broadmeadow *et al.*, 2005, Harrison *et al.*, 2001), but is unlikely to be lost completely (Mitchell *et al.*, 2007), Figure 8.6. For further discussion on forest production see Section 4.2.4.

Although these model projections suggest beech is likely to decline, differences in soils and topography also imply considerable variation in response, with beech being unlikely to be lost completely in these locations (Mitchell *et al*., 2007). The MONARCH2 project could not find conclusive evidence of a major climate change influence on woodland communities of the East Hampshire beech hangers (Berry *et al*., 2005). Risks will be apparent for many other habitats beyond those associated with beech. The higher transpiration demands of trees means that woodland habitat types are likely to be vulnerable to drier conditions, both directly and indirectly through water resource pressures. Furthermore, the beech hangers of South England are also recognized for their cultural landscape qualities (cultural ecosystem service) as well as their biodiversity value.

Figure 8.6 Indicative maps of suitability for beech under UKCIP02 Low and High emissions scenarios for 2020s, 2050s and 2080s
(Source: Broadmeadow *et al.,* 2005)



Note: The maps do not include the additional effects of increased CO_2, pests and diseases, or extreme events. Suitability is measured in terms of productivity, which is separated into classes from less that 2 m^3/ha/yr to more than 8 m^3/ha/yr (General Yield Classes: m^3/ha/yr).

Blanket bog

Blanket bog occurs in the cooler wetter areas of the UK, where peat has accumulated not only in wet basins but also draped extensively over the surrounding land. The UK contains about 15% of global blanket bogs and, therefore, has a special responsibility for protection of this priority habitat. *Sphagnum* species are vital for blanket bog habitat creation, creating the oxygen-free environment in the soil, required for peat formation. *Sphagnum* species take in water either directly from rainfall or via the water-table. *Sphagnum* growth can be very restricted when the water-table drops during dry periods. A shift to a drier regime for blanket bog habitats would have significant implications for biodiversity through species loss and would lead to the underlying peat soil becoming more unstable. At sites where vegetation has been lost in the past (e.g. from pollution or grazing pressure) evidence suggests that the underlying peat is at a much higher risk of erosion and loss of carbon (Orr *et al.*, 2008; Lilly *et al.*, 2009).

Bioclimatic models suggest that 50% of the peatland area in Great Britain would be vulnerable to change, assuming an average 4.4°C rise in temperature, with drier vegetation types and tree species moving into the space of blanket bog habitats (Biodiversity & Ecosystem Services Sector Report), Figure 8.7. In Northern Ireland the reaction of blanket bog to climate change is more uncertain (see Box 8.3).

In addition to its importance for biodiversity, blanket bog has particular significance for climate change mitigation, because of its role as a carbon sink (Worrall *et al*., 2009). Peatlands (blanket bog, lowland raised bogs and fen) contain 5.1 billion tonnes of carbon, of which the majority, 4.5 billion tonnes, is in Scotland (Smith *et al*., 2007a.b). In pristine condition, active peat bogs can accumulate up to 0.7 tonnes of carbon per hectare per annum (Holden *et al*., 2007). Regulation of water flow (notably reduced flood peaks) and water quality are also important services from this habitat. In recent decades, increased concentrations of dissolved organic carbon (DOC) in water have been attributed to peat erosion, requiring expensive treatment to reduce discolouration and potential risks to human health.

Sympathetic management of blanket bog can increase resilience to climate change, such as the blocking of drains to raise the water-table and the exclusion of detrimental land management practices such as excessive burning and overgrazing (LIFE Peatlands Project, 2005). In some locations, peatland restoration could re-establish vegetated surfaces with diverse ecological communities. However, the topographic variability of the habitat means that this is likely to be highly site-specific rather than a universal solution to enhance biodiversity, carbon storage and water quality.

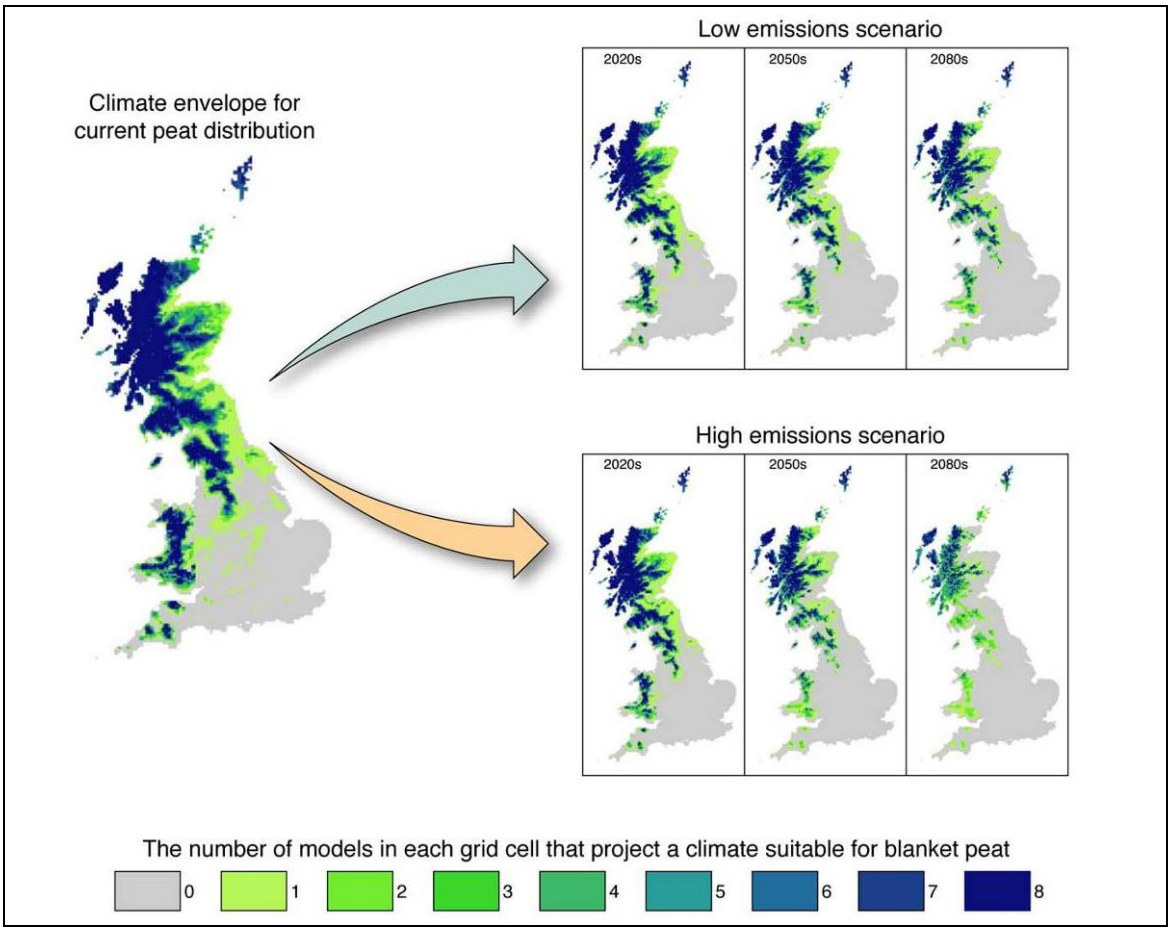
Box 8.3 Blanket bog in Northern Ireland

Blanket bog makes up 10% of the land area in Northern Ireland (UK NEA, 2011). The largest areas occur at altitudes over 200m and are concentrated on the Antrim Plateau, the Sperrin Mountains and in County Fermanagh (LIFE, 1994).

Blanket bogs in Northern Ireland include important species such as: Irish lady's-tresses orchid, marsh clubmoss (*Lycopodiella inundata*), yellow marsh saxifrage (*Saxifraga hirculus*), Irish hare (*Lepus timidus hibernicus*), curlew (*Numenius arquata*), hen harriers (*Circus cyaneus*) and red grouse (*Lagopus lagopus scotica*). Reservoirs that drain areas of blanket bog on the Garron Plateau, the Sperrin Mountains and Mourne Mountains provide much of the drinking water in Northern Ireland (DOENI 2004).

Modelling of the Cuilcagh / Pettigo area by Berry *et al*. (2005) projected the loss of the rare orchid, Lesser twayblade (*Listeria cordata*) due to seasonal drying by the 2050s. Similarly, other species such as Carabidae may experience local extinction. The reaction of peatlands to climate change is uncertain, however. Whereas increased winter rainfall may be beneficial for current blanket bog vegetation, it is also possible that the new climate may favour wet heath, rather than peat bog vegetation (Berry *et al*., 2005).

Figure 8.7 Future projections of blanket peat distribution using a range of bioclimate envelope models and the UKCIP02 Low and High emissions scenario
(Source: Clark *et al*., 2010)



Coastal change

Long-term coastal evolution is the combined influence of a range of events including gradual change and storms that may result in both coastal erosion and flooding, which, in turn, collectively influence the transition from marine to terrestrial habitats. Extreme storm events (in addition to frequent events) also have the potential to cause extensive saline inundation.

Coastal flooding, under current or future climatic conditions, has the potential to flood coastal habitats inland of the natural and defended coastline. The majority of the habitats that would be affected are terrestrial or freshwater and open water habitats that have variable but generally limited ability to tolerate saline inundation. Inundation of these habitats with brackish / saline waters has the potential to result in changes in species composition (loss of salt-intolerant species) impacts on growth through alteration of soil-water interaction, changes in soil structure and changes in fauna (e.g. loss of invertebrate populations) and in turn this may lead to transition and then change to other habitat types. The result would be a change in the distribution of coastal habitats at the country-wide level.

The joint Defra/Environment Agency NEOCOMER project (Defra, 2006b) estimated potential losses of habitats from coastal flooding in Natura 2000/SSSI/Ramsar sites to be over 32,000 ha. Although not quantified by NEOCOMER, climate change may exacerbate this vulnerability with sites flooded sooner or more regularly than is

currently the case. Furthermore, this study did not include an assessment of the sensitivity of habitats to the frequency or duration of inundation, but assumed that all inundation would result in loss.

The Defra project CR0422[169] assessed the risks of flooding due to sea level rise on selected coastal BAP habitats. Over half of the national resource of coastal and floodplain grazing marsh and reedbed and saline lagoons are situated in the coastal floodplain and are sensitive to sea level rise, saline intrusion and changes in wave energy. Coastal habitats play an important part in the buffering and prevention of flood flows. The effect of climate change may alter species composition or encourage range shifts, due to a change in climate space for the species. A series of sensitivity matrices were developed as part of the Defra project CR0422, using existing empirical observations, scientific data and expert judgement, which describe the risk to the BAP habitats of exposure to a range of inundation events in terms of flood frequency and duration. Of those BAP habitats in the coastal floodplain, 81% of the total selected BAP habitats projected to be at risk under any climate scenario are already at risk from prevailing climatic condition and, hence, could be lost to flood events at any time in the next 10 to 20 years.

Coastal erosion occurs around the UK coastline on, for example, soft rock coast, shingle, beaches, etc. under current climate conditions. The result of erosion can be the loss of habitats seaward of the coastline (such as saltmarsh) or inland of the coastline, natural or defended (such as coastal and floodplain grazing marshes, reedbeds, fens, etc). Conversely, accretion of sediment can result in the creation of habitats, such as saltmarsh or coastal vegetated shingle. The impact of climate change on the erosion on beaches, agricultural land and some selected BAP habitats is detailed in Chapter 3.

Currently, around 17% of the UK coastline is experiencing erosion (Eurosion, 2004) and 28% of the combined English and Welsh coast is experiencing erosion rates greater than 10 centimetres per year (Evans *et al.*, 2004). Lee (2001) used a simple model to project areas of habitat change, concluding that there could be a net gain of intertidal habitats (saltmarsh and mudflat/sandflat) of some 2,220 hectares[170] and a net loss of coastal dry land, wetland and open water habitat of approximately 4,000 hectares from protected sites (SAC, Special Protected Areas (SPAs) and Ramsar) in England and Wales over the next 50 years.

Analysis by the CCRA indicated that the greatest proportion of habitat loss through coastal erosion would be for saline lagoons; between 2 and nearly 20% of the resource is projected to be lost in East England alone by the 2080s. Data was not available for the same analysis to be carried out for Wales, Scotland and Northern Ireland. Box 8.4 provides a local example of coastal change in Scotland.

Future coastal flooding and erosion would also impact upon the extent of coastal habitats and species, leading to changes in habitat types and composition of species within coastal environments.

[169] Developing Tools to Evaluate the Consequences for Biodiversity of Options for Coastal Zone Adaptation to Climate Change

[170] This is based on the assumption that much of the gains come from managed realignment programmes

Box 8.4 Habitat changes at the Dornoch Firth, Scotland

Morrich More in the Dornoch Firth is a dune plain resembling a staircase of sand dune ridges that extends from the cliff line down to the present day beach (Hansom, 2001). Within the lower and younger part of the dune system, saltmarsh occupies the low troughs that lie between the higher sand dune ridges. The extent of each habitat reflects subtle altitude changes and the frequency of inundation of sea water.

Dornoch Firth highlights a number of key changes that support the hypothesis that changes in sea level leads to physical and ecological responses within the coastal zone. The northeast facing dunes are eroding. This appears to be the most extensive erosion in the last 7,000 years and is now putting the low-lying saltmarsh at risk. Ecological changes have been seen as pioneer saltmarsh species invading lower edges of mature sand dune habitats. Terrain analysis is being undertaken to establish the areas of sand dune that are likely to change into saltmarsh, under various climate change and sea-level rise scenarios. At a scoping level this analysis will help identify the gross landform and habitat changes that may occur in our dynamic coastal habitats over the coming decades.

Consequences for the Protected Area network

Potential changes in species ranges have important implications for species and habitat conservation. A recent review of the network of conservation sites in England by Lawton *et al.* (2010) evaluated the suitability of the network in terms of its ability to cope with range shifts. It highlighted the current fragmentation of the network which has produced sites that have rather limited connectivity and are too small to accommodate change. In addition to the lack of available habitat, there are often physical barriers to the movement of many species due to infrastructure. As a consequence, although species' range shifts have been recorded, there are many counter examples that highlight that other species have not been as successful in adapting to change, whether due to climate, land use, or other drivers.

The project, CHAINSPAN, assesses the resilience of the UK's network of (SPAs) to climate change. In the short (2020s) to medium (2050s) term for the Low emissions scenario, more species were considered to be likely to benefit from climate change. However, with increasing severity of climate change, a larger proportion of species were projected to decline in abundance. Northern seabirds were projected to be most vulnerable to future climate change. Wintering water birds were projected to benefit from climate change, although the effects on their arctic breeding grounds were not accounted for in the models (Defra, 2011). Coastal SPAs are projected to be at risk from coastal squeeze and saltwater incursion of freshwater habitats (Defra, 2011).

CHAINSPAN analysis indicated that large SPA sites are likely to be relatively resilient to future climate change and they are likely to remain key sites irrespective of climate change. Large sites with good quality habitat will be more resilient to change and better able to accommodate colonisation by new species. Current vulnerability to change has been exacerbated due to human activities, particularly habitat degradation and fragmentation. This also means that it is difficult for species to track their changing 'climate space'; recombination of different species may occur, thus changing communities and ecosystems. Some species will be more greatly affected than others (See Box 8.5).

Box 8.5 Priority habitats, protected sites and climate change (Defra, 2011)

Priority habitat analysis has identified the geographical shift of national vegetation according to the physiological tolerances of plants. Looking at the percentage change in species within 26 protected sites, it can be seen that climate change is expected to have a significant impact on species location. Serious migration (<10% remaining in the same community) could be expected for vital habitats including blanket bog, salt marshes, sand dunes lowland heath and natural pines. The Defra, 2011 study projects that hare's-tail cotton-grass (*Eriophorum vaginatum*), a key blanket bog species, along with other Boreo-Arctic Montane species may decline with climate change. Habitats relatively less affected by climate change according to the model used in this assessment include lowland grassland, deciduous woodland and wet woodland.

Geographically mid to north of England lowlands are projected to change the least, whilst those in the south east of England and the Northern Isles are projected to change the most. The eastern Scottish Highlands are also projected to change significantly. Changes would have been greater if annual precipitation were not projected to rise in many northern and western areas.

8.2.2 Seasonal shifts and changes in seasonal timing of life cycle events (phenology)

Climate change is already altering the phenology (seasonal timing of life cycle events such as breeding) for many species. The influence of these changes in interactions between species and across levels in food webs may be much more profound than the affects on individual species and hence may lead to an increased possibility of major ecosystem disruption. The rate of climate change is likely to be the key variable here.

Upland birds

Many species of subarctic breeding birds of conservation concern occupy blanket bog, grassland and heathland habitats in the uplands of the UK. Crane flies (Tipulidae), the most important prey group for the majority of these birds, occur in abundance on the wet damp soils and around pools. However, these invertebrates are sensitive to changing weather conditions, and warmer drier summers have been shown to have negative impacts on their population and, hence, on the bird populations as well. Analysis by Pearce-Higgins (2010) has shown a link between the breeding success of golden plover (*Pluvialis apricaria*) and the abundance of crane fly prey for their offspring. A trend to increased soil moisture deficits in summer during recent decades has had an impact on prey abundance and, therefore, on the population of the golden plover. Modelling based on this analysis shows that a continued increase in summer temperatures would present a considerable risk of extinction for the golden plover within the next 100 years. Other bird species are also considered to be at risk to changes in the abundance of invertebrates that prefer cool, damp conditions (Pearce-Higgins *et al.,* 2010).

Changes in timing of life cycle events

Many species move from one place to another at certain times of the year or during a particular period of their life cycle, ultimately related to availability of food. The migration patterns of birds are projected to change in response to climate change and other drivers and these changes would have wider consequences for habitats and biodiversity conservation. From a policy perspective, the shift in distribution of

migratory species within the UK could be highly significant as the qualifying features of designated sites move. Maclean *et al*. (2008) have suggested that for waders, some species may continue to use their existing overwinter sites, whilst others may move to new sites, suggesting that, if the species is to continue to receive protection, the site network would need to expand if the new sites did not already receive protection (Biodiversity & Ecosystem Services Sector Report).

For migratory species, pressures do not only occur in the UK. Impacts of climate change or other environmental pressures occur globally and may affect the populations we see in the UK. For example, migrant birds coming from the south may increasingly face additional pressures from more frequent and severe droughts in areas such as the Sahel, which offers a vital feeding ground for many migrant species. For instance, in 1968 a drought in the Sahel resulted in a >90% decline in Common Whitethroat, *Sylvia communis*, from which the species has yet to recover fully (BirdLife, 2010). Other international changes may also affect UK biodiversity, for example, the melting of the polar ice, and a reduction in European populations of important EU species, leading to a lack of colonists for the future southern and south-eastern UK habitats.

Of ultimate concern, however, could be the phenological mismatches that develop as the timing of species' life cycle events, such as migration, changes (see Box 8.6) and become asynchronous with other phenological events. Environmental cues for migration related to climate and food supply will evolve through varying mechanisms for different species, and these will be further transformed through differences in social behavioural cues. It has been hypothesised that certain key individuals within the population may recognise the proximate signal and that others follow through social interaction (Guttal and Couzin, 2010). Whatever the mechanism, these mismatches would impact on breeding success and, through natural selection, the future viability of the species. For example, year-class strength[171] of marine fish is greatly influenced by the timing of spawning and the resulting match or mismatch with their prey and predators (Cushing, 1990). A clear seasonal shift to earlier appearance of fish larvae has been described for southern North Sea cod and many other species (Greve *et al.*, 2001; 2005). In addition it has been demonstrated that rising temperatures have coincided with marked changes in the zooplankton composition (Beaugrand *et al*., 2002). There has also been a decline in the abundance of the copepod *Calanus finmarchicus,* an important prey item for cod larvae in the northern North Sea (Beaugrand *et al*. 2003, Beaugrand, 2004).

Box 8.6 Phenological mismatch

The topic of 'phenological mismatch' illustrates the issues, complexities and uncertainties that a risk assessment for biodiversity must acknowledge. Changes in climate alter the phenology (seasonal timing of events) for many species by modifying the environmental cues that they use for migration, breeding and predation, ultimately influencing their demography and population dynamics. However, the influence of these changes in interactions between species and across trophic levels (steps in the ecosystem food web) may be much greater.

Some evidence for this mismatch has been reported across Europe. A notable example is that of caterpillars hatching and then pupating too early compared with chick hatching of some insectivorous birds e.g. great tits (*Parus major*). This has led to less prey available for some woodland birds and therefore declines in their breeding success and abundance (Visser, 2008; Visser *et al.* 2006; Both *et al.* 2006). Recent evidence has also been presented regarding the interaction of the common cuckoo (*Cuculus canorus*) with its hosts based upon sixty years of data. This suggests that short-distance, but not long-distance, migratory hosts have advanced their arrival more than the cuckoo, with potential consequences for breeding of both cuckoo and hosts (Saino *et al.*, 2009). The mismatch may explain the recent decline of cuckoo populations and observed local changes in parasitism rates of host species.

[171] This term is an indicator of the spawning and survival success of juvenile fish; also referred to as "recruitment".

Disruption of these ecosystem relationships could cause major shifts in key functions that they maintain. However, finding evidence for or against disrupted relationships and their demographic effects is difficult because the necessary detailed observational data are rare, or provide only a partial picture. Moreover, we can often only speculate on how sensitive species will generally be to phenological mismatches when they do occur. It is quite possible that through behavioural change (species' 'plasticity') and natural selection that the phenology between species may through time become synchronous again. Also, we do not really know whether all levels in multi-trophic interactions across the food web will be affected at the same rate, and therefore whether synchronization can be maintained across the ecosystem under large-scale climate change. The rate of climate change is likely to be the key variable here, with the likelihood of asynchronous events increasing as the rate of change increases, and hence leading to an increased possibility of major ecosystem disruption.

8.2.3 Invasive non-native species, pests and diseases

Changes in geographical range may have consequences in terms of greater prevalence of invasive non-native species, pests and diseases. Cold winters in particular are thought to hinder the persistence and spread of a number of pest and disease species. A changing climate may also favour non-native species and allow them to become invasive. Invasive non-native species have the potential to modify ecosystem functioning significantly and, therefore, could have implications for the services we receive.

Invasive non-native Species

Invasive non-native species have been highlighted as a particular issue of concern by stakeholders in the CCRA, due to recent increases in their spread. In England, an audit found 2,721 non-native species living in the wild (English Nature, 2005), but most of them have not had noticeable negative impacts. However, a small minority have currently caused perceptible harm. In the context of climate change, non-native species may be more suited to the changed climate than native species, and in the absence of their native communities, the non-native species may also then be without their native predators and parasites, members of their own species or the other species they usually have to compete with for resources.

In the terrestrial and freshwater environment, this assessment considered the impact of invasive non-native species through investigation of Parrot's-feather *Myriophyllum aquaticum*, an invasive non-native aquatic plant that can produce dense infestations that exclude native species or cause flooding in slow flowing channels. Parrot's-feather has no known natural enemies in the UK and appears to experience very little direct competition from other species. Habitats at most risk are natural ponds and slow flowing canals or rivers. Water chemistry and nutrient conditions do not appear to be important control factors indicating the potential for it to become much more widespread. Parrot's-feather survives most winters in its current southerly location but evidence from continental Europe suggests low temperatures and continued exposure to frost and ice in harsh winters are key limiting factors. Low temperatures limit the plant's growth and its current range to southern UK. With the potential increase of water temperatures (Chapter 3), the species may spread north and occupy a greater extent within the UK. Changes in water flow regimes would also be a key influence, as the plant is at its most aggressive in still water. By covering large areas of aquatic habitat, Parrot's-feather can effectively smother a water body and reduce light, oxygen and nutrients available to other species. Its potential spread has important implications for priority species and habitats.

This assessment also looked at a case study of Zebra Mussels, *Dreissena polymorpha,* which have become invasive in many countries including the UK. They have caused

varied and unpredictable ecological impacts, such as changing nutrient cycles, causing local extinction of native mussel species, changing fish populations through colonisation of spawning grounds and changing habitats and food sources. Zebra Mussels are able to tolerate a relatively wide spectrum of conditions (temperature range -2 to 40°C and short spells of very low water levels) compared with a number of native UK species. Also, the threshold that initiates spawning may occur earlier in the year, promoting recruitment. Zebra Mussels may, therefore, be even more competitively advantaged under climate change conditions than many native UK species.

The introduction and establishment of non-native species to marine ecosystems may cause effects ranging from the almost undetectable to the complete domination and displacement of native communities. Climate change may enable such introduced species to expand further in UK waters. Range expansion is also possible for current native species and species that currently inhabit water south of the UK. This assessment looked at nine invasive non-native marine species that are already present in the UK and which are considered to pose a significant risk to native biodiversity, Table 8.6. Each of the nine species may expand their range to cover the whole of the UK by the 2080s (based on sea water temperatures and species tolerances).

Table 8.6 Initial and most northerly observations of nine marine invasive non-native species in the UK (Marine & Fisheries Sector Report)

Species	Issue	First UK sighting	Native Distribution	Most northerly obs. UK (and year)	Northwards Shift (km)	Ref (Northernmost observation in the UK)
Chinese Mitten Crab *(Eriocheir sinensis)*	Cause erosion through burrowing into soft sediments, prey on native species and damage fishing nets	1935 - Thames at Chelsea	East Asia	NW Scotland	586	Aquamaps
Ctenophore *(Mnemiopsis leidyi)*	Preys fish larvae and fish eggs, multiply rapidly	2006	North America (Pacific)	Eastern North Sea	0	ICES insight Sept (2008)
Slipper Limpet *(Crepidula fornicata)*	Competes with filter feeding inverts, predates on commercial oyster beds.	1872 - Helgoland, North Sea	North America (Atlantic)	Belfast Lough (NI)	129	Marlin website/ Dasie website (2009)
Japanese Wireweed *(Sargassum muticum)*	Outcompetes native species due to rapid growth, fouls waters (propeller block), nets and oyster beds.	1971 - Bembridge, Isle of Wight	East Asia (Japan)	NW Scotland	786	www.Aqualiens.tmbl.gu.se
Wakame *(Undaria pinnatifida)*	Opportunisitc species, spreads prolifically, fouls marine structures	1994 - Hamble Estuary, Solent,	East Asia	Solent	0	Marlin
Carpet Sea Squirt *(Didemnum vexillim)*	Spreads rapidly, carpeting areas of seabed and structures, smothers habitats and fouls structures, particular issue for shellfisheries	2008 - Holyhead Marina, North Wales	East Asia (Japan)	Largs (Scotland)	276	BBC news website 23rd Jan 2010
Pacific Oyster *(Crassostrea gigas)*	Outcompetes native mussels but is itself an important commercial species	1926 - River Blackwater Essex	East Asia	Orkney	804	Marlin

Species	Issue	First UK sighting	Native Distribution	Most northerly obs. UK (and year)	Northwards Shift (km)	Ref (Northernmost observation in the UK)
Common cord-grass *(Spartina alterniflora)*	Outcompetes native intertidal species reduces diversity and impacts on feeding sea birds	1870 - Southampton Water	North America (Atlantic)	NW Scotland	684	www.europe-aliens.org/pdf/Spartina_anglica.pdf
American jack knife clam *(Ensis directus)*	Highly invasive and forms dense colonies, which may compete for food and space with native species	1989 - Holme beach, Norfolk	North America (Atlantic)	Humber estuary	70	Marlin

Notes: [1] Conceivable northward shift (1960/90 vs. 2070/99)

Pests and diseases

Diseases are pathogenic micro-organisms (such as bacteria, fungi or viruses) that cause harm when they infect a particular host. Pests represent either native or non-native organisms that cause damage to native (or non-native) species and/or ecosystems. Pests already present a severe risk to some habitats but their prevalence is limited by the UK climate, particularly minimum temperatures in winter. A rise in temperature is likely to lead to an increased survival rate for pest species and this may be accompanied by other factors that favour their spread such as wetter winters for fungal pests.

Each pathogen or pest has its own characteristic and a comprehensive assessment of all possible disease vectors and pest survival was simply not possible. A sample covering the terrestrial and marine environments was, therefore, selected to provide a limited appreciation of the potential consequences of future risk: *Chytridiomycosis*; *Phytophthora ramorum*; *Elatobium abietinum* (green spruce aphid); red band needle blight; harmful algal blooms; and *Vibrio* species. Bluetongue virus is also an important disease, spread by Culicoides biting midges. This is discussed in more detail in Chapter 4.

Chytridiomycosis

Chytridiomycosis is a potentially fatal frog disease that is now in the UK, although its full extent is uncertain. The causal fungus (*Batrachochytrium dendrobatidis*) was almost certainly introduced by human agency on infected amphibians. It seems to be temperature limited and climate change has been recognised as a causal factor enhancing the ability of the fungus to spread and/or induce disease. Analysis by Bosch *et al.* (2007) from a temperate alpine area of Spain has shown a significant association between epidemic years and specific climatic variables. Shorter milder winters due to climate change would produce elevated temperatures and humidity values that are believed to favour the fungus. Inter-annual variations in these parameters associated with the North Atlantic Oscillation correlate significantly with disease epidemics, such that the presence of occasional severe winters reduces the prevalence of the disease. By inference, the climate 'envelope' for this disease is believed to be expanding across Europe to include the UK and hence future climate projections that demonstrate an increased prevalence of milder wetter winters indicates an increased risk.

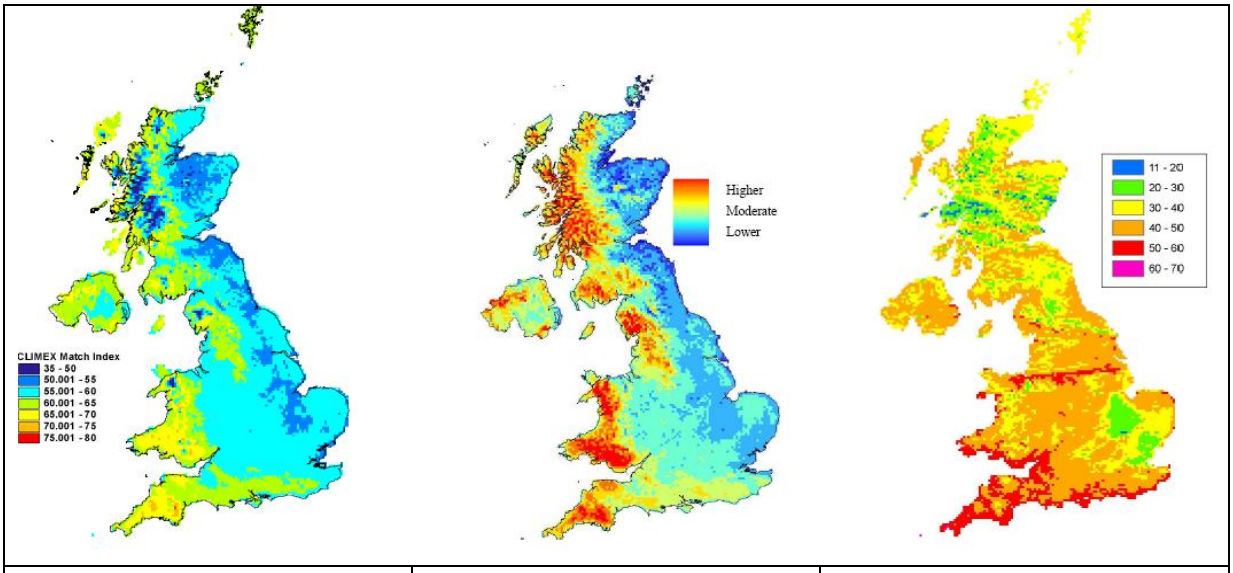
Phytophthora ramorum

Phytophthora ramorum affects trees, shrubs and some plants. It is currently found in the UK. In October 2010, outbreaks had been confirmed in eastern Northern Ireland, across Wales and south western England. Suspected outbreaks had been found in

south-western Scotland[172]. Studies into the sensitivity of *P. ramorum* to temperature, humidity and water potential have identified optimal levels for growth at different stages of the organism's life cycle; studies suggest that *P. ramorum* prevails under moist, warm conditions (Defra, 2004 and 2007b, Tooley *et al.* 2009). For biodiversity, there is serious concern regarding the spread and impact of *P. ramorum*, and similar species, on *Vaccinium myrtillus*, bilberry (or blaeberry in Scotland and winberry in Wales) and other heathland plants (Sansford *et al.*, 2009). The risk level from this disease is currently considered to be high and the possible damage could be extensive if it is not possible to control it (Defra, 2009c).

The potential future distribution of *P. ramorum* has previously been modelled for Europe: Figure 8.8 shows the results of analysis using three different climate-based risk-mapping approaches, the first using climate variables from other outbreak zones (in this case Southwest Oregon) to map suitable areas for outbreaks in other geographical locations; the second using the organisms survival ability in different climatic conditions to determine those areas at highest risk; and thirdly, using a growth index that highlights areas most suitable for growth (see Biodiversity & Ecosystem Services Sector Report for details).

Figure 8.8 Risk of *P.ramorum* derived from three different bioclimatic models
(Source: RAPRA 2009, p.121)



CLIMEX Match Index	Risk Ranking method	CLIMEX Ecoclimatic Index
– a method used to match the climate variables from one area (two locations in Oregon and California, USA, where large-scale outbreaks have occurred) to European climate variables (in this case, specifically the UK), to identify areas where *P. ramorum* might have the potential to flourish. Greater CLIMEX Match Index values infer a better match between climates compared.[173]	– uses four weighted environmental conditions (precipitation, mean maximum temperature, relative humidity and mean minimum temperature) to model where the risk of the organism being able to survive is highest. The original work by Meentemeyer *et al.* (2004) also included a host-species index, but this level of data is not available for the UK. Scale refers to the level of risk.	– combines a "Growth Index" (measure of species' response to temperature and moisture and potential for growth during the favourable season) with four stress indices (hot, cold, wet and dry that describe the probability of the population surviving through unfavourable seasons) to give a measure of suitability of the location for the target species. Scale refers to the level of risk, higher values equate to a higher level of risk.[174]

[172] More up-to-date information on outbreaks can be found here: http://www.forestry.gov.uk/forestry/infd-86ajqa
[173] See http://www.climatemodel.com/climFunc.htm
[174] See http://www.climatemodel.com/climFunc.htm

In the left-most map in Figure 8.8, the colours refer to the climate that most matches the climate in Southwest Oregon where outbreaks of *P. ramorum* have occurred (the higher the match index value, the most similar the climate match). In the central map, the gradation of the model result refers to the level of risk, from high to low of *P. ramorum* survival based on climatic variables. Finally, in the right-most map the scale runs from 11 to 70, also a risk-based scale, the highest levels of risk of *P. ramorum* growth are in the south and west of the UK.

The three maps are best considered together. They show that the whole of the UK is potentially suitable for *P. ramorum*, but that the current risk is highest in the moister west and close to the milder south (less extreme climatic variation that regulates the organism's survival ability) which aligns quite well with reported outbreaks. Further work also needs to be extended to include the availability of host species. Fera also suggests that many other factors act to confound projections. The complexity and sensitivity of disease-host interaction, differential sporulation between species, transmission, population dynamics, and effectiveness of control measures, all interact to define the extent and impact of *P. ramorum*.

Green spruce aphid

The analysis of green spruce aphid was based on evidence that populations of this pest are controlled by winter temperatures (Forest Research, 2010a,b) and that the baseline areal extent of the pest is 10% of the area of spruce forest (Forest Research, 2010a,b). The results suggest that there may not be a major change in extent of spruce forest affected by the pest by the 2020s, but by the 2050s the area affected may have more than doubled to between 200-400 thousand hectares of spruce forest that currently exist in England, Scotland and Wales[175] (Forestry Sector report). The implications of this increase in pests and pathogens are significantly lower yields and higher tree mortality in the tree species that are affected.

Red band needle blight

The forestry sector also experiences the effects of pathogens. In East England, for example, widespread failure of the predominant commercial conifer species, Corsican pine (*Pinus nigra ssp. laricio*), is occurring due to devastating effects of red band needle blight caused by the fungus *Dothistroma septosporum*. The potential spread of this pathogen due to increasing mean summer temperature was assessed and found that by the 2050s[176] over half of all pine forests in the UK may be affected by the pathogen, if the spread follows the potential response to optimal growth conditions as estimated by expert judgement (Forestry Sector report).

Harmful algal blooms

Harmful Algal Blooms (HABs) via their toxins can cause the deaths of fish, sea birds, marine mammals and humans. They are an issue economically as they can render shellfish unfit for human consumption and they are also important in relation to bathing water quality and tourism. Broadly HABs fall into two categories: those associated with massive blooms and those which are low biomass but produce potent toxins.

Experimental evidence for selected HAB species suggests that *Prorocentrum minmimum* responds most positively to increased stability through stratification, whereas *Prorocentrum micans,* a similar species, responds more directly to increased temperature. Response to climate change is species-specific and it is likely that some species would respond positively and others negatively, changing community composition. However, it could be expected that those species most well adapted would survive and, therefore, responses such as that of *P. micans* would be typical. In

[175] High emissions projection, p90; baseline hectares of spruce forest >700 thousand hectares in England, Scotland and Wales.
[176] Medium emissions p50; baseline hectares of pine forest, >400 hectares in England, Scotland and Wales

terms of the example given, a doubling of growth rate is projected for a 4°C rise in temperature. Changes of this magnitude could have major impacts for UK water quality.

While bloom formation is not solely determined by growth rate, it is a recognised key factor along with mortality and flushing[177]. Increased stratification generally leads to lower flushing and it is mortality that controls the size of the bloom. Thus for certain HAB species there are likely to be more incidences with increasing stratification.

Generally, the complexities of the processes that result in HABs are such that projection at the overall level cannot be made. However, it can be stated that there has been an increase in HAB events in the past and that this trend is likely to continue. Currently it is considered that data availability is not sufficient to fully understand the complexities of HAB species and systems and, therefore, quantitative analysis cannot be undertaken.

***Vibrio* species**

The impact of climate change on the dynamics of human infection and disease attributed to *Vibrio cholera* (the causal agent of cholera), is well known and has been extensively investigated. However, less attention has been given to other pathogenic *Vibrio* spp. which may prove to be equally damaging to human health (Martinez-Urtaza *et al.,* 2010). For example, *Vibrio parahaemolyticus* causes acute Gastroenteritis. For both *V. vulnificus* and *V. parahaemolyticus* the most significant factor dictating incidence of infection appears to be sea water temperature (>15°C). It has been suggested that the highest densities of *vibrio* cells occur in waters ranging from 20 to 30°C (Tantillo *et al.*, 2004).

In the UK in certain estuarine areas temperatures in excess of 20ºC are already regularly experienced during the summer. Projections indicate that sea surface temperatures may rise to as much as 20-22°C in summer months, an increase of approximately 1.5 – 3.5°C from current levels (Medium emissions projection for the 2080s). In addition increased frequency and intensity of rainfall events and flash floods may result in decreases in estuarine and coastal salinity that may also encourage the proliferation of *Vibrio spp*, potentially leading to increases in the number, seasonality and severity of marine acquired *Vibri*o infections. Furthermore, even relatively small increases in temperatures could greatly extend the geographical distribution of vector organisms and, therefore, the pathogens themselves (Kuhn *et al*., 2005).

The known association between *Vibrio spp.* and zooplankton is also of relevance (zooplankton is an important food source for *Vibrio spp.*). In the Northern hemisphere it has been suggested that warm water plankton has moved polewards by 10° over the last forty years (Beaugrand and Reid, 2003). In this context the arrival of novel *Vibrio* populations in association with foreign copepods has been suggested as a potential vehicle for disease transmission further increasing risk of incidence within the UK (see Marine & Fisheries Sector Report for details). An increase within UK seas of these pathogens has the potential to disrupt ecosystem services relating to tourism, in particular bathing water quality.

8.2.4 Changes in Community Composition

Generalist species favoured over specialists

Species that are more ‘generalist’ in their behaviour (i.e. those that can exploit a wide range of environmental conditions, habitats, or food types) have a tendency by their

[177] The rate at which water is replaced by new water in a water body

very nature to be more adaptable than species that have more 'specialist' requirements (see Table 8.3). The specificity shown by specialist species can make them more vulnerable to environmental changes, such as habitat loss or changes in climate, as they may be unable to exploit the new ecological niches that become available especially if their existing niches become modified or lost. The success of generalist species in adapting to environmental changes can lead to further pressure upon specialist species through competition or predation, leading to further population declines. A decline in specialist species reduces the species richness of ecosystems and is believed to reduce overall ecosystem resilience to change. The most visible manifestation of this is provided by impacts on pollinators (see Section 8.2.6) where climate change appears to be interacting with a range of other stresses to cause Colony Collapse Disorder and other negative consequences, with knock-on effects for pollination services. A reduction in overall system resilience can also reduce the resistance to invasive non-native species and diseases, which has implications for both biodiversity and human welfare.

The effects of climate change on specialist species are compounded by restrictions on habitat availability due to both past and future habitat loss. Specialist species are typically found in semi-natural habitats, for example, mature woodland, heathland or wetland, which are often restricted in size and distribution and can be highly fragmented due to historic habitat loss. With changes in climate, and as their existing habitat becomes unsuitable, specialist species may be unable to move to remaining areas of optimal habitat. In some cases, climate change may result in a complete loss of suitable habitat due, for example, to increased soil moisture deficits or wildfire. If the species is unable to adapt to these changes in habitat, this may result in loss of the species from the area, or region.

The population of farmland birds provides an example of how specialists tend to fair less well under environmental change than generalists. Data for 19 species monitored across farmland in England shows a 60% decline in specialist farmland bird species between 1970 and 2007. In comparison, generalist species have increased by 8% over the same period; an increase, but notably not of the same magnitude as the decrease in specialist species. The declines in specialist species are believed to be predominantly associated with changes in agricultural practice and land management techniques, not climate change, but demonstrate the principle that specialist species are less able to respond to environmental changes compared with generalists.

It should be noted that at an individual species level, having specialist habitat or food requirements *does not* mean that a species *will* become locally extinct. Other factors, see Table 8.3, also affect the survival and reproductive ability of a species in the face of environmental change. Being more specialist simply increases the risk that environmental changes, climate change or otherwise, will have a negative impact on that species.

Water temperature and thermal stratification impacts

As atmospheric temperature rises as a result of climate change, the consequences for aquatic organisms include changes in distribution, growth rate, metabolism, reproduction, behaviour and tolerance to parasites / diseases and pollution. Ultimately these changes may have an impact on ecosystem function, goods and services including provision of water quality (see Chapter 3 for more detail on water quality). Species that are currently close to thermal or other environmental thresholds are likely to be particularly at risk.

Stratification in the water column may lead to increases in algal blooms, some of which may be harmful to either biodiversity or humans if the food chain is affected. Increases in stratification are projected along the north coast of Cornwall, the Firth of Clyde, the

Moray Firth, and Northeast England. A reduction in stratification is projected in the English Channel east of Dover. However, marked increases in stratification are projected off the south coast of Sussex, and in places along the South Devon coast by the 2080s (Medium Emission scenario).

Investigation of lakes in Scotland by Winfield *et al* (2010) indicated that low altitude, southern lakes with shallow waters were most at risk and that this correlated well with reductions in Arctic charr populations since 1990. Other commercially important species such as salmon are also affected by water temperatures, indicting that provisioning ecosystem services may also be affected by rising water temperatures (see Section 8.3.5). As discussed in the following section, primary productivity may also be increased, having important implications for phytoplankton and cyanobacteria species and influencing water quality.

In the marine environment, large blooms of the dinoflagellate, *Karenia mikimotoi*, which is associated with fish kills, have been observed in northern waters off Ireland and Scotland, while previously it had been confined to the English Channel. These blooms are known to develop in more offshore regions and projections of climate change that indicate an increase in the duration of stratification of the water column in the future could encourage and enhance the development this species.

8.2.5 Supporting ecosystem services

"Supporting services provide the basic infrastructure of life. They include primary production... soil formation and the cycling of water and nutrients in terrestrial and aquatic ecosystems. All other ecosystem, services... ultimately depend on them." (UK NEA, 2011).

Comprehensive coverage of how ecosystems are likely to change was simply not possible, in part because the information is not available, but also this is a vast area of ongoing research. Selected aspects considered to be important were examined and a few specific habitats and species were used to illustrate the current state of knowledge.

It is acknowledged that all ecosystem services may be directly and indirectly affected by changes in climate; the segregation in this chapter reflects relative importance of climate as a driver of these services, based on the UK NEA (2011) and CCRA assessment.

Primary production

Primary productivity, the production of biomass in the ecosystem by photosynthesis, is likely to increase with higher temperatures and increased CO_2 levels (chapter 3). High primary production is an indicator for strong growth and development of plants (grasses, trees, etc. on land and algae in oceans), supporting diversity of other species. This will, however, be limited by climate related pressures such as drought and flooding and other factors such as nutrient availability and land use. The general patterns for changes in primary production are, therefore, location dependent within the UK. Species will react differently to increases in temperature and CO_2, having knock-on effects to community composition and ecosystem function, particularly nutrient cycling[178].

There have been numerous studies on the primary productivity of various terrestrial species and/or habitats. Often, primary productivity is measured in a species or habitat that provides a provisioning ecosystem service, for example, grassland for use in silage

[178] For example, recent reductions in phosphorus in soils available to plants is possibly associated with increased primary production stimulated by increased atmospheric nitrogen deposition and climate warming (UK NEA, 2011).

is strongly influenced by temperature and soil moisture availability (which is partly determined by rainfall amount and distribution). These determine the number of grass-growing days (GGD) per year. The number of GGD is greatest in oceanic western areas on soils with good soil moisture conditions, and least in the upland areas and in areas with a more 'continental' climate (Chapters 3 and 4).

Similar grassland systems exhibit similar sensitivity to rises in temperature, for example for grass-clover swards yields increase by approximately 15% per degree warming. Projecting this relationship forward using UKCP09 suggests increases in yield of between approximately 34% (with a range of 20 to 50%) in the 2050s, although in some parts of the UK this increase may be limited by drier conditions associated with higher temperatures.	High confidence

Increases in grassland yield should benefit livestock production, particularly meat production. Unfortunately, changes in vegetation growth and composition towards faster-growing species have been shown to modify the abundance and activity of soil organisms (Emmett *et al*. 2010), with impacts on rates of nutrient cycling and in turn primary production.

In forestry, experimentation indicates that increased CO_2 levels could, potentially, lead, to increased growth, particularly in young trees and those growing before canopy closure (due to the amount of sunlight available). Therefore, the effect is likely to be most significant for shorter rotation tree crops, such as commercial, fast-growing conifers and those for bioenergy. The absolute growth increase effect will be larger in conditions where water, temperature or nutrients are not limiting to growth. Thus trees in wetter climates and those on deeper, more fertile soils will show most increase.

The Ecological Site Classification (ESC) model uses the climatic variables accumulated temperature and moisture deficit, with information on windiness, continentality, soil type and fertility and tree species characteristics to calculate suitability, assessed as the potential yield class (YC) (a measure of maximum stem growth rate) likely at a particular site. In general, projected climate is likely to affect most conifers in England detrimentally by the 2050s and Wales by the 2080s, whereas potential production in Scotland is projected to increase markedly, in the case of Sitka spruce, Scots pine and lodgepole pine. For broadleaved species, there is a uniform picture of declining production in England, but modest increases in some species in some parts of Scotland (Forestry Sector Report). Increases in CO_2 may further enhance growth in areas such as Scotland, and may go some way to mitigating the decline in production in other areas such as England and Wales.

Crop yield may also increase with increasing temperatures, as long as other requirements, such as water availability, do not become a limiting factor. Given the paucity of data regarding primary productivity at the UK scale in the natural environment, grassland and crop systems are shown here as a proxy for the type of responses that might be possible in the natural environment. Controlled experiments have shown that with rising CO_2 levels, primary productivity of ecosystems tends to increase to a threshold level then begin to decrease. The reasons for this are not completely known but are associated with the influence of nutrient supply and other factors. There may, therefore, be negative changes to supporting services, such as nutrient cycling, and, hence, to many final provisioning and regulating ecosystem services on which humans depend. Changes in regulation of CO_2 release from soils are important factors influencing the rate of climate change. As well as binding and buffering release of nutrients and chemicals, organic matter regulates water retention and infiltration and therefore has a role in mediating against flood risk and supplying clean water.

In the marine environment, climate change may also drive changes in primary production (for more information, see Chapter 3). In the North Sea alone, primary production accounts for approximately 8.5×10^{12} g of carbon taken up per year (Thomas *et al*., 2004). In the North Sea, primary productivity ultimately drives benthic (sea floor) and pelagic (open water) food webs and, therefore, the productivity of fisheries in the region. Furthermore, oxygen depletion along the sea floor, possibly resulting from eutrophication, reduces marine water quality and further affects marine species. However, this system is very complex and not fully understood.

Observational investigations carried out at three sites in the North Sea during 2007 and 2008 indicate that climate warming would increase rates of carbon cycling in the pelagic system (by up to 20% by 2098), making fewer nutrients available to the benthic system. An important implication of reduced biomass of benthic organisms is a reduction in prey items, which are important in the diet of commercially important fish stocks (particularly plaice, haddock and juvenile cod).	Medium confidence

Mineral (Nutrient) cycling

Nutrient cycling processes are directly influenced by climatic conditions, which affect the rate of processes. The impacts of climate change on habitats and biodiversity would change the composition of ecosystems, also influencing nutrient cycling.

Initial nutrient inputs occur in different ways: weathering of rocks and soil, atmospheric additions through windblown soil and vegetation deposits, atmospheric fixation through photosynthesis and direct inputs via fertilisation will increase nutrient levels (Berhe *et al.*, 2005). In the ocean, the main source of nitrogen is runoff from agricultural land brought to the sea via rivers. Atmospheric deposition of nitrogen may also contribute significantly and this nitrogen originates partly from ammonia evaporation from animal husbandry and partly from combustion of fossil fuels in traffic, industry and households. On land, the nutrient cycle then involves the natural decomposition of organic matter, predominantly via biological activity, releasing mineralized nutrients into the soil for plant uptake, which can further release nutrients into the atmosphere and environment (FAO, 2005). Similarly, in the oceans, carbon, nutrients, oxygen and energy are cycled through biogeochemical processes and food webs in the water column and the seabed and can be impacted both by climate change and human activities.

On land, the mineralised nutrients released into the soil for plant uptake include nitrogen, carbon, sulphur and phosphorus. Healthy ecosystems have a wide range of soil organisms acting to consume and decompose plant material that in turn provide for a range of other living organisms including insects, birds and mammals. The amount of nutrients available is related to the vegetation assemblage, levels of soil organism activity and influencing factors, including bedrock composition and human additions. The variety and types of organisms vary the rate of decomposition and allow a range of nutrient concentrations to be continuously added and used within the soil. Climate change can impact on these processes directly and also change the nutrient requirements of plants and the decomposing soil organisms.

Nutrient cycling rates are directly influenced by climatic conditions. The speed of decomposition is affected by the soil organisms, physical environment and organic matter quality. Soil organism activity follows daily and seasonal patterns. Temperature is a key factor controlling decomposition increasing microbial activity releasing more carbon into the atmosphere (Bardgett *et al.*, 2008). Reaction rates doubled for a temperature increase of 8-9°C, although it has been found that associated drying of the soils may suppress biological activity (Allison and Treseder, 2008).

It can, therefore, be summarised that projected warmer wetter winters may increase nutrient cycle rates, but drier warmer summers would act to suppress cycle rates. For Southern England, a decrease in rainfall and increase in temperature suggests that drying out and a reduction in cycle rates may be expected. Limited rainfall reductions

and modest temperature increases in Northern Scotland indicates that a greater nutrient cycle rate is possible.

Increased rainfall is likely to favour quicker decomposition, making nutrients more readily available. However, water saturation through rainfall events can lead to soil saturation reducing biological productivity and anaerobic conditions. Water saturation can also damage crops and roots, reducing nutrient cycle rates. More heavy rain days and more extreme events would possibly negatively impact on the nutrient cycle; loss of nutrients in soil via leaching is particularly notable for provisioning ecosystem services.

The impact of climate change on habitats and biodiversity may change the composition of ecosystems, which would also influence nutrient cycling. Temperature, rainfall, plant type and land-use will influence the nutrients available. The projected effects of climate change indicate that the nutrient cycle changes would be varied and localised, and could either promote on inhibit the cycle depending on the geographical region.

In the oceans, climate change could have serious consequences for ecosystem function and may increase the risk of eutrophication given the same anthropogenic nutrient inputs (Marine & Fisheries Sector Report).

Water cycling

A change in climate would implicitly lead to changes in the rates of water cycling, as temperatures increase, evapotranspiration increases and precipitation increases. Hydrological processes throughout river catchments that may be affected by these changes, include flows in rivers, soil moisture and floodplain hydrology (Chapter 3).

Healthy ecosystems form an important hydrological cycle link between the ground and atmosphere by promoting transpiration and evaporation from a range of plant types (Baldocchi *et al.*, 2001). Exchanges through photosynthesis provide daily and seasonal patterns to the water cycle interaction.

Projected increased precipitation and temperature may lead to changes in the water cycle. Increased soil moisture could provide better conditions for plant growth (as discussed earlier) and greater plant cover could provide more evapotranspiration from soil moisture. Precipitation increases influence the cycle through direct evaporation from the ground and leaf area.

Changes in temperature, wind speed and increased soil moisture act to vary the rate of transpiration (USGS, 2011). Within ecosystems, increased moisture and temperature may also provide better conditions for plant growth increasing plant leaf area.

Plant health directly affects the rate of evaporation and evapotranspiration and a change in vegetation could have a large impact on the local water cycle. Healthy ecosystems may provide greater evapotranspiration and water storage. Increasing temperatures can promote the water cycle positively by providing warmer conditions for optimal plant growth or hinder it by drying the soil, reducing soil moisture and impacting upon vegetation health.

Change in temperature and precipitation may cause vegetation types to change. This could have a knock-on effect for ecosystem biodiversity, but may also affect the water cycle through a change in evapotranspiration. As the South is projected to become drier and hotter, plant growth may become suppressed, to a small degree in the larger plants, but to greater degree in mosses and fungi (Caldwell *et al.*, 2007). Ground water stores including bogs and marshes may become drier. This could have a significant impact on ecosystem biodiversity and the services it provides (including the ability to sequester carbon).

Soil formation

Soil formation is the product of eroded rock and influenced by regional climate, biota, topography and time. Climatic conditions are important in controlling the form and rate of physical and chemical processes in soil formation over long time scales. The living soil organisms are responsible for soil binding, mixing and providing nutrients. Soil organism activity is dependent on temperature and rainfall and follows daily and seasonal patterns. Soil particles are transported through rivers, rain water on land and by wind. Changes in these conditions would influence the transport of sediments and soil formation processes. Potential soil moisture deficit and soil erosion is discussed in Chapter 3.

There is conflicting evidence on the responses of soil systems to climate change. Changes in climate may affect soil biota and soil functioning both directly and indirectly. This may have seriously detrimental consequences for ecosystem services, for example carbon sequestration and nutrient cycling. The mechanisms by which climate change impacts on soil biota and the consequences of this for soil processes, such as decomposition, nutrient and carbon cycling, is not well understood. Increasingly, evidence indicates that extreme events in particular may adversely affect soil biota and their activities (Bardgett *et al*., 2010). Drying of the soil may change ecosystem functions by, for example, limiting soil micro-organism activity. Additionally, saturation of soils can slow activity or kill soil organisms. With a projected increase in winter precipitation (and should extreme events become more frequent or extreme) soil degradation may occur. Climate change may also influence plant type. As organic matter influences the majority of soil forming processes, a change in vegetation would alter decomposition rates and may change the soil characteristics. Even with considerable uncertainty, it is clear that the risk associated with impacts of climate change could be significant. For example, the organic content of soils is a key regulator of plant nutrient cycling and water availability. Any threat to soils is a major source of concern since soils contain at least a quarter of all species biodiversity (Jeffery *et al.,* 2010) and form the basis for both effective ecosystem functioning and associated services, including crop production, water regulation and water purification. Of particular importance is the storage of organic matter and carbon in soils, particularly the highly organic soils such as peat. Peatlands (i.e. blanket bog, lowland raised bogs and fen) are particularly important for the storage of carbon. The ability of peatlands to store new reserves of carbon has been significantly reduced due to damage from a number of sources, predominantly land management. Climate change could cause additional stresses that might affect this habitat, for example changes in soil moisture (see Chapter 3).

While the palaeo-environmental record clearly shows that soil organic content is sensitive to changes in climate, in general there is considerable uncertainty surrounding the potential impact of climate change on soil organic carbon, because of the complexity of interactions involved. Current evidence suggests that climate change would have a greater impact on soil organic carbon in unmanaged systems than in intensively managed systems, because land management techniques are the dominant influence over the carbon content of soils. The various responses of soil carbon to a number of environmental changes are summarised in Table 8.7.

Seasonal shifts would also modify the rates of soil mineralization and nutrient cycling, although the interaction with temperature and CO2 means the outcome is very difficult to project. Further more, changes in soil moisture regimes may present other risks for biodiversity in addition to changing habitat and species distribution. Increased deficits are associated with an increase in wildfire frequency (Chapter 3) and the climate stress imposed on some priority and dominant species can lead to increased vulnerability to pests and diseases, as discussed above.

Table 8.7 Responses of soil carbon to direct and indirect effects of climate change

		Process response			Soil carbon response	
		Plant and litter production	Decomposition	Erosion	Soil carbon	Uncertainty
Environmental Change	Increased CO_2	↗	↗↘	-	↗	Medium
	Increased temperature	↗↘	↗↘	-	↗↘	High
	Dry spells on mineral soils	↘	↘	-	↗↘	High
	Dry spells on organic soils	-	↗	↗	↘	Medium
	Heavy rain events	-	-	↗	↘	Medium
	Increased nutrients	↗	↗↘	-	↗	Low

Source: CLIMSOIL Project (Schils *et al*., 2008)
Note that 'uncertainty' refers to the direction of soil carbon response

Reponses of soil carbon to impacts that include:

- Increased atmospheric CO_2 concentrations could potentially increase plant productivity and therefore biomass and soil organic carbon. However, a general rise in temperature may increase decomposition rates to CO_2, dissolved organic carbon and methane (CH_4).
- Drier summers could also lead to increased CO_2 and dissolved organic carbon loss, but decreased CH_4 emissions due to changes in soil conditions.
- Longer summer drought periods would have the potential to decrease carbon fixation, either directly or via vegetation succession or by increasing decomposition rates. Increased dryness would also suggest a greater susceptibility to loss of soil organic carbon through fire.
- Wetter winters, particularly following drier summers, would increase the potential for soil erosion, especially in peatland areas due to instability.
- More intense and/or sustained rainfall events in combination with other factors such as land cover change (e.g. more autumn-sown crops) may lead to changing patterns of soil formation and erosion.

8.2.6 Regulating ecosystem services

"Regulating services provided by ecosystems are extremely diverse and include the impacts of pollination and regulation of pests and disease on provision of ecosystem goods such as food, fuel and fibre. Other regulating services, including climate and hazard regulations, may act as final ecosystem services, or contribute significantly to final ecosystem services, such as the amount and quality of freshwater." (UK NEA, 2011)

Carbon storage

Climate change impacts for carbon storing habitats would influence the losses and gains of carbon stocks. Warmer drier summers and wetter winters may result in the release of carbon from peatlands. As already outlined (Section 8.2.5) there may be a number of climate related impacts for soils across different land uses. Increases in terrestrial plant productivity may lead to increases of biomass and soil organic carbon, drier conditions may reduce carbon storage and wetter winters may increase susceptibility of soils to erosion. The climate change impacts for habitats, particularly

those impacts that put pressure on the biodiversity of some habitats, may result in the decline of terrestrial carbon stocks. In the marine environment climate warming may increase rates of carbon cycling in the pelagic (open water) system, making less carbon available to the benthic (sea bed) system, resulting in reduced biomass of benthic organisms and possible negative consequences for marine food webs and fisheries (Marine & Fisheries Sector Report).

Ocean acidification and warming

Increasing CO_2 in the atmosphere is leading to ocean acidification (as discussed in more depth in Chapter 3), which can affect breeding cycles and the development of ocean organisms. Ocean acidification is thought to affect a wide variety of ecosystem processes and species although the exact impacts are not yet fully understood. One of the impacts is the effect on calcification processes of shell forming organisms including shellfish (mussels, clams, oysters, etc.) and crustacean species (crabs, lobsters, etc.) This can have a number of effects including increased vulnerability to predators. Functions other than calcification have also been shown to be affected by ocean acidification, including metabolism and behaviour of organisms. Further effects of changing pH include:

- The impact on the propagation of sound through the oceans;
- The rate of conversion between different nitrogen compounds, which could in turn impact upon phytoplankton growth and food webs, further affecting fisheries harvests;
- Disruption or changes in other processes such as stratification, ocean circulation and ice cover, shifts in light and other nutrient availability such as phosphorous and iron;
- The effectiveness of the oceans as a carbon sink; and
- Ocean warming may bring about changes in the distribution of marine biota, including fish and can cause mortality of unfertilised fish eggs.

Pollinators and Pollination Services

Some 84% of European crops and 80% of wildflowers rely on insect pollination with the value of pollination to UK agriculture estimated at £440 million per year (13% of the total value of agriculture). Over the last 20 years, the area of crops dependent on insect pollination has increased by 32% in England. In the agriculture sector, the cost of replacing bee pollination with hand pollination is greater than the total market value of the crops, at over £1.5 billion per year. The value of pollinators and pollination services to wild flowers and for recreational/ cultural services is unknown, but expected to be non-trivial (UK NEA, 2011).

During the last 20 years, habitat losses and intensification of agriculture are believed to be responsible for a 54% decline in honey bee colony numbers in England meaning that more than 50% of our landscapes now have fewer species of bees and hoverflies than in 1980. Intensification appears to change the community composition of bees within agricultural ecosystems by negatively impacting on the least resilient species and reducing overall diversity. When combined with the effects of climate change (such as, for example, changes in phenology or climate space and resulting changed community composition) and pathogens, this has major implications for the stability of pollination services to both biodiversity and agriculture.

Hazard Regulation

Flood Alleviation

Flood alleviation is supported through natural floodplains that accommodate volumes of flood water. The standing vegetation helps to slow the flow of water, and their roots help stabilise soils. A range of climate impacts have been identified for floodplain habitats that may influence their ability to alleviate flooding. Warmer temperatures leading to changes in community composition and potential eutrophication would change the roughness characteristics (which influences floodplain flows and water depths) and absorption capacity (which influences storage) of floodplain habitats. The leafy cover provided by vegetation within catchment areas also provides a large surface area that intercepts precipitation, which also reduces the amount and flow rates of water reaching the ground. Targeted planting of new woodland as a climate change mitigation response may also contribute partially to flood alleviation.

Wildfire Risk

The risk of fire would increase if there is an increased prevalence of hotter, drier conditions. Details on analysis into the potential impact of climate change on large-scale fire risk are given in Chapter 3. Wildfire can have a considerable impact on biodiversity, affecting habitats and species and potentially resulting in the local extinction of species. Fires can impact biodiversity through damage to flora and fauna and have wider repercussions for the natural environment, including increasing rates of soil erosion and deteriorating water quality.

Habitats that are particularly sensitive to fire include woodlands, grassland, peat soils (including blanket bog) and heathlands. Fires in peat habitats can cause the release of stored carbon to the atmosphere. Once ignited, peat habitats can 'smoulder' for an extended period and are difficult to extinguish. Fires in lowland heathland can cause the loss of rare lizards and snakes.

The increased risk of fires may also have an impact on forests. As well as the direct damage to trees, fire can also increase the susceptibility of surviving trees to insect attack, for example secondary bark and ambrosia beetles in conifer forests. This assessment investigated changes in large-scale fire risk as represented by the McArthur Forest Fire Danger Index (see Chapter 3), which shows how conditions that have the potential to lead to wildfire might change. The results suggest that there would be an increase in the index across the whole of the UK by the 2080s, based on the UKCP09 projections. This risk varies across the country, with increases of over 40% in south-eastern parts of the UK.

Erosion Control

Increases in soil erosion and loss of biomass as a result of climate change may impact on the climate regulation function of ecosystems. Soil erosion may increase due to increased drying of soils combined with more frequent flood events and more sustained rainfall events (Chapter 3). Along the coast soil erosion rates may be affected by sea level rise, as well as unforeseen impacts of man-made coastal erosion restriction and cliff erosion control measures. Maintenance of soil cover, particularly in upland areas for example, requires an emphasis on low-intensity land-use and re-establishing wet-heath to reduce rates of water transfer to fluvial networks and soil compaction. This improves plant productivity, processing and retention of nutrients and pathogens, reduces soil loss and river peak flows. It also tends to have positive knock-on effects to other ecosystem services, such as carbon sequestration (Smith *et al.*, 2011).

Water, Soil and Air Quality

A change in rainfall patterns may result in lower river flows. A reduction in flow levels combined with higher temperature would decrease oxygen supplies available for aquatic habitats. Lower flows also means that any pollutants are less dilute than when the river is higher. Historically, negative impacts on water quality are associated with industrial, domestic and land use sources. In recent decades, impacts from industry have declined whilst diffuse pollution in rural areas, mainly from agriculture has increased. By contrast, wastewater treatment plants act as point sources and are strictly regulated in terms of discharges. Heavier rainfall events may also increase the rate of runoff of pollutants. A change in nutrient status, dissolved oxygen or toxins in water bodies can all have detrimental impacts. Water temperature and high nutrient inputs have implications for the phytoplankton communities within lakes as increases in primary productivity occur. Plankton abundance and composition changes and large blooms of buoyant cyanobacteria may occur (Elliott *et al.,* 2006, Mitchell *et al.,* 2007), reducing water quality.

Aquatic communities contain species with varying thermal tolerances. Therefore, the differential impacts between species implies an enhanced prospect of changes to community structure and ecosystem function. Whilst the focus here is on the regulation of water quality, the changes described above also have key linkages and knock-on impacts with other ecosystem services, including nutrient cycling and oxygenation. Poor water quality can also cause issues with human recreational and amenity use of water bodies, including water sports and tourism, to the detriment of local communities. Furthermore, poor water quality also has implications for fish stocks which provide an important economic, social and cultural service in key locations, and for other important species.

The percentage of rivers with a net decline in Ecological Status[179] linked to changes in river flow, based on expert elicitation, is estimated to be ‘very low’ to ‘low’ for the 2020s, with a decline in status of up to 10% of rivers. In the longer term (2080s) larger reductions in summer flows may affect a significant proportion of rivers in England and Wales (Water Sector Report). The benefits of inland wetlands for water quality have been estimated by the UK NEA to be as high as £1,500 million p.a. Planned river quality improvements may generate additional values of up to £1,100 million p.a. It is also worth noting that changing regulations for water quality has a potentially large impact on the level of risk that may be faced.

In terms of marine water quality, projected future changes in rainfall and increasing temperatures pose significant problems regarding the occurrence of microbial pathogens (e.g. viruses, bacteria, protozoans) in the marine environment, with a direct impact on human health, especially in those communities that depend on water-based recreation and tourism and the bivalve mollusc shellfish industry[180].

Current climate change projections for a Medium emissions scenario (central estimate) show that by the 2080s precipitation over marine regions may range from a 3% decrease in the Scottish Continental Shelf to a 18% increase in the Eastern English Channel during the winter, and range from no change at all in the North West Approaches to a 34% decrease in the Eastern English Channel during the summer. The UK is also projected to become warmer in the summer months, with the highest increases projected in southern England (Murphy *et al*., 2009).

These changes would impact on various processes occurring at the interface of land, freshwater and seawater environments, namely:

[179] Good ecological status is an objective of the Water Framework Directive

[180] Bivalve molluscs are filter-feeders and, consequently, may accumulate microbial contaminants, which may be harmful to humans, or potentially, to other animals that feed on them.

- Altering the magnitude and seasonality of pathogens discharged into the sea from pollution sources situated on land;
- Modifying the mechanisms of transport of pathogens across coastal catchments;
- Modifying mixing, dispersion and sedimentation of microbes in tidal waters; and
- Altering biological factors determining the survival of microbes.

There is good evidence internationally that norovirus[181] outbreaks are linked to rainfall driven pollution events (Lee, 2000), particularly when these occur during the winter months, and this has also been observed in the UK. One example is the winter of 2009-10, which was the coldest UK wide winter since 1978-79 (Met Office, 2011) with significant associated precipitation events. This period was associated with an unprecedented number of shellfish related norovirus illness outbreaks (Westrell *et al*., 2010). UK coastal and offshore waters were recently classified as 'Non-Problem Areas' in terms of eutrophication, according to the Charting Progress 2 assessment (2010). However, future climate change might inhibit the ability of marine ecosystems to process carbon or nitrogen, influencing the timing and magnitude of the winter-spring plankton bloom; the quantity and/or quality of organic matter deposition to the sea-bed; and fundamental changes in nutrient cycling and food-webs.

Air quality is improved through the daily cycle of photosynthesis absorbing carbon dioxide and releasing oxygen. Whilst increased CO_2 promotes plant respiration, increased temperature and decreasing rainfall may impact on plant health. Climate alterations could lead to premature leaf loss (Warren *et al*., 2011), significantly reducing the carbon sequestration potential of the ecosystem. Additionally, changing rainfall and temperature patterns could alter the geographical location of species and habitats, resulting in migration and loss of diversity. Climate also influences air quality directly particularly in urban areas (Health Sector Report).

Soil biota, insects and other organisms contribute to soil quality through organic matter breakdown, nutrient release and soil mixing. Climate change may act to dry soils, limiting soil organism activity and plant growth. This could reduce nutrient levels within the soil impacting the overall health of the ecosystem. Increased rainfall could cause water logging of soils reducing productivity. A change in rainfall or temperature patterns may alter the regions in which species are found, altering the functioning of the ecosystems and, therefore, soil quality. Soil quality is also likely to be affected by changing land use and soil management (Biodiversity & Ecosystem Services Sector Report).

8.2.7 Extreme Events

Extreme events can have a sudden and catastrophic impact on local ecosystems both through biogeochemical disturbance (for example increased nutrients from runoff) and physical disturbance; storm events can alter coastal habitats and lead to wind throw within forests and precipitation extremes can cause prolonged drought or large river flows.

At present, average wind speeds are not projected to change, but should storm events increase this would impact on terrestrial habitats. High winds can cause considerable damage to woodlands, particularly in terms of timber producing stock. From a biodiversity perspective, tree flattening can benefit forest ecosystems by increasing light and moisture penetration for plant growth and improving soil conditions. Decomposing trees provide organic matter for fungi, lichens and organisms that

[181] The most common cause of infectious gastroenteritis (diarrhoea and vomiting) in England and Wales (HPA, 2011)

breakdown and release nutrients for plant growth, allowing deadwood habitats to support a more diverse ecosystem.

High river flows can act to erode and scour the river bed and banks. Impact on ecosystems can be significant, but are usually localised (British Ecological Society, 2007). Bank nesting bird and mammal habitats can be destroyed and an increasing regularity of events could potentially threaten the species' survival. As freshwater fish species are currently declining (WWF, 2002), an increased risk of flood scour would pose a large threat to freshwater ecosystems.

Long droughts can impact upon all ecosystems. Terrestrial ecosystems can be affected by the reduction in soil biota activity, reduced plant growth and limited soil binding. This threatens the ability of the ecosystem to be able to support important fauna and flora. Prolonged drought may act to displace species whilst increase the risk of pests and disease. Freshwater ecosystems may be affected by low flow reducing the habitat area and increasing pollution concentrations. Mountain water bodies and streams may dry up all together.

Large storms and sea surges can affect coastal habitats. Currently 17% of the UK's coast is suffering from erosion (Zsamboky *et al.*, 2011). High emissions scenario indicated that relative sea level rise may reach up to 76 cm at some locations around the UK by 2095 (Chapter 3). Important sand dune, mud flat and salt marsh areas can be significantly affected by large storms, causing a major shift in coastal morphology. Storm events can act to significantly alter coastal habitats, either through relocation of material or erosion.

8.3 Indirect impacts

A wide variety of socio-economic interests will drive many different responses to climate change. The indirect impacts on the natural environment are, therefore, difficult to assess until the extent of the impacts of adaptation and mitigation actions have been more fully identified.

Particularly relevant indirect impacts are discussed within the categories of catchment management, marine management and land use change for renewable energy. The impacts upon our urban environment are particularly important with regard to hazard regulation, reducing the urban heat island effect and species conservation.

Crops, livestock and fish are among the most tangible of the ecosystem goods that humans receive from the natural environment. Similarly, trees, peat and water supply are services and goods that may be negatively impacted by climate change. Less tangible are the cultural ecosystem services, obtained from the natural environment. Wild species diversity underpins both the cultural and the provisioning services discussed here and, of course, are the elements that are often also directly affected by climate change.

The indirect impacts relate to those things that we do to the natural environment, typically for social or economic reasons. Many of these actions follow from governance, regulation and management actions (e.g. of land in general, catchments, farms, forests, conservation sites and marine areas) as well as the exploitation of resources.

Determining how changes in management or resource use, that are a consequence of climate change, impact upon the natural environment is inherently complex. For example, when considering the impact of low flows on the natural environment, levels of demand and changes to policy are large drivers of the level of risk faced by the natural environment under low flow conditions. In this context, not only do we have to be able to predict future demand levels, but also future policy choices and the impact that those differences will have on the natural adaptive capacity of the natural environment (which is also uncertain). Both the patterns of socio-economic adaptation and the knock-on effect to natural adaptive capacity of systems need to be more fully understood in order that future assessments can start to address this issue in more detail and in particular, prioritise the impacts and drivers identified.

In this section, we provide a brief summary of the major issues that have been considered. These issues have been identified during the process of this assessment as being highly important and relevant to the natural environment but are not in a prioritised order:

- Catchment management
- Marine management
- Land use changes
- Urban environments
- Provisioning ecosystem services
- Cultural ecosystem services.

8.3.1 Catchment management

This assessment has identified a range of climate change consequences for land and water management, which may have indirect impacts on biodiversity and the natural environment. In addition, the sector analyses provided a qualitative assessment of longer term (2080s) socio-economic drivers of change, including population growth, environmental values and land use change. These indirect impacts may have greater consequences than direct biophysical impacts. For example, changes in land and water use at farm, landscape and river basin scale may cause a number of impacts:

- Land use may change in some areas as farmers take opportunities to increase production or grow new crops. More intense farming practices, particularly in upland areas, may lead to adverse environment consequences, affecting biodiversity and soil erosion. In addition changes to nutrient cycles (primarily nitrogen and phosphorus) may increase pollutant loads in rivers and lakes.
- Any increase in soil erosion is likely to result in increased sediment yields in rivers as well as land degradation (Agriculture Sector Report). The economic costs of soil degradation are estimated at between £250 and £350 million per year for England alone. This is mainly associated with soil erosion, carbon loss and the costs of dredging rivers and water treatment (Foresight, 2010b).

- Reduced water availability would place additional pressures on rivers and groundwater. Lower summer flows, for example, can then lead to a reduction in the dilution and dispersion of contaminants that have originated from both point and diffuse sources (Water Sector report).
- Increased water temperatures would place additional pressures on freshwater ecosystems. Warmer temperatures can act to displace cold-water species to cooler regions. If migration is not possible then extinction may occur. A higher water temperature holds a lower volume of oxygen. Therefore, pressures including eutrophication and algal blooms incidences could increase. Blooms act to starve the ecosystem of oxygen. Water quality would deteriorate through a fall in oxygen levels, release of sediment-bound phosphorus and altered mixing patterns. Migration routes, species composition and nutrient cycling could all be expected to change (Fischlin *et al.*, 2007).
- Increasing pressure for land outside of cities, which may suffer overheating in a warmer climate, poses a major challenge. The desire for increased living space close to employment opportunities with good transport links is challenging to reconcile with support for the protection of the countryside and the natural environment. Increases in such infrastructure are likely to reduce the connectivity of the protected site network, thus reducing the ability of species to disperse to new sites in response to a changing climate.
- Finally, increasing flood risk would also have implications for land use decisions, especially in flood plains and vulnerable coastal areas. Agricultural, forestry and semi-natural habitats have the potential to play important roles in mitigating the effects of climate change, but also have the potential to provide an important role in climate change adaptation, for example, by providing flood storage to protect downstream populations from river flooding (Wheater and Evans, 2009).

8.3.2 Marine management

Marine management ranges from ensuring the sustainable use of marine resources and strategic management of marine activities from renewable energy to nature conservation, fishing, recreation and tourism. As recognised by the EU Marine Strategy Framework Directive, the marine environment is dynamic; marine species, habitats and ecosystems have natural variability and will change and adapt to different pressures from both human activities and climate change over time.

Temperature is one of the primary factors (together with food availability, depth, salinity, shelter and suitable spawning grounds) that determines the large-scale distribution patterns of fish. Because most fish species tend to prefer a specific temperature range (Coutant, 1977; Scott, 1982), an expansion or contraction of their distribution often coincides with long-term changes in temperature. These changes are most evident near the northern or southern-most boundaries of the species' range. Recent analyses of Scottish and English commercial catch data spanning the period 1913-2007, by Engelhard (2005) has revealed that the peak catches of commercial species, such as cod, haddock, plaice and sole, have shifted throughout the 20th Century. Cod catches seem to have shifted north-eastward, towards deeper water in the North Sea, whereas plaice distribution has moved steadily north-westwards (Marine & Fisheries Sector Report). Fishing pressure and temperature increases have occurred over the same time period; making is particularly challenging to disentangle the potential effects of climate change and fishing pressure on distribution shifts. Similar distribution changes in non-native species (see Section 8.2.3) suggest the climatic changes are playing a part in the distributional shifts.

Distribution shifts may have 'knock on' impacts upon catches for commercial fisheries because changes in migration or spawning location affect the 'catchability' of individuals to fishing gears. Populations may move away from (or towards) the area where particular fishing fleets operate and/or where spatial restrictions on fishing are in place. Also species distributions may migrate across the boundaries where quotas belong to different nations. UK fishermen have witnessed and responded to a number of new opportunities in recent years, as warm-water species have moved into UK seas and/or their exploitation has become commercially viable for the first time. Notable examples include new and/or expanding fisheries for seabass, red mullet, john dory, anchovy and squid. Future developments in fisheries policy are, therefore, likely to continue to have to wrestle with the problem of how to manage dynamic fish stock populations that are subject to such direct and indirect pressures of climate change. Distributional shifts would also impact upon nature conservation actions within the marine environment, where, similar to on land, designated sites locations need to be monitored and management altered to reflect the dynamic natural environment and our dependence on the ecosystem services it provides.

Shifting species distributions affecting invasive non-native species may also require significant levels of management. It is clear that most marine invasive non-native species have come from similar regions, in particular from the east coast of the USA (especially the fauna) and from the western Pacific (especially the flora). More than half the total number of introduced species present in the UK is considered to have arrived in association with shipping, many others have been introduced in association with species for mariculture.

The marine environment is also used in many other ways, including by tourists. Ocean, marine and water-based activities are among the fastest growing areas of the tourism and leisure industry and include a multitude of attractions including: fishing, surfing, heritage visits, scuba diving, windsurfing, yachting and marine wildlife watching. Extraction of aggregates, oil and use of the oceans for renewable power, including wave, tidal and offshore-wind power, all have the potential to impact upon the natural environment as well. Aquaculture also has a large affect on the marine natural environment, affecting local nutrient loads and cycling. The way in which these areas are managed may lead to positive, negative or neural impacts from climate change to the marine environment. More research is required to understand all of the interactions and level of risks more fully.

8.3.3 Land use changes

Renewable energy development

Renewable energy projects represent an indirect impact of climate change to the natural environment. Wind turbines, for example, are known to cause deaths among some species of birds and bats, due to collision with the turbine blades, while biomass crops are thought to have both positive and negative impacts on biodiversity depending upon the crop and its management. In response to EU Directive 2009/28/EC, the UK has committed to sourcing 15% of all of its energy from renewable sources by 2020, which means that at least 35% of electricity will need to be generated by renewable sources. Hence, it is likely that there will be an increasing number of sites proposed for development. National planning policy currently includes[182] a requirement for local planning authorities to take into consideration "the effect of development on biodiversity

[182] Note that the planning system is in a period of significant change. DCLG published the draft National Planning Policy Framework for consultation in August 2011, which sets out principles that local councils and communities must follow to ensure that local decision making is consistent with nationally important issues, including climate change.

and its capacity to adapt to likely changes in the climate". This requirement is, however, confounded with respect to future distribution of species by the difficulty of predicting what the effects of climate change on a particular species population might be over the lifetime of a scheme.

The Royal Society for the Protection of Birds published a 'bird sensitivity map' for Scotland in 2006 to assist developers and local planning authorities to select wind farm sites that were less likely to have an impact on bird populations (Bright *et al.* 2006). The assessment shows that wind turbines, if constructed, are more likely to impact upon bird populations in the northwest of Scotland, with the Highlands, Western Isles and Northern Isles being particularly sensitive.

Biomass crops, short rotation coppice (SRC) and forestry by-products are also expanding in the UK. The consequences for biodiversity strongly depend on the location, land use and the land management of the land that is replaced. As many of the current biomass schemes have been developed only on a small scale, it is not certain how these issues will scale up to landscape level. A potential issue related to expansion is that, due to the increased transpiration demands of fast-growing trees, soil moisture deficits may be further increased in combination with the direct effects of climate change, to the detriment of local habitats and species. Beneficial effects may accrue from the development of schemes in the lowlands that enhance farmland diversity, whereas there is a risk of increased disruption in uplands. Large areas of monoculture could reduce habitat diversity in the landscape and present further barriers to species dispersal; smaller areas, suitably located, could enhance biodiversity (Mitchell *et al.*, 2007). Although robust systems are currently in place to assess the potential ecological impacts of proposed renewable energy schemes, the scale of future expansion suggests that the cumulative effects of many schemes could become a problem and, therefore, these systems may need a strategic review in order to help the development of robust habitat networks. A cross-Whitehall study is expected in 2012 that identifies the scale and sources of biofuel and biomass planned for the UK, including a sustainability assessment.

Agricultural intensification or land abandonment

This risk is an indirect consequence of autonomous (unplanned) or planned responses in the agriculture sector. Climate is an important influence on agriculture by providing the pattern of seasonal change for managing crops and livestock. The capability of the land to support different types of agricultural activity is highly variable across the UK. An ultimate consequence of agricultural intensification is usually that a higher proportion of biomass produced by net primary productivity is removed from the ecosystem and that nutrients become depleted unless replaced by artificial fertilisers. This can have negative implications for biodiversity, which together with the application of pesticides and herbicides, results in severe reductions in species abundance and diversity, unless remedial measures are applied. An example of intensification is the shift from spring-sown to autumn-sown crops that has occurred in many arable areas of the UK because of the potential for greater yields: the shorter fallow period in the field means a reduced food supply for wild species.

A changing climate means that the bioclimate factors associated with different agricultural activities will also shift. In Scotland, research has shown that the areas of prime agricultural land may expand and that in marginal areas a greater proportion of land may be capable of agricultural 'improvement' where soils are suitable (Brown *et al.,* 2008, 2011). This change in land use may be further encouraged due to concerns regarding food security. An increase in the area of land used for agriculture could have further negative consequences for biodiversity, particularly in marginal areas that have high biodiversity value.

Marginal agricultural areas in some locations may also be at risk of land abandonment. This may result from high precipitation rates causing soils to remain wet or becoming wetter for key periods of the year in spring and autumn. When soils are at high waterholding levels access to the land is very difficult and would be highly likely to cause damage to soil structure due to compaction. This can severely limit agricultural activities or make them highly dependent on favourable weather from year to year. Farming in marginal areas is, therefore, strongly associated with subsidies that provide a secure income through schemes of the EU Common Agricultural Policy (CAP). If subsidies decline or are ended as CAP is reformed, then a reduction in farming or even land abandonment becomes a possibility. This would have implications for biodiversity as some priority habitats and species are currently maintained by light livestock grazing. For example, this low-level disturbance allows grassland habitats to be maintained that would otherwise be likely to become scrub or woodland through time. Land abandonment would have mixed results for biodiversity: some species would gain and some would lose, but there could be significant consequences for some important and rare UK species that are present only in a few locations.

8.3.4 Urban environments

Towns, cities and urban development host a diversity of wildlife as well as providing for the needs of people. The range of habitats found within urban areas includes parks, gardens, river corridors, patchy floodplains, sports fields and intertidal habitats. The potential impacts of climate change on the natural environment within urban areas are related to the exacerbating effects of the urban environment on heat effects, drought and flooding.

The development of green and blue infrastructure[183] within and between urban areas as a sustainable adaptation strategy may result in the increase in tree planting, the creation of habitats and wider implementation of sustainable drainage systems (SUDs). This may bring benefits for conservation and biodiversity (Defra, 2010f). The impact of climate change on existing green space is discussed in Chapter 7.

8.3.5 Provisioning Ecosystem Services

"*Provisioning services are manifested in the goods that people obtain from ecosystems, such as food and fibre, fuel in the form of peat, wood or non-woody biomass, and water from rivers, lakes and aquifers. Goods may be provided by heavily managed ecosystems, such as agricultural [land].... and plantation forests....Supplies of ecosystem goods are invariably dependent on many supporting and regulating services."* (UK NEA, 2011)

Supporting and regulating services provide the underlying inputs to the provisioning service role that the ecosystem plays in providing the goods that humans obtain from the environment, e.g. food, fibre and drinking water. Of all the ecosystem services, the link with human wellbeing is most apparent for provisioning services. In addition, there are strong links between our management of land to obtain the goods from these services that in turn impacts upon the environment[184]. Therefore, the risk of damage to ecosystems is greater when deriving provisioning services from the environment than for any other of the ecosystem services. The acquisition of the goods from provisioning services is largely driven by the interaction between the ecosystems themselves and the way in which the land is managed. The way that the land is managed is driven

[183] Strategically planned networks of green space and waterways / wetlands.
[184] i.e. agricultural land may be managed to the benefit or detriment of the natural environment depending upon the process used.

primarily by politics, policy, technology and markets (Edwards-Jones *et al.*, 2011). Therefore, with the exception of a few direct climate change impacts to this area of ecosystem services, most impacts of climate change are likely to be indirect, either affecting the supporting and regulating services that underpin the provisioning services, or by affecting the way in which land is managed. Examples of the impacts to a selection of final provisioning ecosystem services are described below. At this time, it is not possible to quantify conclusively which impacts are the greatest. Furthermore, the UK is not self-sufficient in meeting its demand for food, fibre, water and energy. The UK is highly reliant on non-UK ecosystem services. Approximately 66% of the UK's annual water demand, for example, is met by overseas sources (embedded mainly in agricultural products) (UK NEA, 2011).

Wild Species Diversity

Wild species diversity crosses the boundary of provisioning and cultural ecosystem services and is thought to underpin an ecosystem's resilience to environmental change, including changes in climate. Wild species diversity is important for its own sake, being valued by people for intellectual, aesthetic, spiritual and religious reasons as discussed later in this chapter. Wild species diversity is also very important in the context of provisioning services, based on the role that the living component of ecosystems help to deliver the services that provide the ecosystem goods that humans utilise. A full understanding of which species in particular are vital to maintaining productive ecosystems and which species are essentially redundant from a production point of view is currently lacking. In principle, wild species diversity is particularly important in order to maintain a high level of genetic diversity from which humans can then derive new crop and livestock species, if required, in order to adapt to new environmental parameters, such as those that might occur due to climate change. Furthermore, the chemicals found inside or produced by plants, animals and microbes may be important in the future development of pharmaceuticals. Without knowing what our requirements will be in the future, it may be argued that all extant species may be of use and therefore the prudent strategy is to avoid all losses of biodiversity. As discussed in this chapter, species may be affected by climate change in a number of ways including impacts on climate space, phenology, impacts from pests and diseases, by competition between species and through loss of physical land space. Localised or national extinctions of species infer a loss of wild species diversity.

Historically, climate change has had a moderate impact on the provision of wild species diversity. The current and ongoing trend is classified by the UK National Ecosystem Assessment (2011) as "Very rapid increase of the impact" for the future impact of climate change on the delivery of wild species diversity provision (see Figure 8.4).

Crops, Livestock, Fish (UK NEA, 2011)

Most crops are expected to be sensitive to a changing climate with impacts on both land suitability (for existing and new crops) and productivity (yield and crop quality) (see Chapter 4). In terms of ecosystem goods gained from provisioning services, the UK obtains about 60% of its food from UK agriculture (Edwards-Jones *et al.*, 2011). Given the large amount of work put into technological or management improvements in the agriculture sector, it is difficult to delineate a strong relationship with climate. Whilst sugar beet yields have increased steadily since 1990, average wheat yields have shown little increase and at around 8 tonnes per hectare they have failed to increase in line with genetic improvement, suggesting that plant breeding benefits are being given away elsewhere in the production cycle. This could be due to reductions in ecosystem services, including soil development or pest and disease regulation or, alternatively, it

may be due to changes in management, such as failure to control weeds or poor crop nutrition. In the CCRA analysis, both wheat and sugar beet were shown to have weak linear relationships with temperature, with wheat being more sensitive. The provision of crops will also be affected by levels of CO_2. Future projections suggest that yields may increase and it is expected that further technological improvements may improve the yields even further, although benefits may be limited in some areas by availability of water and nitrogen (depending upon management activity taken).

The recent 2010 sugar beet harvest was affected by extreme cold and wet conditions and illustrates that, while the production system is excellently adapted to average climate, it is less resilient to extreme conditions, which may become more frequent with climate change. Assessing the impacts of drought on agriculture and horticulture is not straightforward and some cropping systems have shown adaptation to these events whilst others have not (Chapter 4). The recent drought in the spring of 2011 demonstrated the widespread impacts of drought on agricultural crop yields. Media reports suggest around 10% reduction in national crop yields. In East Anglia there were reports of losses of between 20-50% in some crops while others, e.g. linseed, showed no spring growth, remaining as seed in the ground from the first week of March until June 2011[185]. Based on UKCP09 projections there may be an increased risk of heavy rainfall in winter months, increases in soil erosion potential, increases in landslides and an increasing frequency of river flooding (Chapter 3). Heavy rainfall events that lead to flooding can wipe out entire crops in the floodplain, and excess water can also lead to other impacts, including water logging, anaerobic soil conditions and reduced plant growth (Gornall *et al*., 2010). Relative sea level rise also increases the risk of tidal flooding that can affect large areas of coastal land, particularly in the east of England.

Historically, climate change has had a low impact on the provision of crops, but the trend is classified by the UK National Ecosystem Assessment (2011) as an “Increasing impact” for the current and ongoing future impact of climate change on the delivery of crop provision (see Figure 8.4).

Ecosystem goods from livestock include both the meat for human and animal consumption and dairy products. The provision of livestock relies on the successful growth of grassland for grazing and the provision of winter feeds in the form of hay and silage (also ecosystem goods). Grassland yield is strongly influenced by temperature and soil moisture availability (which is influenced by rainfall amount and distribution). These determine the number of grass-growing days (GGD) per year. The number of GGD is greatest in oceanic western areas on soils with good soil moisture conditions, and least in the upland areas and in areas with a more ‘continental’ climate (with low temperatures in spring plus dry periods in summer, as in eastern Britain). Agricultural productivity of UK grasslands is generally below its theoretical potential. This is often done in order to allow farmers to meet their environmental obligations and farm sustainably (see Chapter 4).

Increased temperatures may also impact on livestock directly, increasing heat stress that may lead to a reduction in productivity, although projections indicate that this may be quite small (Agriculture Sector Report). It may also increase the demand for water for livestock, whilst water availability may reduce. The effects may be countered by improvements in breeding of livestock to tolerate the new climate conditions.

Historically, climate change has had a low impact on livestock production, but the trend is classified by the UK National Ecosystem Assessment (2011) as an “Increasing impact” for the current and ongoing future impact of climate change on our ability to successfully rear livestock for human use (see Figure 8.4).

[185] http://www.telegraph.co.uk/finance/newsbysector/retailandconsumer/8556817/UK-farming-in-crisis-as-drought-hits-crop-yields.html

Climate change impacts on the marine environment are likely to result in consequences for the provision of commercial fishing. This assessment highlighted that the incidence of harmful algal blooms may be affected by climate change; the water quality of shellfish waters may deteriorate; there may be changes to the extent of invasive non-native species; the spatial distribution of marine species may change and ocean acidification is likely to continue (Marine & Fisheries Sector Report). Changes in ocean temperature are already leading to changes in fish distribution and ocean acidification could result in commercial fisheries of shellfish and crustaceans being badly affected. Year class strength in species such as cod and haddock has been weaker than average in recent years, thought to be due to warming temperatures and corresponding changes to their juvenile food supply. Other commercial fish and shellfish species such as scallops, shrimps, sole, whiting and seabass, however, have been shown to benefits from warmer temperatures. The current scientific consensus remains that ocean acidification may pose a serious threat to the integrity of the marine ecosystem, key element cycles, biodiversity and, as a consequence, the provision of resources, goods and services. The complete nature of these impacts is still unknown.

Based on current projections, climate change is unlikely to have a significant effect on UK mariculture over the next decade. Further into the future, however, there may be noticeable effects (MCCIP, 2008). The trend is classified by the UK National Ecosystem Assessment (2011) as an “Increasing impact” for the current and ongoing future impact of climate change on the delivery of farmed fish provision and a “Very rapid increase of the impact” for the provision of wild fish (see Figure 8.4). Scotland is projected to experience rises in annual and seasonal mean water temperature of up to 2.5 ºC by 2080. Similar projections are expected for England and Wales in the same time period. Rising average water temperatures could result in faster growth rates for some species that are more tolerant of higher temperatures (e.g. Atlantic salmon, mussels and oysters), but prolonged periods of warmer summer temperatures may adversely affect some cold water species (e.g. cod and Atlantic halibut) and intertidal shellfish (oysters) as their thermal optima may be exceeded for long periods of time. Such changes could make sheltered, warmer sites unsuitable for those species during the summer months. The culture of species that are currently of marginal (but growing) value to the UK market, but which thrive in warmer conditions such as sea bass, sea bream and hake, could be a positive new opportunity from climate change (MCCIP, 2008). We might also anticipate the culture of introduced tropical species such as *Tilapia* and *Pagasius* in coastal lagoons.

Trees, standing vegetation, peat (UK NEA, 2011)

As discussed in Chapter 4, trees may be affected by climate change in many ways, including drought stress; changes in the prevalence and extent of pests and pathogens; potential increase of wildfires; impacts from increase waterlogging of forests; and the potential increase of snow and frost damage. Increased temperatures and the increased production of carbon dioxide may increase primary production, which would increase the potential productivity of forests. These impacts would have consequences for the production of timber[186].

Climatic conditions, such as drought, can test the ability of a tree to function effectively, potentially leading to a reduction in timber production or loss of tree species. In terms of the ecosystem goods produced, this may mean there is a need to revise forest plans to accommodate alternative species. The balance of positive versus negative climate impacts on timber production will vary by UK region and be dependent on any changes in planting.

[186] Timber can be described as one of many ecosystem goods that humans obtain from the natural environment; “The role that an ecosystem plays in providing these goods is termed a ‘provisioning service’ ” (UK NEA, 2011)

As discussed previously in this chapter, beech woodland habitats are typically associated with thin soils having a relatively low available water capacity (AWC) that increases their vulnerability to drought. Defoliation issues have been linked to soil moisture deficits for two native species in this assessment: beech and oak. Death of beech trees has been associated with drought in some cases and also may lead to an increase susceptibility to pests and diseases. Future projections of climate suitability for beech suggest that the greatest changes would be in the south and east of England where most of the beech woodland priority habitats are located (Biodiversity and Ecosystem Services Sector Report).

Historically, climate change has had a low impact on the provision of timber, but the trend is classified by the UK National Ecosystem Assessment (2011) as "Very rapid increase of the impact" for the current and ongoing future impact of climate change on the delivery of timber provision (see Figure 8.4).

Ecosystem goods include peat, which has historically been used as stable litter and as fuel to heat homes. In more recent times, peat is used in horticulture as a growing medium constituent. Peat is still sold as fuel and is important in the Scotch Whisky Industry. The extraction of peat is primarily driven by consumer demand. The formation of peat, linking closely to supporting services, requires specific conditions. Some peats rely on only rainfall and others rely on a combination of rainfall and high water-table levels to create the conditions required to form. Peat formation is, therefore, susceptible to changes in precipitation, but can also be reduced or cease due to land-use change and management, such as drainage. As previously discussed in this chapter, peatlands in Great Britain[187] are considered to be at risk from the rising temperatures associated with climate change. Changes in the vegetation found in peatlands may result in peat formation slowing or ceasing all together. In addition to peat itself, peatlands also contribute significantly towards other ecosystem services, including water cycling, water quality and carbon sequestration.

Historically, climate change has had a low impact on the provision of peat, the current and ongoing trend is classified by the UK National Ecosystem Assessment (2011) as "continuing impact" for the future impact of climate change on the delivery of peat provision (see Figure 8.4).

Demand for heating is liable to reduce due to climate change; although this may be outweighed by increased population under some socio-economic projections. Nonetheless, there will be pressures on energy resources from both climate related drivers, such as flooding and heat related disruption (Energy Sector report) and energy security considerations and the low carbon agenda. Bio-fuels (ecosystem goods) are anticipated to play a part in these shifts, which in turn may stimulate the increase of biomass production that relies on provisioning services. Wood may become a more popular choice for domestic heating as more efficient boiler designs are developed and as the cost of fossil fuels increases. The Renewable Heat Incentive policy aims to mainstream renewable heat technologies, such as those that use biomass as fuel.

Water Supply (UK NEA, 2011)

Large reductions in summer flows may have significant consequences for water supplies to the environment, as well as to agriculture and for public water supplies (Water Sector Report). Demand for water from people is driven by consumer demand and policy-led drivers (Edwards-Jones *et al.*, 2011). In the near term (2020s) pressure on UK water resources is anticipated to increase, in the longer term (2050s) water users may be affected by more frequent restrictions, unless more supply and demand

[187] As previously discussed, the risk to peatlands in Northern Ireland is less clear than in the rest of the UK, see section 8.2.1

measures are taken to close the supply-demand balance. The combined impact of climate change and increased demand for water may act to modify flow and water levels. Changes in flow and water levels may interact with impacts on water quality and thermal regime, which may reduce the capacity of aquatic ecosystems to adapt to change. Resulting changes to supporting services, such as nutrient cycling and oxygenation, have implications for a range of regulating, provisioning and cultural services that these systems provide. The most pronounced risk occurs during extreme drought events when there could be major biodiversity loss and some ecosystems may experience irreversible change without a more precautionary approach. Beech trees and blanket bog were assessed in the CCRA with respect to soil moisture deficits and drying (Biodiversity & Ecosystem Services Sector Report) and were found to be negatively impacted by a reduction in water availability as discussed earlier in the chapter. It is widely recognised that drought influences tree health, growth and productivity and can ultimately cause tree mortality, often when in combination with other stresses, such as pests and pathogens (Read *et al.*, 2009). Reduction in summer flows also has consequences for business that rely on abstracting water; potentially leading to increased commodity prices of crops such as potatoes, that are currently often irrigated, and wheat, that may need to be irrigated in the future (Business, Industry & Services Sector report).

Historically, climate change has had a low impact on the provision of water, the current and ongoing trend is classified by the UK National Ecosystem Assessment (2011) as "Very rapid increase of the impact" for the future impact of climate change on the delivery of water provision (see Figure 8.4).

8.3.6 Cultural ecosystem services

"Cultural services are derived from environmental settings (places where humans interact with each other and with nature) that give rise to cultural goods and benefits..... Such places provide opportunities for outdoor learning and many kinds of recreation....aesthetic satisfaction and improvement to health and fitness and an enhanced sense of spiritual wellbeing. People's engagement with environmental settings is dynamic: meanings, values and behaviours change over time in response to economic, technological, political and cultural drivers; and change can be rapid and far-reaching in its implications." (UK NEA, 2011)

Landscape character

The changes to the habitats described above that may result directly and indirectly from climate change would have an impact on the landscape character of the UK. Some locations may experience changes in habitat type and others would experience changes in the characteristic species that make up those habitats. These dynamics would change the appearance of the landscape and the nature of the change would vary by regional location, nature of climate impacts and response of the environment to other drivers as well as to climate change. Landscape character may, therefore, become more diverse in some locations and more homogeneous in other locations. Changes in the elements and patterns in the landscape have an impact in the overall quality of the countryside.

Specific impacts on landscape include the potential alteration of upland landscapes toward lowland features, due to altitudinal shifting in species ranges. This may cause potentially significant impacts on the landscape character of upland areas, such as the Scottish Highlands, Snowdonia, the Lake District and the Peak District. Drought and low flows may reduce the distribution of small freshwater streams and lakes.

An assessment of the impacts of climate change on Scottish landscapes and their contribution to quality of life (Land Use Consultants, 2010) indicated that direct impacts from climate change would, for the most part, cause more gradual and subtle changes, which may modify rather than completely transform the landscape's character. They determined that some mitigation activities, such as installation of wind farms and small scale or micro-renewables, such as solar panels on buildings, may lead to a "significant effect on landscape character".

Recreation

The recreational benefits provided by the natural environment are influenced by diversity of features, accessibility of local places and characteristics of the landscape or seascape. Increased temperatures may increase tourism and outdoor-based recreation. This may, however, be limited by other climate change impacts such as reduction of water resources available for water based recreation; increased management of forest pests and pathogens leading to restrictions on access to woodlands; and increased occurrence of hazards such as wildfires and flooding. The intensification of management of forests and agricultural areas for wood fuel and bio fuel may lead to the need to control visitor numbers to some woodlands and footpaths across open farmland. The diversity of features within the landscape may be influenced by climate change, which may in turn affect the quality of the countryside for people to enjoy, with some regions benefiting from increases in diversity whereas others may experience increased homogeneity.

Recreation services may also contribute a monetary value to the UK economy, for example, case study work carried out by the RSPB found that:

- At Bempton Cliffs for 2009 an estimated income of over £750,000 that was coming into the local area was attributable directly to seabirds. This equates to 21.5 full-time jobs being supported by seabirds in the region, or over 5% of all employed people in the Bempton Parish Council area. These jobs 'supported by seabirds' are in addition to those staff actually employed at the reserve (4x full-time; 2x part-time; 5x part-time seasonal). Therefore the seabirds at the RSPB's Bempton Cliffs Reserve are a significant contributor to the local economy.
- At the Rathlin Island Reserve, in 2009, an income into the local area of over £115,000 was attributable directly to seabirds. This equates to over 3 full time jobs being supported by expenditure on seabirds in the region, in addition to the full time and seasonal staff employed at the Reserve. In 2007, 458 people in the Bonamargy and Rathlin Ward (an area covering the Island and part of the mainland) were employed full time, meaning annual spend by visitors to Rathlin in 2009 accounted for about 0.7% of fulltime employment in the region. However, with a total population of approximately 80 people, of whom not all are of working age or in employment, seabird attributable expenditure supports around 4% of the Rathlin Island population.

Historic and spiritual services

Changes in habitats, biodiversity and landscape would affect the historical and spiritual services provided by the environment. The reduction of numbers or even potential extinction of some species of flora and fauna due to climate change (Biodiversity & Ecosystem Services Sector Report) would reduce the historical value of the environment, as there would be a loss of continuity of existing biodiversity and, therefore, a loss of connection between future and past environments.

Historic services

Peat soils, unlike other soils, are able to preserve organic matter (such as wooden tools, clothing, plant pollen, animal and human remains) due to the fact that decomposition rates are very low. This allows archaeologists to build a picture of the prehistoric landscape. Also, pollen and animal remains allow scientists to investigate how climate may have impacted species in the past, which helps with our understanding of climate change in the future. Degradation of peat soils would reduce our ability to understand our past, an important but intangible service from our environment.

Spiritual services

People may search for spiritual environmental connections through both individual personal reflection and organised experiences; cults and rituals. Spiritual values may be placed on certain environmental ecosystems, species and features, e.g. 'Holy forest', sacred animals and inspiring waterfalls (Berhe *et al.*, 2005). For those "finding themselves", "getting away from it all" or "recharging the batteries" spiritual and wellbeing benefits are usually sought in the natural environment.

Natural woodlands can represent the continuity between past and present and can be a source of wonder. Artistic works, sculpture and carvings, enhance the experience and services that the ecosystems offers (EFTEC *et al.*, 2006). Additionally ecosystems provide inspiration for artists, architects and folklore, giving them a more tangible value by those inspired (Defra, 2007a).

Despite the positive role that the natural environment has been seen to contribute toward religious, spiritual and mental wellbeing, it is extremely difficult to quantify the importance of the natural environment to these experiences or to assign particular landscapes or ecosystems as being conducive to these experiences occurring. Areas of religious or spiritual importance vary in their characteristics greatly, from the holy islands of Iona, Lindisfarne and Bardsley to areas such as Walsingham in North Norfolk (UK NEA, 2011).

8.4 Evidence gaps

Understanding the interaction of climate and other drivers of change on the natural environment is an area of large uncertainty. Scaling up local, species or habitat specific studies to a more integrated understanding of the relative influence of different drivers at a regional or national scale will require a sustained research effort over the next decade.

Key areas where further work could increase understanding of the impacts of climate change; help remove uncertainties regarding their scale and nature; and aid climate change adaptation in relation to the natural environment include, but are not limited to, the following:

- Development of systems-based approaches that can improve understanding of the multitude of interactions within the natural environment, between species, habitat shifts and landscape structure and geomorphological changes, to provide a more robust evidence base that bioclimatic envelope models alone.
- Development of a greater understanding of the drivers of changes in the natural environment, for example, the cause-effect pathways that lead to harmful algal blooms and the contribution of human-led drivers, such as pollution versus climate change.

- Evaluation of the effectiveness of long-term landscape-scale initiatives, such as measures to improve landscape upland water retention and water quality (freshwater and marine).
- Develop and increase understanding of the 'protected areas' approach, e.g. development of mechanisms to improve and integrate protected areas into the wider landscape and so deliver more ecological benefits. For example:
    - Modification of marine and terrestrial protected site management and quality, to increase the ability for species to adapt;
    - Development and use of UK wide priority habitat projections for different geographical areas; and
    - More detailed biogeographical information is needed to increase resolution of knowledge, especially in Northern Ireland.
- More systematic UK-level collation and interpretation of site monitoring and other available data (e.g. phenology), against inter-annual patterns of climate variability and trends of long-term change.
- Exploration of land use methods that better integrate biodiversity adaptation with climate change mitigation, e.g. the potential contribution of biomass energy plantations to habitat diversity.
- Development of regional/national-level assessments of the climate sensitivity of freshwater and marine ecosystems.
- Generation of more information on genetic diversity within species, to help identify and monitor genetic constraints and manage genetic diversity to allow species to adapt successfully.
- Vulnerability assessment of key locations and pathways for migratory routes (e.g. using space-for-time substitutes based upon current climate variability).
- Detailed epidemiological knowledge of different invasive non-native species, pests and diseases (and their vectors) and their relationship with climate and climate change, in the terrestrial, marine and freshwater environments.
- Further information on understanding hydro-ecological stress from modifications of the flow regime as a whole is needed. In addition, there is a need to capture the impacts on groundwater dependent wetlands impacted by unsustainable abstraction and the relative importance of point versus diffuse pollution sources under climate change for the natural environment and for the ecosystem services obtained e.g. drinking water.
- Development of better assessments of medium- to long-term climate impacts on ecosystem functions (e.g. marine CO_2 absorption, nutrient cycling, soil functions, effects of CO_2, pollution, impact of wildfires and measures being introduced in response to the low carbon agenda) and the knock-on consequences of these.
- Improved understanding of the implications of the rate of climate change for natural adaptive responses in different ecosystems (including across different species), including the role of extreme events, and hence the limits to and thresholds for maintaining adaptive capacity.
- Critical thresholds ('tipping points') in the interactions between climate and ecosystem responses beyond which the system may undergo a major non-linear change or shift to a new ecological regime (e.g. coastal systems in response to a major storm surge event). Some recent advances have been made with

regard to identifying key thresholds for animal population declines (e.g. Drake and Griffen, 2010)

- Understanding, assessing the drivers and valuing ecosystem services, including specific gaps, for example:
    - Understanding the future implications of climate change for fishing fleets, fishermen, economies and society;
    - A better understanding of the likely socio-economic benefits of increased arctic ship-passage balanced against environmental risks; and
    - Better understanding of the role of culture and social capital (i.e. non-monetary benefits) in ecosystem-based management and the wider benefits of ecosystem services for human wellbeing.
- Trade-offs in adaptation capacity between different sectors. One of the key principles of sustainable adaptation is that adaptation in one sector should not unreasonably limit the ability of another sector to adapt. However, there is very little information available on the potential trade-offs that might occur and how they can be optimised for multiple sectors with different needs and responses.

8.5 Summary

Biodiversity is already threatened by human-induced degradation of habitats and climate change is adding extra pressures to already vulnerable ecosystems.

There is very high uncertainty surrounding the exact nature and scale of response. Sensitivity to biophysical impacts can be identified in a number of areas, including, but not limited to soil moisture deficits, low flows and coastal erosion. However, the interrelationships and feedback loops between species and habitats to climate change and other drivers adds further complexity and difficulty in estimating the level of risk to the UK.

The response of individual species will be driven by their natural adaptive capacity as well as by the extent to which systems can be put in place to allow natural adaptation to occur and to reduce inherent vulnerability under a changing climate.

This chapter has provided an overview of the risks posed to the natural environment as a result of climate change, drawing on the risk metrics that have been developed as part of this assessment, Table 8.8. For some of the impacts, the scale of the consequences can be estimated based on evidence of impacts from past climate change or expert judgement and understanding of the response of species and habitats to changes in drivers and pressures. For other impacts, the exact nature and scale of the response is more difficult to estimate. The high uncertainty associated with understanding the potential risks for the natural environment from climate change relate to the complexity of the potential response and lack of evidence for the tolerance or sensitivity of species to specific changes in environmental conditions. The interrelationships between the response of different habitats and species to climate change and changes in other drivers will influence outcomes.

Many of the bio-physical impacts on the environment are projected to increase (Chapter 3). This includes such things as soil moisture deficit, extremes that cause both high river flows and flooding or low flows and shortages of supply, and wildfires. The role of pests, diseases and invasive non-native species, coastal erosion and ocean acidification are less certain, but may have a significant impact. A number of other bio-physical impacts, including changes in soil organic carbon, spills from combined sewer overflows, water quality and sunlight/UV are even less certain (low confidence) but may be potentially significant in magnitude.

There are a number of interdependencies amongst these various impacts. For example, soil moisture, the condition of water bodies, prevalence of droughts, as well as relevant climate variables (e.g. temperature and precipitation) would all influence the prevalence of particular pests, diseases and the ability for non-native species to become established. Taken collectively the results suggest that there is the potential for medium to high magnitudes of change by the 2050s, increasing to a high magnitude in the majority of cases. The environmental stresses are, therefore, anticipated to change and predominantly in a direction that is most likely to have an adverse effect on the condition of the current assemblage of habitats and species. This would serve to exacerbate the existing pressures on biodiversity, due to land use and other constraints.

8.5.1 Changing state of the natural environment

The way in which changes in the bio-physical impacts (such as the amount of flooding, frequency of droughts and erosion of soils) interact and lead to changes in habitat is highly complex and the subject of ongoing research. In a few cases, the risk assessment provides a preliminary indication of how these impacts may in turn impact on habitat condition or state.

Some of the impacts noted above would have consequences for water bodies in terms of both water quality and ecological status. This in turn has implications for the classification and management of rivers under the Water Framework Directive. The combined influence of the many pressures on UK river systems, due to a wide range of uses, means that restoring rivers to good ecological status is already a challenge. Climate change may make this more demanding and, hence, these consequences are reported to be of high magnitude from the near-term onwards.

On the coast, the potential for erosion in response to sea level has been estimated with a high degree of confidence, but with some uncertainty about the magnitude (particularly at the local scale). This would most likely impact agricultural land and also important habitats, including BAP habitats[188]. This change would be progressive and the rate would depend on the rate of sea level rise (which is projected to accelerate) and the availability of sediments from the near shore, eroding cliffs and other sources. The response to-date has been to re-align the coast where possible and, as reported in the Biodiversity & Ecosystem Services Sector Report (risk metric BD7) the potential for managed re-alignment to offset the loss of these habitats is likely to increase.

In the marine environment ocean acidification, due to an increase in the amount of carbon being absorbed in sea water, could potentially have a dramatic impact on the state of the marine environment. The impacts of acidification on marine species and ecosystems are not fully understood, although the subject is attracting significant and increasing concern. A wide variety of ecosystem processes and species are thought to be vulnerable, including calcification processes, the propagation of sound, and biogeochemical cycling (notably nitrogen). Whilst progressive acidification has been estimated with moderate confidence to increase from low to high magnitude over the

[188] Habitats identified as important in the Biodiversity Action Plans

coming century, the impact that this may have on marine species remains highly uncertain.

Another major change in habitat state is happening a long way from the UK in the Arctic. The melting of the polar ice is set to radically change the environment in this region and in turn may lead to a number of other changes also at a global scale. In this assessment some consideration was given to bird migration (Biodiversity & Ecosystem Services Sector Report) based on changes in birds arriving in the UK, but this did not examine the potential changes to their breeding grounds that this level of change in the Arctic may bring about. In addition, the marine habitat will be significantly altered if the extent of ice coverage changes as projected, potentially altering the distribution of algae and fish species, including those of economic interest. In the opposite direction, migrants coming from the south may increasingly face additional pressures from more frequent and more severe droughts in areas such as the Sahel, which offers a vital feeding ground for many migrant species.

8.5.2 Adaptation in response to climate change

As discussed earlier in this chapter, all species are expected to be able to adapt to changes in their environment to an extent through responses that can either be classed as evolutionary or ecological adaptive responses (Williams *et al.,* 2008). The capacity for evolutionary adaptation is exceptionally difficult to quantify and this was not undertaken for this cycle of the CCRA. Ecological adaptive responses were considered:

Shifts in distribution, following changes in "climate space": There is already good evidence that many species are moving to track their changing climate space. Although generally northerly, and/or upslope in hilly and mountainous regions, complex interactions in precipitation, temperature, soil and surrounding habitat conditions can affect species movements in different ways, making the actual realised range more complex that simply the range in which their suitable climate space is found. Such **contraction of range into areas that remain suitable (refugia)** and/or **shifts in the type of habitat or micro-habitat used** is one way in which some species may be able to adapt. For example, observations suggest that migratory bird species are shifting their over-wintering grounds to higher latitudes (Lehikoinen *et al*., 2004). Alternatively, it may be a way in which habitats can be managed to encourage adaptation. Such changes occur on a species by species basis, but at the landscape and more local scale, biotic interactions and land use change and management will have a large impact on the natural adaptive changes that some species can make. In the future, therefore, species communities may be very different from the ones found today and, thus, so may be the ecosystem services derived from the changed environment.

Changes in interactions with other species: in upland areas in particular, the lower or upper limits of many species are already dominated at the local scale by biotic interactions, i.e. competition, predation and prey availability. A further concern is that in a changing climate, generalists would be favoured over specialists. Increases in success of generalist species over specialist species would result in the reduction of overall biodiversity and, in the long-term, the adaptive capacity of the system and its ability to deliver ecosystem services.

Changes in phenology: Climate change is undoubtedly altering the phenology (seasonal timing of life cycle events) for many species by modifying the environmental cues that they use for migration, breeding and predation, ultimately influencing their demography and population dynamics. However, the influence of these changes in interactions between species and across trophic levels (steps in the food web) may be

much more profound, leading to not only negative changes in biodiversity, but also knock-on effects to ecosystem services.

Acclimatisation to the new climate: Species have the potential, within the physiological range of climate variables they can withstand, to become acclimatised to different climate factors (Vicca *et al.,* 2007). In some cases, species may do better in the new climate. For example, selected crops are projected to give greater yields in the near and medium term, although there is some evidence that this may not be sustained in the longer-term in areas where water availability may become limited. The fitness of some species, predominantly generalists, may well improve, leading to population growth and increased productivity of some species. That said, the overall impact on biodiversity is expected to be negative.

The extent to which a species is required to adapt to changes in climate will also depend on its exposure to those changes. The degree of exposure may be mitigated by the actual degree of climate change that occurs in the area in question, buffered by local microhabitats and the extent to which behavioural responses can reduce exposure (Williams *et al*., 2008). It is likely that in the face of rapid climate change, species, habitats and ecosystems would require a more extensive, larger, well-managed and joined up conservation network and enough time to allow for natural adaptive responses (Lawton *et al.,* 2010; Williams *et al*., 2008).

Due to the complexities associated with natural adaptive capacity, vulnerability to climate and measuring the changes that have occurred so far in the natural environment, many of the estimated of magnitude and timing in Table 8.8 are based on informed judgement. Climate is, however, a vital component of ecosystem structure and function and is, therefore, likely to be the focus of further research to understand better the inherent adaptive capacity and vulnerability of such systems.

Table 8.8 Scorecard for natural environment

Metric code	Potential risks for the natural environment	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
MA4b	Changes in fish catch latitude/centre of gravity (plaice, sole)	M	~	1	~	~	2	~	~	3	~
AG10	Changes in grassland productivity	M	1	1	1	1	2	2	1	2	2
FO4b	Increase of potential yield of Sitka spruce in Scotland	M	1	1	1	1	1	1	3	3	3
AG1c	Changes in potato yield (due to combined climate effects and CO_2)	L	1	1	2	1	1	2	1	1	2
FO1a	Forest extent affected by red band needle blight	M	1	2	3	2	3	3	2	3	3
WA7	Insufficient summer river flows to meet environmental targets	L	1	2	3	2	3	3	3	3	3
BD7	Risks to coastal habitats due to flooding	M	1	2	3	2	2	3	2	3	3
BD14	Ecosystem risks due to low flows and increased water demand	M	1	2	2	2	2	3	2	3	3
MA2a	Decline in marine water quality due to sewer overflows	M	1	2	2	1	2	3	2	3	3
FL4b	Agricultural land at risk of regular flooding	H	2	2	2	2	2	3	2	3	3
BD11	Generalist species more able to adapt than specialists	L	1	2	3	2	2	3	2	3	3
BD3	Risk of pests to biodiversity	L	1	2	2	2	2	3	2	3	3
BD4	Risk of diseases to biodiversity	L	1	2	2	2	2	3	2	3	3
MA6	Northward spread of invasive non-native species	M	1	2	3	2	2	3	2	3	3
BD5	Species unable to track changing 'climate space'	H	1	2	3	2	2	3	2	3	3
BD9	Changes in species migration patterns	H	1	2	3	2	2	3	2	3	3
BD10	Biodiversity risks due to warmer rivers and lakes	M	1	2	3	2	2	3	2	3	3
BD2	Risks to species and habitats due to coastal evolution	M	1	2	2	2	2	2	2	3	3
BD8	Changes in soil organic carbon	L	1	2	2	1	2	3	1	3	3
WA9a	Potential decline in summer water quality (point source pollution)	L	1	1	3	1	3	3	1	3	3
WA9b	Potential decline in water quality due to diffuse pollution	L	1	1	3	1	3	3	1	3	3
BU2	Monetary losses due to tourist assets at risk from flooding	M	1	1	2	2	2	3	2	3	3
MA4a	Changes in fish catch latitude/centre of gravity (cod, haddock)	M	~	1	~	~	2	~	~	3	~
BE5	Effectiveness of green space for cooling	M	1	1	2	1	2	3	2	3	3
BD1	Risks to species and habitats due to drier soils	M	1	1	1	2	2	2	2	3	3
MA3	Increased ocean acidification	M	1	1	1	2	2	2	2	3	3
FO4a	Decline in potential yield of beech trees in England	M	1	1	1	2	2	2	3	3	3
FO1b	Forest extent affected by green spruce aphid	M	1	1	2	1	2	2	1	2	3
BD12	Wildfires due to warmer and drier conditions	M	1	1	2	1	2	3	2	2	3
BD13	Water quality and pollution risks	M	1	1	2	1	2	3	1	2	3
MA10	Disruption to marine ecosystems due to warmer waters	M	~	1	~	~	2	~	~	2	~
FL14b	Priority habitats lost due to coastal erosion	H	1	1	1	2	2	2	2	2	3
MA8	Potential disruption to breeding of seabirds and intertidal invertebrates	M	~	1	~	~	1	~	~	2	~
BD6	Environmental effects of climate mitigation measures	L	Too uncertain								
MA1	Risk of Harmful Algal Blooms due to changes in ocean stratification	L	Too uncertain								
MA2b	Risks of human illness due to marine pathogens	L	Too uncertain								

M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

9 Evaluation and Conclusions

9.1 Introduction

There are multiple dimensions to climate risks that need to be considered together to inform future adaptation planning. So far in this report, we have focused on the magnitude of potential risks to the UK and our overall confidence in the findings of the risk assessment. In this section we consider other criteria, such as urgency for decision making and other dimensions of risk, such as rates of change, geographical variations and the economic valuation.

The purpose of this chapter is to evaluate the information available on the potential risks of climate change to the UK. As there is no single way of comparing risks across the eleven sectors, this chapter takes a number of steps to highlight the most important risks:

- Firstly it starts with a discussion on how potential risks can be characterised using different criteria, such as magnitude, geographical variation and relevance to Government policy.
- It then focuses on potential risks with a high magnitude and compares these with criteria concerned with our overall confidence in the magnitude of these risks and the perceived urgency for early adaptation action (Section 9.2).
- It considers some other dimensions of future risks, such as rates of change, international aspects and monetisation of a selection of risks (Section 9.3).
- The main findings are included in the conclusions (Section 9.4), which highlight the most significant potential risks and some of the main methodological findings related to completing the first national risk assessment.
- Finally, at the end of the chapter a five page thematic summary of potential risks provides headline information on each of the five themes.

More than 700 climate risks were identified in this assessment and from the outset these were classified according to the perceived magnitude of potential impacts, level of confidence and 'urgency of decisions.' Scores were moderated by stakeholders, including policy makers, as part of an extensive participatory process. A more detailed assessment of selected risks was able to quantify some risks and gather expert feedback on others. This provides an improved evidence base on the consequences of climate change, vulnerability of people and places and the adaptive capacity of a sub-set of sectors. While the first CCRA has made good progress (Box 9.1), the evidence base can be improved much further through the development of methods and integration of new science in subsequent assessments.

Using this evidence the selected risks can be **re-evaluated.** For this purpose there are a set of measures that relate to the study findings and a further set of considerations that also need to feed in to future adaptation planning and resilience strategies.

The measures used in this assessment include:

- **Magnitude of threats and opportunities**
  for example specific risk metrics have estimated areas of habitats potentially affected by change, the numbers of people at significant risk of flooding and the exposure of economic sectors to climate risks for future time periods and a range of scenarios. Economic valuation was completed for some risks.

- **Level of confidence in the risk assessment**
  our overall confidence in projected changes in climate, through biophysical impacts and consequences was classified from 'very low' to 'high' for all risks. Even in the UK with a long history of climate impacts research, 'deep uncertainty' remains for many important risks, which leads towards adaptation responses based on resilience, robustness and flexibility.

- **Urgency of decisions**
  this reflects the timing of consequences and our ability to make difficult decisions related to current and future risks; in the CCRA two specific analyses inform the urgency of decisions:

  - Speed of onset of high consequences at the national and DA scale; and
  - Adaptive capacity of organisations, based on preliminary assessment of selected sectors.

Both these 'urgency' characteristics vary considerably, and identifying areas where there are current risks and limited capacity for dealing with them, provides a strong rationale for Government intervention. Also major policy or investment decisions aimed at managing climate risks may take significant time to implement and, in some cases, an even longer time period to have the desired outcome.

In addition, it may be necessary to consider a number of other dimensions, including:

- **Rates of change and geographical extent**
  the speed at which risks change and how the risks are likely to affect different parts of the UK.

- **Connectivity**
  the extent to which biophysical impacts and consequences are linked in causal chains, often with feedbacks, highlights those cross-cutting risks that may have greater consequences for the UK; research completed as part of this assessment provides some important insight into key cross-cutting risks.

- **Policy relevance**
  to identify what risks are covered by current policies, where there are gaps and where risks are outside areas of policy influence. Engagement with policy makers helped to shape the sector analyses for this assessment and to identify the findings of greatest relevance to Government.

- **Agency**
  to identify those risks that Government policy, and specifically the policy and programmes required under the Climate Change Act (2008), can influence through Government action or by encouraging adaptation action at local levels.

- **International dimensions of climate change**
  the extent to which the UK must prepare for dealing with the repercussions of climate risks elsewhere in the world that may affect the UK interests including trade, supply chains, finance, liabilities, international development and security; research completed by Foresight and the DECC/Defra 'Avoiding dangerous climate change' programme has helped to identify key issues.

- **Costs and benefits**
  the risk assessment has attempted to put a financial cost on some of the risks examined. This is necessarily incomplete but provides a first assessment of the potential costs to the UK. When developing plans for adaptation, these costs will need to be set against the potential benefits of reducing the risk. This aspect will be considered in the Economics of Climate Resilience (ECR) study which follows on from the CCRA.

In the following section we give some further consideration to how the measures developed in this assessment might be used to evaluate the risk and inform future adaptation planning and resilience strategies. The other dimensions, noted above, are then discussed to provide a broader basis for the evaluation of risk. This is followed by some conclusions, which focus on the main achievements of this, the first CCRA; a summary of all the main findings having been presented in the Executive Summary.

Box 9.1 What the CCRA has achieved
This assessment goes further than any previous UK assessment by drawing together different strands of evidence, comparing risks and providing a preliminary evaluation of the consequences of climate from social, economic and environmental perspectives. Prior to this assessment, much of the evidence was based on either narrowly focused research studies or regional scoping studies that relied heavily on anecdotal evidence, with minimum quantification of consequences of climate change. As each study adopted a different methodology (often using different climate models), comparison between regions, or developing a national view, was problematic. Outside of the UK, other national assessments have typically relied on synthesis of available research rather than providing a comparative assessment. The benefit of this assessment is that it brings the best available evidence together using a consistent framework that describes the sensitivity, vulnerability and adaptive capacity to climate change. It identifies the important risks for the UK and Devolved Administrations that may require further action as part of National Adaptation Plans. The subsequent Economics of Climate Resilience study (ECR) will consider adaptation options and identify where early action on climate change may be able to reduce the costs of climate change and where forward planning may present opportunities for UK businesses.

9.2 A framework for evaluating risks

There is no single measure of risk that can be used across themes and for different sectors. Some risks, like damage due to flooding, can be expressed in monetary terms but others are more difficult to quantify. In addition, this assessment is concerned with risks for UK as a whole, not just for the UK Government, and some risks threaten particular groups at the same time as benefiting others. Therefore any categorisation is imperfect and comparative assessment needs to consider multiple dimensions of risk, including economic, social and environmental consequences for the UK.

The risk metrics considered in this assessment vary in character and whilst some have been quantified others have had to rely on expert elicitation, or a narrative based on the literature. To allow some inter-comparison of these different risks, they have been categorised into classes of ‘high’, ‘medium’ and ‘low’ consequences and confidence scores. A more detailed description of this classification and the thresholds used for these classes for a number of selected risk metrics is provided in Appendix 2.

Box 9.2 Turning quantitative and qualitative estimates of potential risks to broad risk magnitude classes

Estimates of potential risks are presented in 'theme' chapters 4 to 8 and in detail in the eleven sector reports. Some potential risks were quantified to determine economic damage, areas of land affected or numbers of people harmed but other estimates were based on expert elicitation or simply qualitative reviews of the evidence. In order to compare risks the CCRA used simple 'order of magnitude' criteria so the findings for each climate and socio-economic scenario could be classified and compared (Table A, provide example criteria only).

For most risk metrics the unit of measurement was clear and it could be assigned using the economic, environmental or social column. Some metrics could be scored from different perspectives and these were classed according to the highest score. The approach was similar to the risk screening stage, which scored impacts and consequences, but worked with specific risk metrics and therefore was based on the more detailed evidence collected during the CCRA.

Class	Economic	Environmental	Social
High	Major damage and disruption *~ £100 million per year*	Major or widespread loss or decline in long-term quality of valued habitats *~ 5000ha lost/gained* *~ 10000km river water quality affected*	Potential for many fatalities or serious harm or major disruption *~million affected* *~1000s harmed* *~100s fatalities*
Medium	Moderate damage and disruption *~ £10 million year*	Medium-term or moderate loss *~ 500 ha lost/gained* *~ 1000 km river water quality affected*	Significant numbers affected *~100s thousands affected, ~100s harmed ~10 fatalities*
Low	Minor damage and disruption *~ £1 million per year*	Short-term/reversible/local effects sites *~ 50 ha of highly valued habitats, etc.*	Small numbers affected/within 'coping range' *~10s thousands affected, etc.*

It is important to note that the criteria were only a guide and this process involved judgement and moderation within the project team. For example, there is a spectrum of possible consequence for people between being 'affected' and being 'harmed' by risks such as overheating of buildings, respiratory problems, UV exposure and so on.

Users of the CCRA should also make use of the available reports and data rather than using the classification to support decisions. Indeed, regional and sector decision makers are guided to considering their own criteria and developing more targeted methods for their own risk assessment and adaptation planning.

In addition, the concept of 'urgency' is useful to focus efforts on current and near term decisions, rather than the highest magnitude consequences in the long term. Due to the inherent uncertainty in climate change, adaptation policy needs to be flexible and adjusted as and when new information becomes available. The 'urgency for decision making' was also classified into one of three classes; 'high', 'medium' or 'low', as defined in Table 9.1. Again some further amplification of these descriptions is provided in Appendix 2.

Table 9.1 Classification of 'urgency of decisions'

Class	Summary urgency description	Short response descriptions
High urgency	• Major decisions required before 2020 that affect future resilience to climate change • There is a significant shortfall in adaptive capacity	Adapt now Increase capacity
Medium urgency	• Major decisions required before the 2050s that affect future resilience to climate change • There is some shortfall in adaptive capacity	Watch carefully Promote robustness and flexibility Targeted capacity building
Low urgency	• 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 Monitor and review

Note: Classified based on either statement in the second column being true. E.g. if major decisions are needed this is classified as 'high' irrespective of the level of adaptive capacity.

Many of the major risks identified are highly uncertain and our confidence in individual risk metrics is variable. However, decisions are still needed based on the information available. This section sets out a simple framework for drawing out what is likely to be important from the information provided by this risk assessment. In what follows we **focus on risks that are projected to belong to a 'high' risk category for the UK as a whole** in at least some of the future scenarios. The same approach could, however, be followed for other levels of risk or smaller geographical areas.

The 'high' magnitude risks were classified based on what proportion of the scenarios in a specific time period is found to be 'high' risk. Four classes were used, namely:

All Risks are high across all emissions scenarios and probability levels;

Majority More than half of the projections considered are high;

Minority Less than half of the projections considered are high; and

None None of the risks in any of scenarios considered are high.

This simplified view of the magnitude is then related to the two other measures; confidence and urgency. This allows the risks to be summarised in two simple matrices:

- Magnitude against confidence. This helps to identify those risks which we know most about and can consider definite actions and those for which things are much less certain and a flexible response or simply monitoring may be the best course of action.
- Magnitude against urgency. This makes clear those risks which are significant and have a more urgent need for action, against those for which monitoring or research may be a more appropriate course of action, at least in the short-term.

The format of these matrices and the implications for decision making are summarised in Table 9.2 for risk magnitude versus urgency criteria. This is illustrative and at this stage serves mainly to:

- Identify important risks for the UK as a whole that may require early action; and
- Highlight a potential approach for making use of the CCRA results for adaptation planning.

Based on a more detailed investigation of the adaptation options, it may be more appropriate to use different criteria (including those outlined in Section 9.1) and to set different action levels to those proposed in Table 9.2. The decision making aspects of the CCRA will be subject to a separate economics research study (the Economics of Climate Resilience (ECR)), and as such, the information presented here is a starting point to help decisions on the analysis carried out under the ECR.

Where there is a High degree of confidence and/or urgency and the magnitude of the risk is High for 'all' or the 'majority' of scenarios, the actions are likely to entail adaptation or measures to introduce greater resilience (e.g. ability to recover from extreme events). When confidence in the results is high it may be possible to optimise adaptation decision making as outlined in recent reports prepared for the Adaptation Sub-Committee (Ranger *et al.*, 2010).

For the same magnitudes with only Medium levels of confidence and/or urgency, the appropriate response is likely to entail actions that are robust across different futures, with inherent flexibility, so that there is scope for change if things turn out differently. Building in flexibility may incur additional costs in the short term. However the application of robust and flexible decision making approaches may be more appropriate in these cases than optimisation approaches (Ranger *et al.*, 2010).

Table 9.2 Accounting for different levels of confidence and/or urgency against the scenarios with high consequences in the decision making process

		Urgency		
		Low	Medium	High
Magnitude (across a range of plausible scenarios)	High (all scenarios)	☽	✷	✓
	High (majority)	☽	✷	✓
	High (minority)	☽	✷	✓
	Too uncertain to quantify magnitude	☽	☽	✷

Key

☽	Continued monitoring and further research needed to support future CCRA cycles and NAPs, plus potential for precautionary actions from some risks
✷	Potential for measures to ensure robustness and flexibility in adaptation programmes and plans
✓	Priority for full range of adaptation measures as part of first CCRA cycle and NAP

Where confidence and/or urgency are Low but the magnitude is High across at least some scenarios (Low column), then monitoring and further research are likely to be key components of any action plan. This course of action may also be the most appropriate for risks that are found to be High magnitude for only some of the climate scenarios ('minority') and for which there is Medium or High confidence and/or urgency. However in these cases some form of precautionary action may also be appropriate. In such cases, this will again be characterised by the need to be flexible reflecting the fact that the outcome is dependent on the future climate (i.e. the magnitude is high for only a 'minority' of climate scenarios).

This framework is now applied using the potential risks examined in this assessment. While only a guide, this approach can help decision makers consider the most

appropriate high level adaptation measures such as the need for research, monitoring systems, precautionary action as well as piloting practical adaptation measures.

In the following sections, a little more explanation of magnitude, confidence and urgency is provided, to make clear some of the assumptions used in deriving the resulting matrices.

9.2.1 Magnitude of consequences and levels of confidence

The preliminary comparative assessment used a set of consequence thresholds that were developed to indicate whether the overall effects for the UK or a Devolved Administration were potentially 'high', 'medium' or 'low', (Table A2.1 in Appendix 2). Some of the risk metrics examined did not fit easily in this framework and some metric specific thresholds were developed. Wherever possible these were developed using the data available. For example by considering the variance in historical data to define classes, with changes categorised as 'low' if they were within historical ranges and 'high' if there were significantly higher or lower than historical observations. Table A2.3 in Appendix 2 provides a list of the low and high thresholds used for various metrics, grouped according to the way in which the thresholds were defined.

This assignment of magnitude in simple classes allows some comparison of risks and was used to develop the score cards used in the theme chapters. However, the broad classification used in this national assessment may not be appropriate for regional assessments or studies concerned with specific receptors; other studies will need to develop more detailed classification schemes, ideally involving participation of both experts and stakeholders.

As explained in Chapter 1, confidence has been assigned to risk metrics based on a combination of the degree of agreement and nature of the evidence (Figure 1.4). Initial assignments made as part of the initial risk selection process were reviewed and updated following the completion of the more detailed assessment. These in conjunction with the estimates of risk magnitude are the basis of Table 9.3, which is for the 2050s. The data from this assessment allows other time intervals to be evaluated in a similar way.

9.2.2 Urgency of decision making

The perceived 'urgency of responses' was used to identify those decisions required before 2020. This was based primarily on expert opinion and a number of criteria set out in Appendix 2. Further work on the assessment of adaptive capacity and the decision making aspects of climate change adaptation is ongoing as part of the Economics of Climate Resilience (ECR) study.

The 'urgency' scoring considered issues related to flexibility of decisions, the risk of 'lock in' and potential adaptation pathways. By highlighting areas requiring 'urgent' decisions, the assessment should help to avoid the risk of maladaptation to climate change.

In general terms this approach has identified decision making related to:

(a) The management of current risks and those that may emerge in the near term (2020s); and

(b) Major policy, investment or other decisions that will undermine or strengthen the resilience of infrastructure, investments, communities or biodiversity in the longer term (2050s and 2080s).

In some cases decisions involve both (a) and (b), for example current flood risks are already high and long term decisions are needed on future investment in flood risk management strategies, locations of new developments and major schemes to reduce flood risks. As the UK considers major infrastructure projects, such as power generation new build and new transport links, these will need to consider the potential impacts of climate change.

The estimates of urgency for those risks of high magnitude provide the second matrix, Table 9.4, which is also for the 2050s. Again, the data from this assessment allows other time intervals to be evaluated in a similar way.

- Table 9.3, which plots potentially high magnitude risks versus confidence in the assessment, highlights the most significant potential risks for which we have relatively good evidence. The right hand column outlines the priorities for action on risks based on the best evidence available from the CCRA.
- Table 9.4, which plots potentially high magnitude risks versus 'urgency', highlights the most significant potential risks that require action because major decisions are needed or there is perceived shortfall in adaptive capacity. The right hand column outlines the priorities for action based on urgency.

Table 9.3 A summary of selected risks with potential high consequences categorised according to overall *confidence*

		Confidence		
		Low	Medium	High
Magnitude (proportion of scenarios with 'high consequences' for the 2050s)	High (all scenarios)		• Ability to obtain flood insurance for residential properties • Effects of floods/storms on mental health • Hospitals and schools at significant risk of flooding • Insurance industry exposure to UK flood risks • Winter mortality/morbidity	• **Expected Annual Damage (EAD) to properties due to flooding**
	High (majority)	• Insufficient summer river flows to meet environmental targets • Potential decline in summer water quality (point source pollution) • Potential decline in water quality due to diffuse pollution	• Energy demand for heating • Forest extent affected by red band needle blight • Public water supply-demand deficits • Reduction in water available for public supply • Power stations at significant risk of flooding	• Energy infrastructure at significant risk of flooding • Flood risk for Scheduled Ancient Monument sites • Increase in hospital admissions due to higher temperatures • **Increase in summer mortality due to higher temperatures** • **Residential properties at significant risk of flooding**
	High (minority)	• An expansion of tourist destinations in the UK • Changes in soil organic carbon • Environmental effects of climate mitigation measures • Generalist species benefiting at the expense of specialists • Increased soil erosion due to heavy rainfall • Risk of diseases on biodiversity • Risk of pests to biodiversity • Risk of restrictions in water abstraction for industry	• Changes in sugar beet yield (due to warmer conditions) • Changes in wheat yield (due to warmer conditions) • Decline in marine water quality due to sewer overflows • Drier soils (due to warmer and drier summer conditions) • Ecosystem risks due to low flows and increased water demand • Ecosystem risks due to warmer rivers and lakes • Effectiveness of green space for cooling • Increases in water demand for irrigation of crops • Loss of staff hours due to high internal building temperatures • Lower summer river flows (Q95) • Monetary losses due to tourist assets at risk from flooding • Opening of Arctic shipping routes due to ice melt • Power stations at significant risk of flooding • Risk of unsustainable water abstraction • Risks to ecosystems due to coastal flooding • Scouring of road and rail bridges • Vulnerable people at significant risk of flooding • Water quality and pollution risks • Wildfires due to warmer and drier conditions	• Changes in species migration patterns • Energy demand for cooling • Energy transmission efficiency capacity losses due to heat - over ground • **Overheating of buildings** • Railways at significant risk of flooding • **Species unable to track changing 'climate space'**
	Too uncertain to quantify magnitude	• A decrease in output for businesses due to supply chain disruption • Climate risks to investment funds • Heat related damage/disruption to energy infrastructure • Loss of productivity due to ICT disruption • Risk of crop pests and diseases • Risk of Harmful Algal Blooms due to changes in ocean stratification • Risks of human illness due to marine pathogens	• Health risks due to summer air pollution (ozone) • Increased hospital admissions due to summer air pollution	• **Urban Heat Island effect**

Notes: Text in bold denotes risks that are classed as 'High' for both confidence and urgency

Table 9.4 A summary of selected risks with potential high consequences categorised according to overall *urgency*

		Urgency		
		Low	**Medium**	**High**
Magnitude (proportion of scenarios with 'high consequences' for the 2050s)	**High (all scenarios)**		• Effects of floods/storms on mental health • Hospitals and schools at significant risk of flooding • Winter mortality/morbidity	• Ability to obtain flood insurance for residential properties • **Expected Annual Damage (EAD) to properties due to flooding** • Insurance industry exposure to UK flood risks
	High (majority)	• Energy demand for heating	• Energy infrastructure at significant risk of flooding • Flood risk for Scheduled Ancient Monument sites • Increase in hospital admissions due to higher temperatures • Insufficient summer river flows to meet environmental targets • Potential decline in summer water quality (point source pollution) • Potential decline in water quality due to diffuse pollution	• Forest extent affected by red band needle blight • **Increase in summer mortality due to higher temperatures** • Power stations at significant risk of flooding • Public water supply-demand deficits • Reduction in water available for public supply • **Residential properties at significant risk of flooding**
	High (minority)	• Changes in sugar beet yield (due to warmer conditions) • Changes in wheat yield (due to warmer conditions) • Risk of diseases on biodiversity • Risk of pests to biodiversity • Wildfires due to warmer and drier conditions	• An expansion of tourist destinations in the UK • Changes in soil organic carbon • Changes in species migration patterns • Decline in marine water quality • Drier soils (due to warmer drier summers) • Ecosystem risks due to warmer rivers and lakes • Effectiveness of green space for cooling • Energy demand for cooling • Energy transmission losses due to heat - over ground • Environmental effects of climate mitigation measures • Generalist species benefiting at the expense of specialists • Increased soil erosion due to heavy rainfall • Increases in water demand for crop irrigation • Loss of staff hours due to high internal building temperatures • Monetary losses due to tourist assets at risk from flooding • Railways at significant risk of flooding • Restrictions in water abstraction for industry • Unsustainable water abstraction • Ecosystems due to coastal flooding • Scouring of road and rail bridges • Water quality and pollution risks	• Ecosystem risks due to low flows and increased water demand • Lower summer river flows (Q95) • Opening of Arctic shipping routes due to ice melt • **Overheating of buildings** • Power stations at significant risk of flooding • **Species unable to track changing 'climate space'** • Vulnerable people at significant risk of flooding
	Uncertain	• A decrease in output for businesses due to supply chain disruption • Risk of crop pests and diseases	• Climate risks to investment funds • Distribution of marine alien/invasive species • Health risks due to summer air pollution (ozone) • Heat related damage/disruption to energy infrastructure • Increased hospital admissions due to summer air pollution • Loss of productivity due to ICT disruption • Harmful Algal Blooms due to changes in ocean stratification • Human illness due to marine pathogens	• **Urban Heat Island effect**

Notes: Text in bold denotes risks that are classed as 'High' for both confidence and urgency

9.2.3 Considering Magnitude, Confidence and Urgency

Considering these criteria can help to identify important risks that require early adaptation action. Table 9.3 draws out the fact that, by the 2050s, flooding and increased risk of summer mortality are likely to be of high magnitude whatever climate change scenario is considered. There is good evidence to support this view and so there is a high confidence in this conclusion. For most of the scenarios (but not all) this list would extend to include water availability. At a slightly reduced level of confidence, and for the majority of climate scenarios, low river flows, risks from pests and diseases and risks to the insurance industry also need to be considered.

In Table 9.4 flooding, summer heat are again highlighted as being of high magnitude under the majority or all of scenarios and of high urgency. In addition, declining water availability and the impact of some pests (as exemplified by red band needle blight) are also likely to be of high urgency for the majority of climate scenarios. Risks that are classed as 'High' in terms of both Confidence and Urgency (i.e. the risks that are common in the right hand column of the two tables) have been identified using **bold** type. Considering those that are of high magnitude for all climate scenarios shows that, for the 2050s, the two issues about which we can be most confident and for which there is a high degree of urgency are:

- Flood risk management as various aspects of flooding are highlighted;
- Health risks, particularly summer mortality and morbidity due to heatwaves;

Widening the criteria introduces concerns about:

- Water availability and the sustainable abstraction of water;
- Overheating in buildings and urban areas; and
- Aspects of the natural environment, including productivity and biodiversity.

Overall this preliminary analysis indicates the greatest need for early adaptation action (Table 9.2) in flood and coastal erosion risk management, specific aspects of natural ecosystems, the built environment and health. Table 9.5 summarises the main findings in five adaptation themes and includes all risk metrics that are potentially 'high magnitude', with 'high' confidence and/or 'high' urgency. However, adaptation actions may be needed across all sectors and decision makers need to consider their own objectives for prioritising the full list of risks presented in this assessment. Table 9.5 provides a starting point and it may be possible for decision makers to add, remove or refine this base on other important policy criteria.

Table 9.5 excludes potential risks that may have 'medium' consequences nationally but are important for specific Devolved Administrations and other important criteria. The Economic of Climate Resilience (ECR) project will consider the rationale for adaptation action and the cost effectiveness of action to support the National Adaptation Plan.

Table 9.5 Potential high priority risks for the UK, considering magnitude of consequences for the 2050s, confidence in the risk assessment and urgency criteria

Group	Risk metrics
Flood risks to people, property and businesses	Ability to obtain flood insurance for residential properties Energy infrastructure at significant risk of flooding **Expected Annual Damage (EAD) to properties due to flooding** Flood risk for Scheduled Ancient Monument sites Insurance industry exposure to UK flood risks **Power stations at significant risk of flooding** Railways at significant risk of flooding **Residential properties at significant risk of flooding** Vulnerable people at significant risk of flooding
Overheating of buildings, infrastructure and the potential health risks	Energy demand for cooling Energy transmission efficiency capacity losses due to heat - over ground Increase in hospital admissions due to higher temperatures **Increase in summer mortality due to higher temperatures** **Overheating of buildings** **Urban Heat Island effect**
Risks to ecosystems	Changes in species migration patterns Ecosystem risks due to low flows and increased water demand Forest extent affected by red band needle blight **Species unable to track changing 'climate space'**
Water resource scarcity	Lower summer river flows (Q95) Public water supply-demand deficits Reduction in water available for public supply
Opportunities for the UK economy	An expansion of tourist destinations in the UK Opening of Arctic shipping routes due to ice melt (Also consultancy and financial services related to climate change risk management and adaptation planning were identified as opportunities but not defined in terms of a risk metric).

Note: Items in **bold** have 'high' confidence and urgency attributes

9.3 Other dimensions to risk evaluation

The evaluation of risk also needs to consider such things as geographic variability, the rate and timing of changes, the connectivity between risks and across sectors, the policy context, influences from outside of the UK and the potential costs.

9.3.1 Rates of change in response to climate change

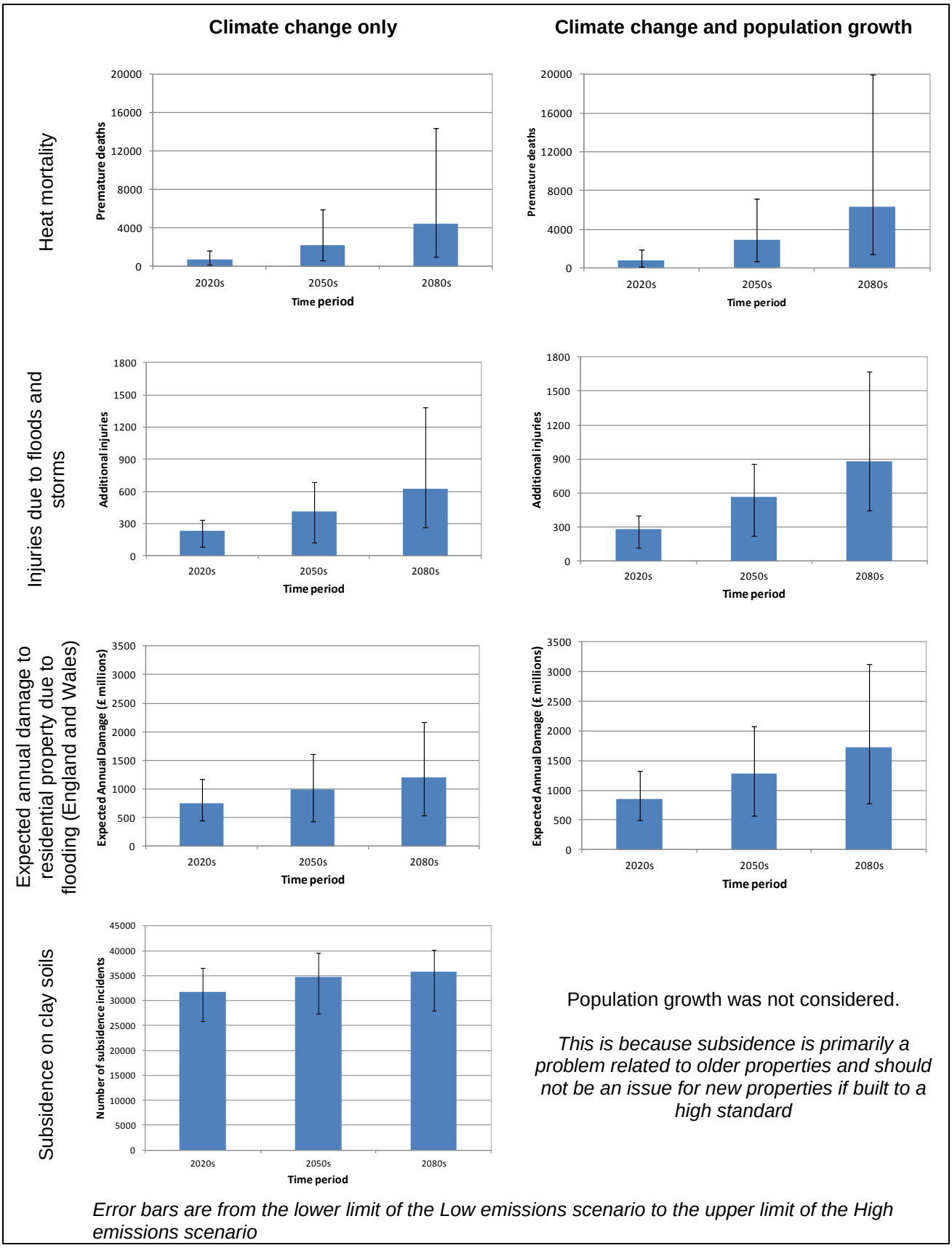
This assessment shows that the magnitude of consequences from the current situation to the 2080s varies considerably for some metrics. Prior to this assessment, it was assumed that changes are most likely to be seen first in risks related to temperature and others related to precipitation and hydrological changes would lag behind. This was because statistically significant changes in temperature variables are expected by the 2020s and some trends are already evident in the observed record (Jenkins *et al.*, 2009a,b) whereas statistically significant hydrological changes are not expected until the 2050s and 2080s.

In Figure 9.1 a number of risks are shown, with results for the ‘climate change only’ scenario and also with the principal population projection. The error bars on these plots indicate the upper and lower estimates of risk magnitude for the scenarios considered. Heat mortality, shown at the top of the figure, is a potential risk with a rapid rate of change, which could increase particularly sharply when both climate and population changes are considered. Fatalities from flooding and storms are shown to rise steadily. Flood risks to residential properties, shown in the third row, increase more slowly due to climate change alone, but they then show a steady rate of rise when population growth is included. Finally property subsidence risk, due to drier conditions on clay soils, increases slowly and, based on the assumption that new houses built will be less susceptible, should not increase with population growth.

For the metrics shown this figure also highlights the relative importance of the uncertainty when set against the absolute level of risk. Taking the top and bottom plots as an example. For heat mortality the variability in the projected risk across all the different scenarios considered, as indicated by the black error bars, is very large, particularly as a proportion of the central estimate for Medium emissions (the blue bar). In contrast, the error bars for subsidence are much smaller, giving a relatively small variation about the central estimate for the Medium emissions scenario.

Both the anticipated rates of change and the level of uncertainty are important characteristics in the context of monitoring potential climate risks and adaptation outcomes (an ASC objective). In addition, risks with relatively fast anticipated rates of rise, like overheating in urban environments, may be regarded as higher priority for action. This is partly covered in the ‘urgency’ criteria and Table 9.4, but may be an important additional consideration for some adaptation decisions.

Figure 9.1 Results for selected risk metrics with rapid to slow rates of long term increase in risk



Error bars are from the lower limit of the Low emissions scenario to the upper limit of the High emissions scenario

The urgency of decisions is related to the speed of onset. In the theme chapters, current climate risks were discussed and it was noted that these are dominated by extreme events – floods, heatwaves and droughts – and that some of these are likely to increase in the near term. The time of onset plots, at the start of each theme chapter, show how the magnitude is projected to change over time (for the central estimate, Medium emissions scenario). Inspection of these plots provides some indication of those risks that are current, or near term, and those likely to become significant in the medium term (see the plots at the beginning of each theme section and overview plot in the Executive Summary).

9.3.2 Geographical variation in risk

The CCRA has shown that there are variations in risk across the UK that reflects current risks and vulnerabilities, different rates of warming and different land and infrastructure characteristics. There are some common concerns across the UK related to flood risks and changes to ecosystems. There are also important differences in the magnitude of risks between England, Wales, Scotland and Northern Ireland and there are clearly identifiable regional 'hot spots' for some risks metrics, for example overheating in urban centres and the south east of England and the increased demand for irrigation of crops in the East of England.

Climate change and population projections vary across the UK for the two levels of aggregation – UKCP09 administrative areas and UKCP09 river basin areas – that were used in this assessment and there are similarly, significant variations in climate risks. The identification of regional 'hot-spots', areas that were low risk that become higher risk under climate change and areas that appear to be more resilient, provides some useful insights into future climate risks. However, it is essential that the reasons for these findings are clearly understood as they may be driven by different factors, for example:

a. The current geographical variation in the risk. At present the risk of overheating is confined to the south east and large city centres of London, Birmingham and Manchester. Similarly, the vulnerability of some regions may already be greater than others, for example, London has a high level of protection from tidal flooding due to the Thames Barrier.

b. Differences in projected rates of warming across the country. The UKCP09 projections suggest that warming will be greatest in the south of England. Other dependent variables will then reflect this spatial variation; for example the south appear to benefit most from reductions in winter mortality and be at greatest risk to rises in summer heat mortality.

c. Differences in land and river basin characteristics. These differences will mediate the response to changes in climate. Examples include soil moisture deficits, subsidence, increases in winter runoff, reductions in summer river flows, the availability of public water supplies and the suitability of land for different crops. So, for example, the risk of subsidence is greatest in clay soils in the south and east of England and much lower in parts of the north and west of the UK, whereas the risk of erosion of organic soils is far greater in Scotland and Northern Ireland. Both of these examples are simply due to the spatial variation of soil types in the UK.

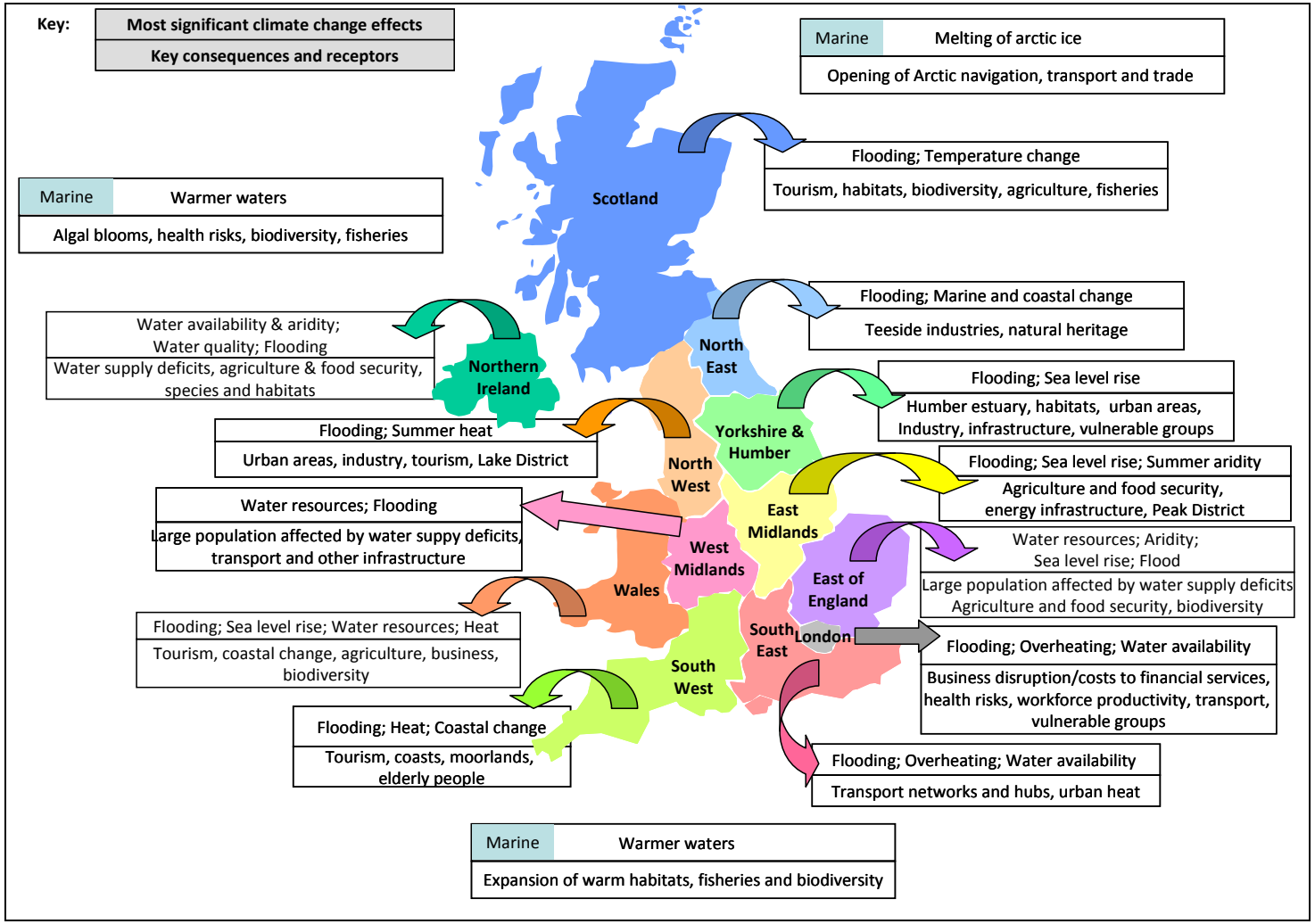
d. Differences in infrastructure. The age, condition and design of infrastructure across the UK influences future risks. This is partly reflected in the current geographical variations in risks related to transport, flood management, water and energy infrastructure (item a). For example, we

have found the sensitivity of rails to buckling varies across the UK due to the different regional practices in laying rails, we also found that public water supplies in the north-west were sensitive to drier conditions due to insufficient (licensed) water storage.

e. The use of universal assumptions on anticipated adaptation (for the purpose of consistency). However, future adaptation is more likely to be targeted in those areas where the risks are greatest. This is particularly relevant for the flood risk metrics in England and Wales, as the Environment Agency's investment strategy is targeted towards schemes that provide the greatest cost effectiveness in reducing risks.

For those risks that show distinct regional variations, there are specific regional hotspots, where risks are either greatest, or where risks increase considerably over time, more than adjacent regions. Some of the key geographical variations are summarised in Figure 9.4, to provide an indication of issues that are likely to be more important in specific regions.

Figure 9.2 Notable changes in climate and key consequences for UK



9.3.3 Connectivity – the causal chain and cross-cutting risks

The risks examined in this assessment combine two important aspects of climate change risk:

i. Direct risks that can be linked back to bio-physical impacts and the associated climate drivers; and

ii. Indirect risks that arise from the interconnectivity of the various sub-systems, issues such as market responses and the very perception of risk, which do not necessarily have a clear process based dependency on climate drivers.

The majority of the risks identified in the risk assessment fall into the former category. The second is more difficult to define. Such risks may arise through the collective influence of climate change on society. Interactions between sectors abound. For example, responses to climate change in agriculture or fisheries may well have knock-on consequences for the natural environment and hence the ecosystem services that benefit and provide resources to other sectors. Such changes may be picked up and responded to by the markets (commercial response) or society (social response), or may result in some form of market failure or social inequity (e.g. that vulnerable people are disproportionately affected). In some cases, this may be 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, or affected by, the causal event.

The response can also reflect the perceived level of risk, rather than the evidence. The often reported perception that flying presents a greater risk than driving a car, the risk associated with nuclear power and the GM debate all provide examples where the public acceptance reflects a complex mix of evidence and belief. So, for example, if the net effects of climate change projections are underestimated, or overestimated, this could affect investment performance, or insurance (Chapter 5 and the Business, Industry & Services Sector Report). Similarly, if the collective public perception of the climate change risk militates against robust governance and management across a range of sectors, then the capacity to adapt will be constrained. Thus, the interaction between sectors, market responses, societal perceptions and the associated adaptive capacity can be seen to entail risks that result from 'system-dependent emergent behaviour[189]' rather than direct 'cause-consequence processes' (i.e. risks of type (ii) rather than type (i) as defined above).

The perception issue is particularly challenging. Despite the evidence in support of climate change, there is still a great deal of inertia within some sectors of business and industry; with many companies considering that this is a future risk issue that can be dealt with in due course. In some sectors, climate related risks are already being managed and climate change simply alters the relative significance of such risks. For other sectors the risks due to climate change are small in relation to the other risks that businesses have to manage. There is, therefore, a need to promote a balanced view of the relative importance of climate change, which in general will be business specific. In general, a potential risk for business and industry could arise from any failure to understand the relevance of a changing climate and then mainstream climate change considerations into decision making (Business, Industry & Services Sector Report and Foresight, 2011a).

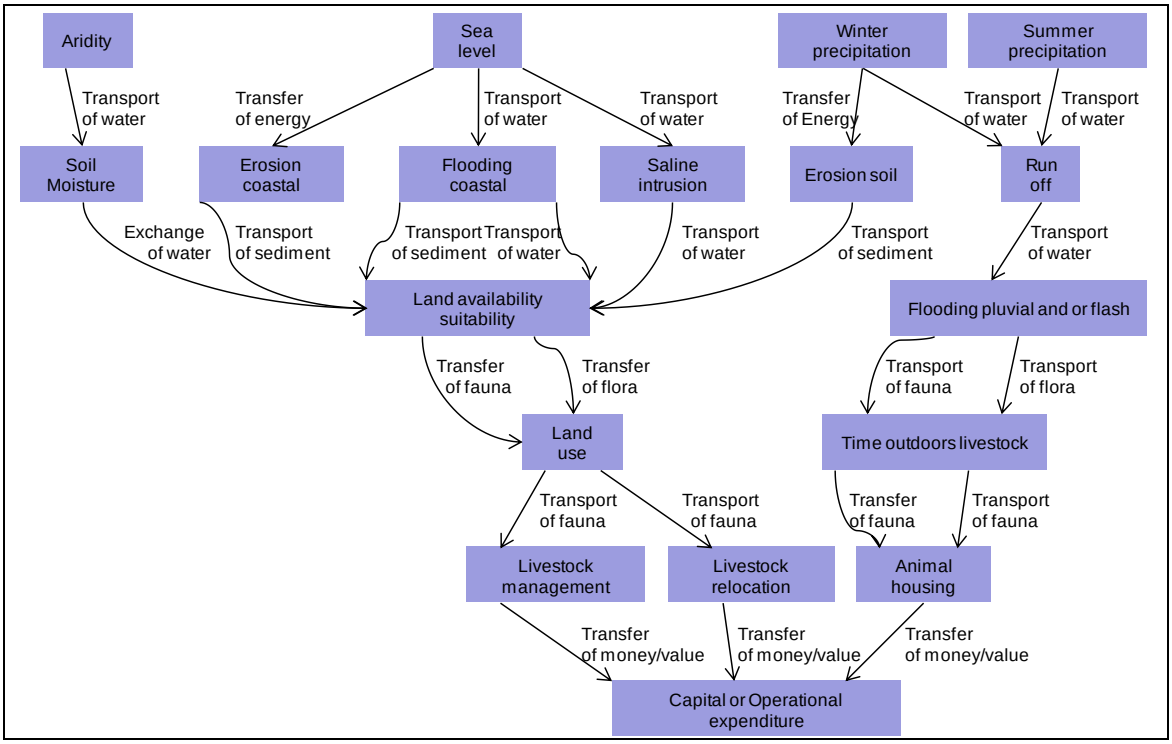
There are also a number of risks that were perceived to be important by stakeholders and as a result scored highly in the selection process but, when the evidence was explored, turned out not to be particularly significant. For example, concern over solar

[189] This is distinct from an 'emergent risk', which is usually taken to be a risk that is, as yet, poorly understood but is expected to grow in significance. Here we refer to risks that arise from *emergent behaviour*, which is where new and coherent structures, patterns and properties arise because of interactions within a complex system.

heat faults in energy systems and the impact of higher temperatures more generally on ICT systems fall into this category, where the perceived risk was high but subsequent investigation indicates the consequences are low. Conversely, a small number of cross-sectoral risks only just made it through the 'Tier 1 to Tier 2' selection process, but turned out to be very important in the final analysis; these included the mental health effects of floods and the effect of overheating buildings on workers' productivity. By addressing such perceptions alongside acknowledged risks (e.g. flooding), the CCRA cycle will progressively establish a better common understanding of the impacts that are likely to be of most significance.

An initial examination of how risks have multiple influences and consequently lead to strong interdependencies between sectors was undertaken as part of the CCRA and is referred to as the systematic mapping (CCRA, 2011). The resultant mapping provides an extensive resource to explore and better understand many of the key cause-process-consequence links. However, the complexity is such that it cannot be easily summarised and needs to be explored interactively. An illustration of the results of a query that produces a diagram small enough to be reproduced is shown in Figure 9.3. This provides a basis for more detailed evaluation of specific risks and should provide a building block for research efforts between now and the next CCRA.

Figure 9.3 Systematic Map based on search for Agriculture links to "Capital or Operational Expenditure"



9.3.4 Policy relevance

The framework set out above, highlights high magnitude risks and provides a screening based on:

- The degree of confidence and therefore ability to respond with minimal risk of maladaptation; and
- The urgency with which decisions need to be made.

However, not all adaptation actions are for Government. An additional dimension is therefore is the relevance of the risk to Government policy. 'Policy relevance' criteria would identify those risks that are either addressed under existing policies, or for which it would be appropriate for governments to develop policy at the appropriate time (which will depend on the timing and rate of onset for the particular risk(s)).

9.3.5 International dimensions of risk

The UK operates in a global economy and international climate change risks may have a much greater or earlier impact than those affecting the UK directly. The Foresight Report on the International Dimensions of Climate Change (IDCC) identified a large number of international risks that could affect the UK (Foresight, 2011a). It strongly recommended that planning for climate change adaptation and mitigation considers the significance of external impacts (both threats and opportunities). Furthermore, recent research on "Global Food and Farming Futures" showed that climate change, water scarcity and the competition for resources may have significant implications for the food security (Foresight, 2011b).

Many of the key findings of the Foresight IDCC study have been noted under the relevant themes in preceding chapters. A short summary of the main international risks posed is given in Figure 9.4. These are likely to influence priorities and urgency of some of UK adaptation actions, for example international water and food security issues may influence UK agricultural and land use policy.

Figure 9.4 Summary of international dimensions of relevance to the UK

Climate change projections	• Uncertainties are large but do not diminish the need for policy makers to take action now
Geopolitics	• Leading to changes to UK alliances and trading partners
Tipping points in global system	• Catastrophic changes and ecosystem failures
International water security	• Water scarcity may lead to impacts on health, wellbeing, food production and manufacturing
International food security	• The UK imports 50% of its food; wide ranging risks and opportunities for the UK
International finance and trade	• The UK has a high exposure in the finance sector, which may not have fully recognised the risks
Changes in coastal processes	• Low lying coastal cities may be flooded disrupting production, shipping and trade
Oil/gas availability and transportation	• Any disruption to energy production and imports could have major global consequences
Early impacts in vulnerable countries – Africa	• Climate impacts in vulnerable countries may prompt faster action on climate change
Green policies / sustainable development	• International agenda and promotion of green economy in the UK may present opportunities for UK business

Source: Foresight, 2011a

Whilst the IDCC report highlights the potential risks, it can only speculate on issues such as the evolving geopolitics, and how this might affect movement of people, security of food and water and trade around the globe. It highlighted that climate

change may have the potential to cause the failure of already unstable states, which could have impacts for the UK through humanitarian and aid assistance, crime and terrorism, and pressure for military intervention. The risks identified were considered to become increasingly significant by the middle of the century.

It is clear that action is needed in the least developed countries to tackle climate variability and change, support adaptation and low carbon growth. International efforts to improve water and food security are needed to manage climate risks in the least developed countries and promote climate resilient development[190].

The development of an improved understanding of how international climate risks may disrupt UK society can be addressed by ongoing monitoring and regular review of potential risks. The cyclical nature of the CCRA is well suited to this purpose; there was limited analysis in this cycle but future cycles provide an opportunity for more detailed consideration.

9.3.6 Economic valuation

Comparative risk assessment is challenging because the wide range of risks considered cannot easily be reduced to a single metric and different perspectives lead to different prioritisations. However, expressing risks in monetary terms, i.e. in £, does provide such a common metric and allows comparison within and between sectors. The CCRA has therefore undertaken a monetary valuation analysis, noting that such an approach is consistent with the approach recommended for use in UK Government appraisal (HMT, 2007). This approach values risks from the perspective of social welfare, and therefore, captures the wider costs and benefits to society as a whole, rather than considering only the financial aspects, i.e. it assesses environmental, social and economic consequences.[191] The project considered ecosystem services, but it was not possible to complete a full valuation from this perspective and further work will be needed as part of future CCRA cycles.

The approach places monetary values on the physical impacts quantified in the sector analysis. However, recognising that the CCRA has often adopted a semi-quantitative or qualitative approach, it has not been possible to place monetary values in this way on all risks. The results therefore only provide a partial picture and they need to be considered alongside the social and environmental considerations highlighted in the theme chapters.

The risks that were considered in more detail as part of the CCRA have been monetised. The aim was to express the risks in terms of their effect on social welfare, as measured by individuals' preferences using a monetary metric. However, due to the availability of data, it was sometimes necessary to use alternative approaches (e.g. repair or replacement costs) to provide indicative estimates. It should also be noted that where quantitative risk data did not exist, it was necessary to use expert judgement and these estimates should be considered as indicative only.

A summary of the main monetary valuation results are provided in Figure 9.5. It is important to highlight that some results are presented for a scenario of future climate change only, whilst others include climate change including some assumptions of future socio-economic change[192], the basis being determined by that adopted in the underlying physical risk assessment. The reader should also be aware that there are some overlapping risk categories, i.e. where there is the possibility of double counting. An example of this is the overlap between energy use for building cooling (quantified as

[190] Policy area for DFID http://www.dfid.gov.uk/climate

[191] As such it attempts to consider all three aspect of risk magnitude (Box 9.2) and therefore the classification in this section may not be the same as any risks previously classified using economic damage alone.

[192] The combined effects of socio-economic and climate change together provides the total risks faced, but care should be taken when attributing the relative (or marginal) risk due to climate change specifically, since this is measured here as being incremental to the current socio-economic baseline.

an autonomous response and impact in the energy sector) and building overheating and productivity loss/additional health risks (considered in the business, buildings and health sectors). These are important when considering the aggregated risks to the UK. These estimates do not include autonomous adaptation, and in general, do not take account of existing planned adaptation measures.

The degree of confidence in the certainty that can be attached to the monetary results (i.e. the additional uncertainty over and above the quantification of risks) is indicated as high, medium or low.

To simplify comparison, the magnitude is defined as low (L) = £1-9m/yr; medium (M) = £10-99m/yr; or high (H) = £100-999m/yr; VH= £1000m/yr+, with the sign indicating whether this is a cost (-ve), or a benefit (+ve). The values are presented for the Medium p50 scenario in constant 2010 prices, without adjustments and as undiscounted values.

In some cases the range across the full UKCP09 range, i.e. the lower and upper estimates (see Chapter 2), can alter the magnitude of the threat or opportunity, and in some cases even change the sign. Therefore, these results should be viewed in the context of those presented in the individual sector reports.

The detailed results in the sector reports cover all metrics but in Figure 9.5 those risks that remain low over all three time intervals have been omitted. The figure therefore focuses on those risks that are likely to have an annual cost of £10m or more.

The analysis clearly identifies flooding as a major risk with “high” consequences as early as the 2020s, increasing to “very high” consequences by the 2080s (estimated in the order of £2-3billion/yr). Indeed this is the only risk which has been estimated with a “high” degree of confidence. This does however merit an explanation. Flooding is a major risk today and the annual spend on flood risk management is currently over £700 million in England alone[193], although the Environment Agency’s funding is set to decline by approximately 10 percent for the period to 2014-15 (NAO, 2011). Consequently, this risk has been well researched and there is a strong body of evidence behind the assessment. There is inevitably an element of bias towards a risk that is well “measured” over those that have been less well studied. A good example of this is the potential risks of overheating in the work place, which could be significant in the absence of autonomous cooling responses, but is more uncertain and is not supported by a reliable national analysis that considers different property types, urban heat island effects and cooling methods.

A number of the risks have positive and negative effects across the seasons, notably the reduced demand for energy for heating in winter versus the increased demand for energy for cooling in the summer. In this case the analysis suggests a net positive effect in economic terms, i.e. the reduced total cost of heating energy outweighs the increased cost of energy for cooling. There are also positive and negative health impacts associated with reduced cold (positive) and increased heat (negative) though in this case a simple aggregation across the year is considered inappropriate.

A very different picture arises with the results for water risks. With changing rainfall patterns, the supply-demand balance is likely to change with potential shortfalls (under the central estimate) projected for the middle of the century. In the absence of adaptation, there could be competing demands between households, industrial and agricultural use, as well as competing environmental considerations that argue for maintaining minimum base flows to protect important habitats and associated ecosystem services (food chain, maintenance of water quality, etc.). The economic analysis provides some initial estimates of the potential costs to sub-sectors (e.g.

[193] Defra has policy responsibility for flood and coastal risk management. In 2010-11, it spent £664 million and gave 95 per cent of this (£629 million) to the Environment Agency. The Environment Agency has operational responsibility for flood risk management. In addition, local authorities spent £101 million supported by formula grant from central government on flood risk management activity (NAO, 2011).

industrial water abstraction), whilst also providing estimates of the welfare costs that would arise from low flows under climate change scenarios. Further analysis is needed to identify the full range of costs and benefits involved in delivering an acceptable balance between these competing interests, and associated with alternative plans to alter demand, or the supply-demand balance.

It is also stressed that this is the first CCRA, and that the economic analysis of risks is partial and incomplete, partly reflecting the underlying level of physical risk quantification. This is important in considering the summary results below. Nonetheless, the study has significantly advanced the number of risks monetised from previous studies in the UK (Metroeconomica, 2006) and, compared to other national studies, providing a much richer and more comprehensive scoping of the potential effects[194].

The monetary valuation undertaken only considers the risks examined in Tier 2 analysis of the CCRA. It is highlighted that even for this narrow list of risks, the full consideration of the range of scenarios (and the range of estimated levels of climate change) would imply higher economic costs associated with higher rates of changes, non-linear increases, and exceedence of threshold levels. Finally, the estimates derived do not include consideration of the economic costs of climate change overseas, and how these might affect the UK, nor the potential economic costs of major events post 2100. All of these issues are critical to the assessment of the overall aggregate costs of climate change in the UK.

[194] Tier 2 risks identified in the Biodiversity and Ecosystem Services sector have been assessed in more depth in the Biodiversity Ecosystem Services Sector Report using the UK National Ecosystem Assessment (2011) in addition to the results presented here.

Figure 9.5 Range of potential magnitude (all estimates) and time of onset (Medium emissions scenario, central estimate) for those risks considered important from an economic perspective (refer to notes of following page)

		2020s	2050s	2080s	Confidence
FL6a	Residential properties at significant risk of flooding	-H	-H	-VH	High
FL7a	Non-residential properties at significant risk of flooding	-H	-H	-VH	High
AG1b	Changes in wheat yield (due to warmer conditions)	+H	+H	+H	Medium
BE9	Reduction in energy demand for heating	+H	+H	+VH	Medium
AG1a	Changes in sugar beet yield (due to warmer conditions)	+M	+M	+M	Medium
WA5	Public water supply-demand deficits	+M	-H	-H	Medium
BD2	Risks to species and habitats due to coastal evolution	-M	-M	-H	Medium
BD7	Risks to coastal habitats due to flooding	-M	-M	-H	Medium
BE2	Increased subsidence risk due to rainfall changes	-M	-M	-M	Medium
FL14a	Agricultural land lost due to coastal erosion	-M	-M	-M	Medium
FL4a	Agricultural land at risk of flooding	-M	-H	-H	Medium
BU8	An expansion of tourist destinations in the UK	+H?	+H?	+H?	Low
HE6	Decline in winter morbidity due to higher temperatures	+H	+H	+VH	Low
HE5	Decline in winter mortality due to higher temperatures	+M	+M	+H	Low
EN3	Heat related damage/disruption to energy infrastructure	-L/M	-L/M	-L/M	Low
FL15	Flood risk for Scheduled Ancient Monument sites	-L	-L	-M	Low
FO1a	Forest extent affected by red band needle blight	-L	-L/M	-M	Low
HE1	Summer mortality due to higher temperatures	-L	-M	-M	Low
HE2	Summer morbidity due to higher temperatures	-M	-H	-H	Low
HE4a	Mortality due to summer air pollution (ozone)	-L	-L	-M	Low
TR1	Disruption to road traffic due to flooding	-L	-L	-M	Low
BE3	Overheating of buildings	-M	-M	-H	Low
EN10	Energy transmission efficiency capacity losses due to heat - over ground	-M	-M	-M	Low
EN2	Energy demand for cooling	-M	-H	-H	Low
FL11a/b	Power stations/sub-stations at significant risk of flooding	-M	-M	-M/H	Low
FL12a/b	Hospitals and schools at significant risk of flooding	-M	-H	-H	Low
HE3	Extreme weather event (flooding and storms) mortality	-M	-M	-M	Low
HE7	Extreme weather event (flooding and storms) injuries	-M	-M	-M	Low
WA7	Insufficient summer river flows to meet environmental targets	-H	-H	-H	Low
BD3	Risk of pests to biodiversity	-L	-M	-M	Low
BD4	Risk of diseases to biodiversity	-L	-M	-M	Low
BD5	Species unable to track changing 'climate space'	-L	-M	-M	Low
BD9	Changes in species migration patterns	-L	-M	-M	Low
BD10	Biodiversity risks due to warmer rivers and lakes	-L	-L	-M	Low
BD11	Generalist species more able to adapt than specialists	-L	-L	-M	Low
BD12	Wildfires due to warmer and drier conditions	-L	-L	-M	Low
BU1	Climate risks to investment funds	-H?	-H?	-H?	Low
BU9	A decrease in output for businesses due to supply chain disruption	-M	-M	-M	Low
BU10	Loss of staff hours due to high internal building temperatures	-H	-H - VH?	-H - VH?	Low
MA3	Increased ocean acidification	-L	-M	-M	Very low
MA2a	Decline in marine water quality due to sewer overflows	-L	-M	-M	Very low
MA2b	Risks of human illness due to marine pathogens	-L	-M	-M	Very low
MA5	Opening of Arctic shipping routes due to ice melt	+L	+M	+M	Very low
MA6	Distribution of marine alien/invasive species	-M	-M	-H	Very low

Cost		Benefit		Confidence (including valuation)	
-L	Low (£1-9m/yr)	+L	Low (£1-9m/yr)		High
-M	Medium (£10-99m/yr)	+M	Medium (£10-99m/yr)		Medium
-H	High (£100-999m/yr)	+H	High (£100-999m/yr)		Low
-VH	Very high (£1000m/yr+)	+VH	Very high (£1000m/yr+)		Very low
?	Uncertain	?	Uncertain		

Guide on interpretation of Figure 9.5

In Figure 9.5 the confidence ranking is modified further to include the valuation step and as such the confidence score is low in most cases. There are also many assumptions and caveats related to this figure.

- Values are presented in current prices, for the central projection.
- Some results are presented for a scenario of future climate change only, whilst others include climate change under assumptions of future socio-economic change.
- In some cases the magnitude of the impact (or opportunity) changes across the full UKCP09 projections (the p10 to p90 range) and in some cases even changes in sign.
- Care must be taken in aggregating risk categories, as there are some overlapping impacts, and thus the risk of double counting at the UK level.
- Furthermore, it is stressed that these results do not include autonomous adaptation, and in general, do not take account of existing planned adaptation measures.
- The list of possible impacts is partial, Further, consideration of the range of scenarios – and the range of estimated levels of future climate change – include much higher economic costs associated with higher rates of changes, non-linear increases, and exceedences of threshold levels.
- Finally, these current estimates do not include consideration of the economic costs of climate change overseas, and how these might affect the UK, or the potential economic costs of major events post 2100.

All of these issues are critical to the assessment of the overall aggregate costs of climate change in the UK.

9.4 Conclusions

The CCRA is a new process and this assessment is the first of what will be a five year cycle. The assessment has been challenging. It has, however, succeeded in developing an appreciation of the risks across a wide range of sectors in a consistent manner. This has provided many new insights, whilst also exposing some limits to the method adopted and our current knowledge base.

The Climate Change Act 2008 made the UK the first country in the world to have a legally binding, long-term framework to cut carbon emissions. Part of the process is to assess the risks posed by climate change for the UK; this Climate Change Risk Assessment provides the first of these assessments and was laid before Parliament in January 2012. The following section summarises main conclusions from the study as a whole, considering both the process and the study findings.

9.4.1 Current risks

The Cabinet Office's National Risk Register (2010a) highlighted the national importance of risks related to coastal flooding, inland flooding and severe weather on the UK. A major coastal flood is regarded as one of the most significant risks to the UK, alongside pandemic human disease and terrorist attacks (Cabinet Office, 2010a). The CCRA confirms that extreme events dominate current risks. Flooding from surface water and inadequate drainage, from rivers and the sea are all important risks and vulnerability of the UK was highlighted by the summer flooding of 2007, with costs of more than £3 billion for the UK economy, and by the flooding in Cumbria in 2009.

The recent cold winters have shown that extreme cold and snow and ice conditions present a significant challenge for the UK. The Government's independent review of the 2009/10 winter indicated annual average transport disruption and welfare costs of £1 billion per annum (Dft, 2010). The CCRA has not provided a detailed analysis of the future risks of snow and ice conditions; according the UKCP09 these conditions are projected to decline in the long term with warmer winters, but it is important to recognise that cold extremes would still occur in the near term due to the natural variability of the UK's climate (Annex 1).

The UK avoided the worst affects of the 2003 European heatwave as the 'epicentre', with the greatest temperature anomalies, was in France. However, around 2000 excess deaths were reported in the UK due to extreme heat. In London the Urban Heat Island effect meant that evening temperatures reached 9°C higher than the surrounding countryside during the 2003 heatwave (Davies, 2011, UKCIP event). The overheating of buildings and transport systems is already a risk in some large cities, for example in London there is currently risks of overheating for an average of 18 days per year (as presented in the Built Environment Sector Report), and the high temperatures causing these risks are projected to become the norm under future climate projections.

Other risks may magnify the effects of climate variability and change. The recent National Ecosystem Assessment (NEA) has shown that the loss of ecosystem services due to the combination of land use pressures, climate and other factors is already affecting vulnerable habitats (Watson and Albon, 2010). The competition for resources, particularly water, is an important consideration for land use planning, public services (water, energy and health), agriculture, industry and the environment. Implementation of the Water Framework Directive in the context of changing climate is a key policy area that needs to reconcile these multiple demands for water from different sectors.

This assessment and ongoing work by the Adaptation Sub-Committee have emphasised the need to understand the current risks of climate change (ASC, 2011). However there is a lack of information on the distribution of risks across the UK at the regional and local scales. For example, it has been difficult to develop consistent UK data sets on flooding, water resources and health in England and Wales, Scotland and Northern Ireland as different government agencies use different data sets and risk assessment methods. This is considered further in our conclusions on methods and data for national risk assessments (Section 9.4.6).

9.4.2 Future risks

The most significant risks, in terms of their magnitude and 'urgency', were outlined in Section 9.2 and were dominated by flood risks, potential health risks, pressure on water resources and natural ecosystems. These included:

- An up to nine-fold increase in the damage caused by flooding. Increases in the frequency of flooding would affect people's homes, the well being of vulnerable groups in society, the operation of critical infrastructure systems, such as

transport, energy and water supply and disrupt a wide range of businesses located in the floodplains.

- Significant potential health risks related to hotter summer conditions as well as other risks that may place an additional burden on the NHS. Sustained hot summer conditions, which may be exacerbated by overheating in city buildings and transport systems, can have measurable health impacts. Increases in flooding and air pollution incidents would also add additional pressure on health services.
- Increasing pressure on the UK's water resources due to changes in hydrological conditions, population growth and regulatory requirements to maintain good ecological status. For public water supplies our analysis projects major supply-demand deficits in five river basin regions – Anglian, Humber, Severn, North West England and the Thames basin.
- Increasing pressure on sensitive ecosystems, some of which are already threatened by land use changes. The combined affects of land use and climate change may damage ecosystem services, which would affect many sectors of the UK economy.
- Some climate changes projected for the UK provide opportunities to improve sustainable food production, use resources more efficiently and provide services to manage risks.

Differences between High and Low emissions scenarios

Comparison of UKCP09 to the results of Met Office modelling of an 'aggressive mitigation' scenario suggests that a certain amount of warming is inevitable due to historic greenhouse gas emissions. The comparison of potential risks under the lowest and highest risk scenarios considered in the CCRA shows that following a lower emission pathway may significantly reduce potential risks in terms of flooding, water resources, forestry and overheating in urban environments. This is evident in the scorecards at the end of each themed chapter, which show the differences between the low end of the Low emissions scenario, central estimate from the Medium emissions scenario and high end of the High emissions scenario for the lower, central and upper estimates respectively. Further data for each emissions scenarios are provided in each Sector Report. This finding supports a 'triple track' approach of mitigation, adaptation and management of residual risks to reduce the consequences of climate change.

Timing

Some risks, such as the increase in summer mortality due to hotter periods in summer and the counter benefit of reducing winter mortality in warmer winters, have the potential to become significant over the relatively short-term. Other risks become more significant and may start to dominate the risk landscape by the latter half of the century. These include such things as greater demand for cooling, pressures on water availability, potential declines in water quality due to low flows, loss of land and habitat due to coastal erosion and a mix of threats and opportunities for business (e.g. increased opportunities for climate related investments need to be set against the potential for disruption, particularly due to the impacts of climate change internationally).

Potentially significant risks that are highly uncertain

A number of risks examined are potentially very significant but our current level of knowledge means that there are also large uncertainties. This is particularly the case for complex systems such ecosystems and business networks.

- In ecosystems, the spatial extent and distribution of species is likely to shift according to climate preferences and this would be coupled with the affect of changing migration patterns and the influence of species' life cycle events (seasonal behaviour).
- In the marine environment many potential risks could be significant but are highly uncertain, in particular, the onset of ocean acidification further complicates the understanding of the potential climate change risks on marine life.
- In the business world, the behaviour of fund markets and the complexity of supply chains pose similar levels of complexity. Whilst we have some understanding of these systems, we are a long way from being able to predict outcomes with any degree of certainty.

Some of the most important knowledge gaps are discussed in Section 9.4.7 and most notable potential risks are summarised for the five research themes at the end of the conclusions.

9.4.3 Cost to the UK

The CCRA has undertaken a monetary valuation of the quantified risks in order to investigate the potential comparative costs and benefits of different risks and their overall scale in the UK. It is stressed that the valuation of risks in this – the first – CCRA is only partial and has to make some major assumptions because of the limited risk quantification that has been possible. Nonetheless, the study has significantly advanced the number of risks monetised from previous studies in the UK and provides a much richer and more comprehensive scoping of the potential effects.

Bearing in mind the caveats relating to the limitations in this analysis (Section 9.3.6), and noting that this considers only a subset of the overall risks, and the range of outcomes associated with them, the balance of risks that have been considered can be assessed. It is highlighted that the full consideration of the range of scenarios (and the range of estimated levels of future climate change) imply much higher economic costs associated with higher rates of changes, non-linear increases, and exceedences of threshold levels. Furthermore, the current estimates do not include consideration of the economic costs of climate change overseas, and how these might affect the UK, or the potential economic costs of major events post 2100. All of these issues are critical to the assessment of the overall aggregate costs of climate change in the UK.

9.4.4 Social vulnerability

The CCRA included some research on vulnerability and the application of simple vulnerability checklists in each sector (Annex B). This research found that the vulnerability of people to current climate risks varies according a number of factors including location and place, quality of housing, health and access to resources. Today's social vulnerabilities to climate reflect and reproduce other patterns of inequality in society. Where there is vulnerability to particular climate impacts e.g. coastal erosion, those people who are affected by poverty, poor health, disabilities, etc.

tend to experience disproportionate negative effects. Understanding the consequences of climate change for these groups is an important consideration for the adaptation or resilience planning.

9.4.5 Adaptive capacity

The level of risk that will be experienced depends on 'adaptive capacity': the ability to respond to information about expected future impacts. Preliminary findings on adaptive capacity in a selection of UK sectors suggest this varies significantly between sectors. While many sectors (but not all) are well placed to handle current risks, all sectors could improve their capacity for dealing with expected climate risks. To achieve this, organisations will need to change and structural barriers need to be removed. This is broadly consistent with a number of other studies. For example, the Adaptation Sub Committee (ASC, 2010) found that some progress had been made, particularly in the public sector, but there was limited tangible action on the ground in several sectors that needed to adapt to future climate change. Further work on adaptive capacity is ongoing as part of the Economics of Climate Resilience study.

9.4.6 Methodology and data

The methodology developed for this assessment focused on understanding current risks, sensitivity to climate and socio-economic drivers, vulnerability and adaptive capacity, at a national scale. Sector desk studies and a series of workshops and meetings were used to gather evidence, select risks for detailed analysis and consider methodological and communications issues. A large amount of information was compiled in sixteen reports to underpin the Report to be laid before Parliament and to inform the subsequent Economics of Climate Resilience study and National Adaptation Plans (see Chapter 2).

This was the first assessment and the methodology was developed to meet objectives within a fixed timescale and based on existing data. Nevertheless it was also a learning process and there are a number of key learning points for future assessments, for example:

- The methods adopted were relatively simple to understand, were achievable in the short amount of time available (18 months for the first CCRA cycle) and allowed for comparison of the relative risks to the UK and Devolved Administrations. In addition, the approach was able to make use of existing studies, research outputs and expert opinion. It also made use of the UKCP09 projections to characterise some of the main uncertainties related to future climate change.
- It is recognised that much of the methodology was predominantly top-down, impacts led and reductionist and did not fully develop socio-economic scenarios, behavioural aspects of change, complex systems, non-linear changes and systemic risks. Original and innovative work on methods, social vulnerability and (in particular) adaptive capacity did address some of these concerns in particular areas of the project. Future assessments should be able improve on these parts of the methodology.
- Developing consistent national risks metrics is a challenging task due to limitations in the amount, consistency, quality and availability of national data sets across the UK. As the CCRA will be updated every five years early work is needed on developing appropriate indicators of climate risks and to measure progress in adaptation. This issue is being addressed by the Adaptation Sub-

Committee (ASC, 2011) but there is also a role for the UK Research Councils to develop research programmes that provide the data and information needed to understand future risks.

- A separate 'lessons learned' report for the CCRA project provides a review of the pros and cons of different methods for completing national risk assessments. This will inform the next CCRA and may also flag immediate research and monitoring needs for the first set of National Adaptation Programmes.

Making use of UKCP09 in the CCRA

The CCRA made extensive use of the UKCP09 projections, which was the first time these projections had been applied for broad-scale national assessments in multiple sectors. Therefore a number of conclusions can be drawn from this to inform the development of new projections and new risk assessments.

A comprehensive set of projections of 21st Century climate change over the UK were provided by UKCP09, covering changes in annual, seasonal and monthly mean meteorological quantities and also some extremes. Three emissions scenarios were examined, covering the range of scenarios previously examined in the IPCC's Special Report on Emissions Scenarios.

The CCRA made use of UKCP09 statistical summaries UKCP09 data for basins and administrative regions, the 'full samples' of the data for some climate variables, RCM outputs, research studies that had used RCMs, the UKCP09 Weather Generator and UKCP09 Extremes Atlas. The wide use of UKCP09 in the project has identified a number of issues that would merit further investigation, including:

- Where the baseline definition for present day risks differs from the baseline epoch of 1961-90 used in the projections it can be difficult to reconcile the two.
- Extreme events are a dominant feature of the risk landscape but their treatment and interpretation remains a real challenge and there are concerns related to changes such as the clustering of events, which need to be better resolved.
- Observed data are essential to establish a baseline for the present day risks, particularly when examining derived variables rather than climate parameters. Access to this data is, however, often problematic (usually due to access restrictions or cost).
- The probabilistic results provided by UKCP09 capture a significant proportion of the range of current uncertainty (see Chapter 2). For some of the consequences examined this spread of results was amplified leading to estimates with a very large range. Such large uncertainties can be off putting but it is essential that decision makers consider this wide range rather than wait for more refined projections; in fact there is no guarantee that newer projections will narrow the range of uncertainty.
- The marine projections provide very different outputs to the land based projections. They are based primarily on the Medium emissions scenario and, with the exception of sea level rise, do not provide information on the possible spread of outcomes, which is needed for adaptation planning.

Future advances in climate modelling may alter the projections, so decisions based on the current projections should be flexible or robust to a wider range of possible climate futures. Rates of warming, sea level rise and even the direction of change from some hydrological variables may be different in the next set of UK projections.

9.4.7 Evidence and research gaps

The CCRA has identified a wide range of evidence and research gaps, both within individual sectors and across sectors, noting that many priority risks arose in cases where flooding, overheating and water scarcity had indirect impacts on other sectors.

Individual Sector Reports have defined the main gaps in evidence and the lessons learned report will provide a comprehensive review.

Examples of some of gaps identified from sector reports include:

- In the **Agriculture** sector there were some detailed models available, for example for specific varieties of potatoes, and excellent field investigations, for example on the yields of grasslands. There was a lack of integrated models that can consider changes in climate at the regional and national scale, which can reconcile the positive influences of temperature, CO_2 and potential negative influences of water scarcity and pests and diseases.
- Similarly in the **Forestry** sector**,** there has been some good progress made on the development of models but further work is needed to include and integrate factors related to the ecological ranges of species, different geographical characteristics, multiple climate variables, the effects of more extreme weather and potential risks of pests and diseases.
- In the **Biodiversity and Ecosystem Services** research areas the recent National Ecosystem Assessment has made a positive contribution; however there is a lack of standardised and long-term datasets and further work is needed understanding changes and ecosystem dynamics, including the interaction of people within ecosystems.
- In the **Built Environment sector** there have excellent studies at the scale of buildings but less is known about how different factors combine to increase the potential risks in urban environments, such as building design, people's behaviour, the role of green (and blue) space and its contribution to cooling. Similar to other sectors some of strong site specific evidence exists but there is a lack of integrated models.
- In the **Health** sector, there has been some good work linking climate with winter and summer morbidity and mortalities but further work is needed on the interaction between physical variables (e.g. climate) and social demographics, human behaviour and regional factors to improve projections of future health burdens.
- In the **Transport sector,** there has been some good progress on specific risks, like rails buckling in extremely hot temperatures, **but** more research is needed on how extreme weather events affect transport networks. A detailed inventory of all hard infrastructure, climate trigger mechanisms and thresholds are required to build a better picture of how climate change may cause delays, disruption and potential failure of UK transport networks.

Cross-cutting gaps include:

- The evidence on **social vulnerability** to climate lacks comprehensive coverage. There are a number of areas, such as flood risk management, where the research is relatively well developed but in other sectors it lags behind the more detailed studies on biophysical impacts of climate change. More research is needed on how social vulnerability affects risk and also how vulnerability may change over time as part of studies on future socio-economic scenarios. The next CCRA would benefit from a set of quantitative socio-economic scenarios to provide a richer picture of how society may change in the medium to longer term.
- Providing **projections of future changes to extreme events** is a developing area of science that is particularly challenging due to limitations in the current generation of climate models. Technical challenges include extreme value estimation in a 'non-stationary' climate and extreme event characteristics such as spatial extents, duration and clustering that are all poorly resolved in climate models. Overall confidence in extreme hot and cold events and coastal flooding is greater than for surface water flooding, storms and gales and drought. As well as continued monitoring, further research on climate change and extreme events is needed to improve future risk assessments.
- Robust methods for understanding **potential climate risks and the interactions between complex systems**, particularly regarding how climate risks may affect financial performance or supply chains of UK businesses. Some recent attempts to model financial systems may provide a way forward (Haldane and May, 2011) but further research is needed to integrate and link potential biophysical impacts to consequences across multiple sectors and ultimately understanding the effects on UK financial institutions, businesses and consumers.

The simple confidence scoring concept used in the CCRA can be used as a guide for potentially significant risks that require further research (see Table 9.3).

9.4.8 The very uncertain

For some of the risks considered in this assessment it was not possible to do more than characterise the nature of the risk. Typically these risks fell into one of two categories. In some cases, there was a high degree of confidence amongst experts that the change would happen (and in what direction) but the magnitude was uncertain. In other cases, even the direction of change was uncertain, either because of uncertainty about the nature of the response, or because the collective change could be either positive or negative, depending on the circumstances (e.g. for different species).

Ecosystems typically involve a multitude of complex interactions. Moreover, natural responses to climate change are extremely difficult to predict confidently, as habitats and species can exhibit different responses in different places. In addition the threats posed can be quite different (e.g. between marine and terrestrial habitats). Significant uncertainties therefore exist in the assessment of the climate-related risks facing this sector. The sensitivity of biodiversity to climate change has not yet been estimated with any real degree of confidence. Although understanding is reasonably good in terms of the response of some animal and plant species to climatic changes, knowledge is less well developed in the key areas of species interactions and habitat change.

Another important consequence is the climate that is likely to prevail in our cities. However, most climate models do not incorporate sufficient resolution to include a

representation of urban areas, so projections of Urban Heat Island effects under climate change scenarios are not yet available.

A number of impacts identified by stakeholders related to wind and storm damage. Changes in storms and monthly mean wind speeds are projected to be small in the models used within UKCP09, with the sign of the projected wind speed varying from positive to negative. There is, however, some uncertainty inherent in the models used and given its potential significance for many activities in the UK, and past experiences of the damage that storms can cause, some further work to confirm these findings would be worthwhile.

Impacts associated with sunlight/UV exposure are also highly uncertain. The figures are based on limited evidence and do not take behavioural factors into account, although these may affect future exposure levels very significantly. Similarly, predictions of future ground-level ozone concentrations are highly uncertain, as they are based on the modelling of complex emissions scenarios and behavioural processes which are still the subject of debate within the scientific community.

Finally, the sensitive nature of information and the inherent complexity of many of the networks in the business world make even the identification of risks that can be attributed to climate change a challenge. The complex web of interactions in markets has some parallels with the complexities of ecosystems and these two areas of work certainly require further work for the next CCRA. This assessment and the Foresight examination of the international dimensions of climate change both noted that the numerous dependencies within supply chains make this a particular source of vulnerability but the magnitude of the risk remains highly uncertain.

9.5 A final summary of future climate risks by theme

Biophysical Impacts

Changes in climate are expected to have a range of direct impacts on biological and physical processes in the natural and built environment. The main biophysical impacts considered in this assessment are listed below:

- Heating degree days (HDD), which provide an indication of winter energy demands, will decrease across the UK. For the Medium emissions scenario, heating degree days are projected to decrease in step with changes in winter temperature with immediate impacts in the short term. In the long term (2080s) HDD in Southern England are projected to be 50% lower than the 1961-1990 period and 30% lower in Scotland.
- Cooling degree days (CDD), which provide an indication of summer cooling demand, are projected to increase across the UK but with much greater impacts in Southern England. In Southern England the baseline CDD are 25 to 50 degree days and, for the Medium emissions scenario, these are projected to increase to 125 to 175 degree days in the 2080s. In Scotland the increase is much smaller, in the range of 25 to 50 degree days.
- Growing degree days (GDD) provide an indicator of plant productivity and the timing of biological processes such as bud burst. For the Medium emissions scenario, GDD are projected to increase across the UK with the greatest rises in Southern England and in coastal areas. By the 2080s, GDDs are projected to

increase by around 900 degree days[195] over Southern England and 400 degree days over Scotland.

- Increases in plant productivity due to warmer conditions and elevated levels of CO_2. The average rise in yield is approximately 15 % per degree rise in temperature. For example, for the Medium emissions scenario, grassland yields in Wales are projected to increase by 20% (11 to 31%) in the 2020s and by 36% (22 to 54%) in the 2050s.
- Warmer and drier conditions, leading to drier soils across the UK. In the medium term (2050s), significantly drier soils are projected to spread to the north and west. For example, for the Medium emissions scenario a measure of soil dryness, the maximum potential soil moisture deficit, in Wales is projected to increase from ca. 129 mm to ca. 300 mm (171 to 461 mm) in the 2050s. This level of soil water deficit is greater than that observed in Eastern England today.
- Increases in the heavy rainfall events across the UK, particularly in winter months and increase in soil erosion potential. For example for the 2080s Medium emissions scenario erosion caused by rainfall is projected to increase by ca. 50% (8 to 71%) in Northern Ireland, which would have significant consequences for erosion of carbon rich soils and increase the sediment loads in rivers.
- Increases in peak river flows and the frequency of river flooding, mostly in winter months. The range of results for changes in river flows is large, typically from no change to an increase of 60 %. For example for the 2080s Medium emissions scenario, peak flows in West Wales are projected to increase by 30% (14% to 55%) and the frequency of flooding is projected to increase four-fold (two- to ten-fold).
- Lower summer rivers flows across the UK due to warming and drying conditions. The greatest changes are projected for the Anglian basin. For the 2050s the Q95 low flow indicator[196] is projected to decrease by 35% (-7% to -54%), which presents a major challenge for future water resources management.
- On the UK coastline, sea level rise will continue to increase the risk of flooding from the sea and coastal erosion.

While many biophysical impacts are negative and may threaten ecosystems, there are some potential positive biophysical impacts including greater primary production, which may benefit agriculture and forestry and some species, as long as other land characteristics (land use, topography, soil type) and water availability pressures do not prevail.

Agriculture and Forestry

Climate change may have positive or negative consequences for UK agriculture and forest production depending on the balance between the benefits of warmer conditions and detrimental impacts of water scarcity and other factors. In the near to medium term, the effect of warmer temperatures and CO_2 fertilisation may benefit production. Warmer conditions and other climate factors will influence land suitability, presenting opportunities to grow new crops, and may increase the productivity of grassland and livestock systems as well as arable and horticultural crops. The UK and other northern

[195] The day-by-day sum of the mean number of degrees by which the air temperature is more than a value of 5.5 °C (see Met Office UKCP09 FAQ 7 for further details).
[196] Q95 is the flow exceeded 95 percent of the time, so in an average year, flows are above this threshold for approximately 347 days and below it for approximately 18 days.

European countries are projected to have more favourable agricultural conditions than southern Europe, which may present a comparative advantage for the UK. However, these opportunities will only be realised if productivity is not limited by lack of water, land, nutrients and other factors. Further work is needed on the integrated impacts of climate and economic risks and opportunities for farming and forestry in the UK.

This assessment has shown that climate change may result in a range of threats and opportunities for UK agriculture and forestry, including:

- Increased temperatures may improve yields for current crops (e.g. wheat & sugar beet) as long as water and nutrients are not limiting. For example, considering temperature effects alone, average sugar beet yields are projected to increase by 39% (18 to 68%) in the 2050s and by 55 % (23 to 105%) in the 2080s. Similarly, average winter wheat yields are projected increase by 79% (36 to 137%) in the 2050s and 111% (46% to 212%) in the 2080s. In parts of England, drier conditions may limit these increases.

- Warmer conditions may favour new specialist crops used for bio-fuel and/or pharmaceutical production. Examples of potential new crops include herbs – chamomile, coriander and dill, food – globe artichokes, blueberries, grapes, and energy crops – miscanthus, reed canary grass and maize. Some new crops may have negative environmental consequences, which would need to be considered before widespread uptake.

- Climate impacts modelling for the High emissions scenario in the 2050s and 2080s show an overall decline in potential production for most conifers and broadleaves currently grown in England. For some species in some English regions the decline is severe and will require management intervention to maintain productivity. In contrast, the modelling identifies significant increases in potential production in Scotland, especially for conifers, mainly as a result of increasing temperature. In Wales, some species increase in production whilst others decline. The projected rate of change in potential production is larger after the 2050s for most species. These projections are based on key climate, soil and tree species suitability information, and do not include interactions with other factors that may be affected by climate change, in particular pests and pathogens.

- In some of the UK's commercial forests, timber yields and quality of timber may decline due to projected drought and the incidence of pests and diseases, such as red band needle blight, which has already devastated crops of Corsican Pine in the East of England. This is a particular concern as this disease is projected to spread aggressively in warmer conditions with the majority of forests in England, Wales and Scotland affected by the 2050s. Projected drought may also reduce forest yields, for example yields in South East England may decline on average by 17% (11 to 23%) in the 2050s and by 19% (12 to 26%) in the 2080s.

- Reduced water availability in the summer months and increased competition for limited water resources. The demand for irrigation would increase with projected warmer and drier conditions, particularly in the south and east of England. For example, considering all scenarios, the effect of climate change alone suggest an increase in demand of 34 % (-9% to +76%) for the 2050s and 45 %(-4% to +108 %) for the 2080s. This increase in demand is projected to occur at the same time as increased competition for water and requirements for more sustainable abstraction to maintain environmental flows. Similar to other metrics influenced by summer rainfall the possible range of changes includes small decreases as well as large increases demand.

- The climatic conditions that promote an increase in wildfire risk such as higher temperatures, lower summer rainfall and drier soils are projected to increase over the next decades. Forest fires can endanger timber resources but pose a greater risk to wildlife habitat and recreational opportunity. An analysis of likely change in outdoor fire incidence using the McArthur Forest Fire Danger Index suggests a 30-50% increase by the 2080s (ensemble mean; Medium emissions scenario) depending on country and region, with the highest risk experienced in the south of England.
- Increased risks of flooding and coastal erosion for high quality agricultural land. Flooding of agricultural land is projected to increase two-to three-fold on average in the 2050s and by greater than three-fold in the 2080s. However, flooding can also provide long-term benefits for agricultural production, through the provision of nutrient-rich sediment. For this reason agricultural land is sometimes deliberately flooded through a practice known as 'warping'.

Business

Climate change affects most aspects of business including: fixed assets, workforce, procurement (raw materials, supply chains, logistics), operations (supply of services, customer demands, regulation), and environmental and social performance.

A large part of the UK economy relies on imports and exports. Therefore, there is high dependency on activities overseas, such as, transport and communication links and the integrity of supply chains. The World Economic Forum's Global Risk Report[197] considered climate change as the most important environmental risk and more importantly showed how it is inter-related with global food and water security, macro-economic and geopolitical risks. A recent UK Government Office for Science report highlighted the risk that the financial sector and business generally may fail to evaluate and take account of changes in the balance of risks associated with climate change overseas (Foresight, 2011a).

The main domestic climate change risks facing UK businesses are related to projected increases in flooding, hotter average summer conditions, heatwaves and water scarcity. These identified and assessed in the CCRA included:

- Damage to fixed assets, stock, etc. from river, tidal and surface water flooding;
- Potential increases in combined sewer overflow frequency, which may affect the marine environment and bathing water quality with potential knock-on effects for coastal tourism;
- Loss of business continuity due to flooding;
- Increased flood insurance claims for the insurance industry and hence increases in costs for customers, including business customers and potentially an increase in the number of uninsured businesses;
- Higher insurance costs or difficulty getting insurance may lead to reductions in mortgage value of properties with knock-on impacts on house sales;
- Impacts of projected sea level rise on beaches and other tourist attractions due to sea level rise;
- Loss of productivity due to overheating and warm weather periods;
- Increased energy costs for summer cooling; and

[197] World Economic Forum. 2011. Global Risks 2011. 6th edition. http://riskreport.weforum.org/

- Reductions in water availability in some parts of England and Wales, which may lead to more frequent water restrictions, potential increases in water charges and difficulties for some industries, like the food and beverage sector, that abstract their own water supplies.

The main opportunities for businesses arise from the move to a low carbon economy and delivery of adaptation measures. These have the greatest potential to benefit the financial, utility, manufacturing and consultancy sectors.

- By fully internalising climate change risks into fund management, new products for investors seeking climate resilient opportunities could be developed;
- Reductions in winter heating costs would provide some economic benefits that may outweigh the costs of summer cooling in the short term;
- The tourism and leisure industries may particularly benefit with a lengthening of the domestic tourist season and increased attractiveness of domestic weather conditions; and
- Melting of Arctic Sea ice opening up the North East Passage (also referred to as the Northern Sea Route) creates the opportunity for new trading routes with Asian markets. However, the loss of ice may have significant implications for UK climate.

There may also be significant opportunities in retailing, the development of climate adaptation products related to cooling or water efficiency and the development of services for dealing with extreme weather and providing advice on climate risks and adaptation internationally. These have not been assessed in detail as part of this report, but all are arguably relevant aspects of developing a sustainable green economy.

Health and Wellbeing

Some of the potential impacts of climate change on human health, such as changes in cold and heat related mortality, have been widely researched in the UK (e.g. Kovats and Hajat, 2008) but other impacts related to vector-borne and water-borne infectious diseases, UV exposure and air pollution and soil bacteria, which may be harmful, are less well understood. The potential impact on wellbeing is a newer area that was introduced in this assessment but also requires further research.

The main health risks and opportunities considered in this assessment include:

- Increases in heat mortality and morbidity, for example for the 2050s our analysis indicates more than 2,200 additional premature deaths per year (580 to 5,900) as a result of hotter summer conditions (without further adaptation of buildings or health services). This is a similar number to the additional premature deaths attributed to the 2003 heatwave, but in the 2050s this is projected to occur in an average year. The risks are greatest for vulnerable groups, such as the elderly, and in London and southern England that are projected to experience the highest temperatures.
- Decreases in cold related mortality and morbidity may have considerable benefits; the numbers of people affected are larger than for heat morbidity and mortality. For the 2050s, our analysis shows that approximately 3,900 to 24,000 premature deaths per year may be avoided due to warmer winter conditions. These changes would benefit vulnerable groups, such as the elderly or those with poor health, and affect the whole of the UK. The net benefits of cold versus

heat related deaths are marginal in the 2080s for average years and any increase in heatwave frequency may tip the balance to a negative impact.

- An increase in the number of deaths, injuries and people suffering mental health effects as a result of flooding. Our analysis of the current risk of fatalities from river and pluvial flooding, tidal flooding and storms indicates an average of 18 deaths per year in the UK. For the 2050s, our analysis suggests an additional 21 deaths per year (6 to 34 deaths per year) due to projected changes in flood frequency and storm activity nearshore. The number of non-fatal injuries is projected to increase at a similar rate. In addition, the increased numbers of people affected by flooding may lead to an increase in mental health problems for flood victims. The additional numbers of people affected per year are projected to be between 4,000 and 7,000 per year in the 2050s and between 5,000 and 8,000 per year by the 2080s. For those already affected by frequent flooding, the health and financial impacts may become more acute.

- Any increase in low level ozone levels by the end of the century is likely to lead to an increase in levels of mortality and excess respiratory hospital admissions. A set of specific scenarios for the 2080s were analysed as part of the CCRA. These suggested that particular pollution episodes, like those that occurred in 1995, 2003 and 2005, would result in approximately 910 to 4,000 additional deaths and 3,200 to 14,000 additional respiratory hospital admissions, under the principal population projection.

- Projected changes in cloud cover, UV radiation and higher summer temperatures combined with a potential increase in periods of time spent outdoors may lead to an increase in the number of skin cancer cases and deaths. Links between future levels of skin cancers and climate change as a result of a change in levels of UVB is extremely complex and driven more by changes in social behaviour than by any climate effect. We anticipate that if detection rates and better treatment of cancer cases continue to improve, the overall percentage mortality may decrease in the future.

- A projected increase in temperatures and changed seasonal rainfall patterns may lead to increased health risk due to water, vector and food borne diseases. Cryptosporidiosis is the most significant water borne disease related to public and private water supplies in the UK (Hoek *et al.*, 2008; Kovats, 2008). Climate change may have a negative impact on raw water quality but this assessment anticipated that high drinking water standards would be maintained. Similarly, vector-borne diseases, parasite development, bite frequency and food poisoning generally rise with temperature but we anticipate the UK health infrastructure is well prepared to manage these health risks and suggest that social factors are more important than climate change. The greater health burden may be from UK tourists returning from countries with endemic malaria and dengue fever and requiring treatment in the UK.

- A projected increase in sea temperatures is anticipated to lead to an increase of marine pathogens and harmful algae blooms with a consequent negative effect on human health. Ad-hoc monitoring of marine pathogens that can cause stomach problems in humans indicates that they are on the increase (Cefas). The main disease pathogens are suited to warmer sea conditions and this assessment suggests that the risks may increase in future but more research and monitoring are needed to increase our understanding of the links between climate change and marine pathogens.

As well as the reduction in cold related winter mortality and morbidity, there may be other positive consequences of climate change including the possibility of adopting more active lifestyles with longer periods of time spent outdoors, which could have

health benefits. Taking these opportunities depends on behavioural responses to warmer summer conditions, which is an area that requires further research.

Buildings and Infrastructure

The built environment and national infrastructure have already been identified as priority areas for adaptation (ASC, 2010). The current risks of flooding of buildings and infrastructure assets are significant and are projected to increase in the future. Water scarcity and summer overheating of buildings are anticipated to emerge as significant risks by the 2050s. Heat related damage and disruption to energy and transport networks may become more significant by the 2080s and the urban environment is likely to function less effectively by the 2080s, due to an increased risk of the Urban Heat Island (UHI) effect and reduced effectiveness of existing green spaces[198]. The UHI effect is due to urban surfaces absorbing heat during the day and releasing it in later in the evening and may significantly elevate temperatures. Large UK cities with high concentrations of vulnerable groups may be affected disproportionately by combinations of increases in flood risk, heatwaves and water scarcity.

Buildings and the main infrastructure sectors (energy, transport, water, waste and telecommunications) are highly interdependent. Vulnerability in one sector can influence others and failure of critical infrastructure components may lead to 'cascade failures' with significant consequences. This has not been assessed in detail as part of this first CCRA, but is the focus of new research, which should be available for future CCRA cycles.

Spatial planning has a key role in minimising vulnerability and maximising the benefits for those living and working in the built environment. The long life of buildings and infrastructure assets means that future changes in vulnerability need to be considered in today's designs and plans.

This assessment has shown that climate change presents a range of threats and opportunities for buildings and infrastructure. Considering a range of scenarios based on the UKCP09 projections, the major threats include:

- Increased flood risk for buildings and infrastructure located in areas exposed to tidal, river and surface water flooding. The expected annual damage to properties (residential and non-residential) caused by flooding from rivers and the sea in the UK is currently £1.3 billion per annum. New analysis for England and Wales showed that future damages are projected to be within the following ranges:
    - £1.5 billion to £3.5 billion by the 2020s;
    - £1.8 billion to £6.8 billion by the 2050s; and
    - £2 billion to £12 billion by the 2080s.

    These estimates assume continued investment to maintain the condition of existing flood defences but do not include other flood risk management measures. Future risks of flooding will depend upon the location and pattern of future development and level of additional investment in flood risk management (by government and local communities), as well as changes to the hydrological cycle and rates of sea level rise.

[198] The evidence for the decreased effectiveness of green spaces is presented in the Built Environment report. The CCRA did not consider future land use change, so this analysis was based on existing extent of green space. The management and provision of more parks, greens and open areas in cities is likely to be an important part of adapting cities to future climate change.

- In England and Wales, the risk of flooding of critical infrastructure is projected to increase. For example, by the 2050s the number of power stations in areas at significant likelihood of river and tidal flooding[199] is projected to increase from 19 at present to between 25 and 39 and the number of substations at a similar level of risk may increase from 46 to between 51 and 73 (assuming that locations and numbers do not change). The length of road at significant risk of fluvial or tidal flooding in England and Wales may increase from around 12,000 km at present to between 13,000 and 16,000 km by the 2020s, rising to between14,000 and 19,000 km by the 2080s. In some parts of the UK, a large proportion of emergency services infrastructure is located in the floodplain.

- Overheating of buildings in the summer can contribute to heat 'morbidity', particularly for vulnerable groups. It could also cause deterioration in working conditions leading to a potential loss in productivity and changes in working patterns and lifestyles. Risks are greatest in London and southern England. In this report, overheating risks are considered to be greatest when maximum daily temperatures exceed 26°C. On average this happens 18 days a year in London with the current climate but is projected to occur 50 (range 25 to 92) days per year in the 2050s. Large cities already experience an 'Urban Heat Island' effect, which increases evening temperatures significantly and in future there may be an increase in the demand for cooling buildings and urban spaces. The use of green space for both recreation and the cooling effects it provides will become more important. Under the more extreme scenarios with higher rates of warming, green spaces are likely to dry out, which would make them less effective at cooling urban environments. Both the use of air conditioning and drying of green spaces may create positive feedbacks adding to the Urban Heat Island effect.

- Heat related damage/disruption to energy, transport and ICT infrastructure may increase in the future. The annual costs of carriageway repairs and replacement of buckled rails are projected to be relatively small, but the extent of the disruption caused as a result may be more significant.

- Changes in water availability, particularly reductions in the summer, may lead to less reliable supplies, more frequent restrictions and potential water shortages in the longer term, unless more measures are taken to reduce demands and develop supplies. The projected widening gap between the water available and demand would affect public water supplies, agriculture, industry and public sector services that use direct abstractions and the environment. Changes in water quality may also be significant in some locations, as lower summer flows would provide less dilution for pollutants.

- The CCRA analysis indicated the potential for major supply-demand deficits in five major river basins – Anglian, Humber, Severn, North West England and the Thames basin. The Thames basin, which provides the current water supply to London of around 2,000 Ml/d as well as supplies to large areas of the Home Counties, is projected to face the largest deficits. The CCRA analysis for the Thames basin indicates deficits of 478 Ml/d (0 to 1,040 Ml/d) in the 2020s and 1,700 Ml/d (773 to 2,570 Ml/d) in the 2050s based on a central population projection. This excludes anticipated adaptation, such as water efficiency and planned supply schemes, which should close the deficit in the near term (2020s) but the widening supply-demand gap still presents a considerable challenge for the 2050s.

- Incidence of subsidence and landslip is projected to increase in the future, affecting buildings and some infrastructure assets, particularly transport. The

[199] Significant likelihood is defined as exposure to a flood frequency (to any depth) greater than 1 in 75 years.

average number of households suffering subsidence in areas of England with shrink-swell clay soils is projected to increase by about 17% (reduction of 10% to increase of 30%) by the 2050s. The incidence of landslips is projected to increase with double the number of roads in England and Scotland being at risk by the 2080s.

There will be some benefits. For example, the projected reduction in heating degree days would decrease the demand for heating in winter months, which may outweigh the projected demand for cooling in the short term and reduce energy costs for businesses and the public, and reduce carbon emissions. However, in 2006 the peak electrical energy demand in the summer in London was greater than the peak winter demand for the first time (Mayor of London 2010). Therefore, further work is needed to understand the net effects of heating versus cooling demand, which includes a better assessment of extreme conditions and urban heat island effects.

Otherwise, the main opportunities for the building and infrastructure industries (as highlighted under Business above) arise from the move to a low carbon economy and benefits realised through the delivery of adaptation measures. These may include improved management of the natural environment, for example to provide flood storage and improved water quality, as well as the development of green infrastructure in towns.

Natural Environment

Human activity places a range of pressures on the natural environment, which may be exacerbated by changes in climate and in some cases, provide feedbacks that influence the rate of future climate change. For example, the world's oceans provide an enormous store of carbon but increased greenhouse gas emissions are causing 'ocean acidification', which has the potential to harm marine ecosystems and alter the oceans' ability to further take up excess CO_2 from the atmosphere.

In the UK, land use pressures are expected to have a significant impact on habitats. The current fragmentation of habitats is particularly important in the context of climate change. The recent Lawton Review stated that "there is compelling evidence that England's collection of wildlife sites are generally too small and too isolated, leading to declines in many of England's characteristic species. With climate change, the situation is likely to get worse." This study found that this is a complex area and it was difficult to quantify the consequences of future climate change. However, several qualitative conclusions can be drawn from the assessment.

The main direct impacts of climate change on the natural environment are:

- Changes in phenology (the timing of life cycle events), which can lead to loss of synchrony between species and therefore a reduction/loss of individuals and/or species;
- Changes in species distribution and ranges (including loss of 'climate space' for some native species, arrival of non-native species and change in species' habitat preferences), which in turn may lead to changes in community composition;
- Changes in ecosystem function and processes (as modified by climate and exposure to extreme events such as drought, floods and storms);
- A loss of physical space due to sea level rise and coastal erosion, which may lead to loss of valued species and habitats; and

- Climate change may also lead to changes in land, water and coastal management that may have greater indirect impacts on the natural environment.

The CCRA considered a selection of main direct impacts of climate change on the natural environment. Examples of key findings include:

- Changes in the hydrological cycle would have a range of biophysical impacts on the natural environment. These include lower summer river flows, particularly in southern and eastern England. The CCRA analysis projected the largest reductions of river flows in the Anglian UKCP09 basin, with average reductions in the '$Q95_{61-90}$' low flow indicator of 35% (range 7% to 54% reduction) for the 2050s. This indicator reports the amount of river flow exceeded 95 percent of the time, on average, in any one year. Lower summer flows may influence water quality as there is a lower volume of water in rivers to dilute pollution from point discharges or diffuse urban or agricultural sources.

- Hydrological changes may be exacerbated but increased pressure on water resources as demands increase due to population growth, changes to agricultural practices and higher temperatures. There may be increased competition for water resources and, without major reductions in demand, there may be significant trade-offs required between maintaining environmental flows and meeting the increasing demand for water.

- Climate change is likely to lead to some species gaining, and some species losing 'climate space', with some species shifting, typically northward and upwards, to move to more suitable locations. For example, the assessment identifies that birds such as stone-curlew may benefit but sky larks, black grouse, capercaillie and song thrushes may lose climate space (Walmsley *et al.*, 2007); in the long term, some bird species, including the Bittern (Berry et al., 2007), could be lost from the UK. Substantial efforts of NGOs, such as Royal Society for the Protection of Birds, are invested in creating new habitats and expanding existing bird populations and these efforts need to consider climate risks.

- Habitats that require cooler and wetter conditions are shown to be particularly vulnerable, for example the occurrence of peat forming conditions may decline significantly. Other studies have shown that over half of the peatland area in the UK is vulnerable to warmer and drier conditions (Clark *et al.*, 2010) and these drier peat soils are vulnerable to soil erosion and loss of carbon (Orr *et al.*, 2008; Lilly *et al.*, 2009).

- Species that can cope with a range of conditions, known as generalist species, are likely to fare better than specialist species that depend on niche environments. This includes alien and invasive species; for example, a number of problematic invasive species are expected to spread further under future climate projections. These include Slipper Limpets, Pacific Oysters and Zebra Mussels that disrupt ecological balance and destroy or damage local shell fish fisheries.

The UK's National Ecosystem Assessment, completed in 2011, described how ecosystem services are constantly changing, driven by societal changes – demographic, economic, socio-political, technological and behavioural – which influence demand for goods and services and the way we manage our natural resources. A comprehensive understanding of all these drivers is needed to manage ecosystems in a changing climate. Some adaptation may be able to provide opportunities to enhance biodiversity, or the delivery of ecosystem services, whilst delivering their intended objective. At the same time other drivers, such as land use, are likely to be of greater significance in determining the extent of further biodiversity

losses in the UK. The UK NEA provides a strong evidence base and platform for more detailed assessments of adaptation options and early action to improve the management of ecosystem services.

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Appendices

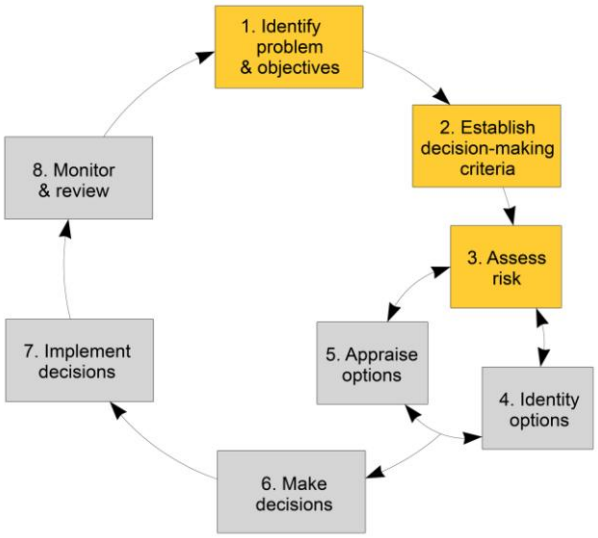
Appendix 1 Summary of Risk Assessment Method

A1.1 Introduction: CCRA Framework

The overall aim of the CCRA is to inform UK adaptation policy, by assessing the main current and future risks (threats and opportunities) posed by the current climate and future climate change for the UK to the year 2100. The overall approach to the risk assessment and subsequent adaptation plan is based on the UK Climate Impacts Programme (UKCIP) Risk and Uncertainty Framework (UKCIP, 2003). The framework comprises eight stages as shown in Figure A1.1. The CCRA has undertaken the Stages 1, 2 and 3 as outlined below. Stages 4 and 5 will be addressed as part of a separate economic assessment, entitled the 'Economics of Climate Resilience', and the remaining stages will be implemented by the UK Government and Devolved Administrations. The framework presents a continual process that can adapt as new evidence and policy emerges; in the case of the CCRA the process will be revisited every five years.

Figure A1.1 Stages of the CCRA (yellow) and other actions for Government (grey)

(Adapted from UKCIP, 2003)



- Stage 1 is defined by the aim of the CCRA project, to undertake an assessment of the main risks (including both threats and opportunities) posed by climate change that will have social, environmental and economic consequences for the UK.
- Stage 2 established decision-making criteria for the study, which were used to inform the selection of impacts for analysis in Stage 3. These criteria are the social, environmental and economic magnitude of consequences and the urgency of taking adaptation action for UK society as a whole.
- Stage 3 covers the risk assessment process. This involved a tiered assessment of risks with Tier 1 (broad level) identifying a broad range of potential impacts and Tier 2 (detailed level) providing a more detailed analysis including quantification and monetisation of some impacts. A list of climate change

impacts was developed based on eleven sectors with further impacts added to cover cross-cutting issues and impacts which fell between sectors. This list of climate change impacts is referred to as the **'Tier 1' list of impacts**. This list contained approximately 700 impacts – too many to analyse in detail as part of this first CCRA. A consolidated list of the highest priority climate change impacts for analysis was developed and referred to as the **'Tier 2 list of impacts'**.

The background to the framework and the approach used for each of the first three stages is set out in more detail in the CCRA Method Report (Defra, 2010b). This appendix aims to summarise the CCRA method for the risk assessment stage (Stage 3 in the framework above) because this includes the specific steps for which results are presented in this report.

A1.2 Outline of the method used to assess impacts, consequences and risks

The risk assessment presented in this report is the focus of Stage 3 in the CCRA Framework (see Figure A1.1). This was done through a series of steps as set out in Figure A1.2. These steps are explained in Sections A1.3 – A1.6 below and are discussed in more detail in the CCRA Method report (Defra, 2010b).

The components of the assessment sought to:

- **Identify and characterise the impacts** of climate change

  This was achieved by developing the Tier 1 list of impacts, which included impacts across eleven sectors as well as impacts not covered by the sectors and arising from cross sector links (see Appendix 4 of this report).

- **Identify the main risks** for closer analysis

  This involved the selection of Tier 2 impacts for detailed analysis from the long list of impacts in Tier 1. Higher priority impacts were selected by stakeholder groups based on the social, environmental and economic magnitude of impacts and the urgency of taking action (see Section A1.5 below).

- **Assess current and future risk**, using climate projections and considering socio-economic factors

  The risk assessment was done by developing 'response functions' that provide a relationship between changes in climate with specific consequences based on analysis of historic data, the use of models or expert elicitation. In some cases this was not possible, and a narrative approach was taken instead. The UKCP09 climate projections and other climate models were then applied to assess future risks. The potential impact of changes in future society and the economy was also considered to understand the combined effects for future scenarios (See Section A1.6 below.)

- **Assess vulnerability** of the UK as a whole

  This involved:

  iii. A high level review of Government policy on climate change in the eleven sectors

  iv. A high level assessment of the social vulnerability to the climate change impacts

v. A high level assessment of the adaptive capacity of the sectors (see Section A1.4 for an overview of the approach, below).

- **Report on risks** to inform action

  The results for the eleven sectors are presented in detail in the Sector Reports and this report draws together the main findings from the whole project, including consideration of cross-linkages, and outlines the risks to the UK as a whole.

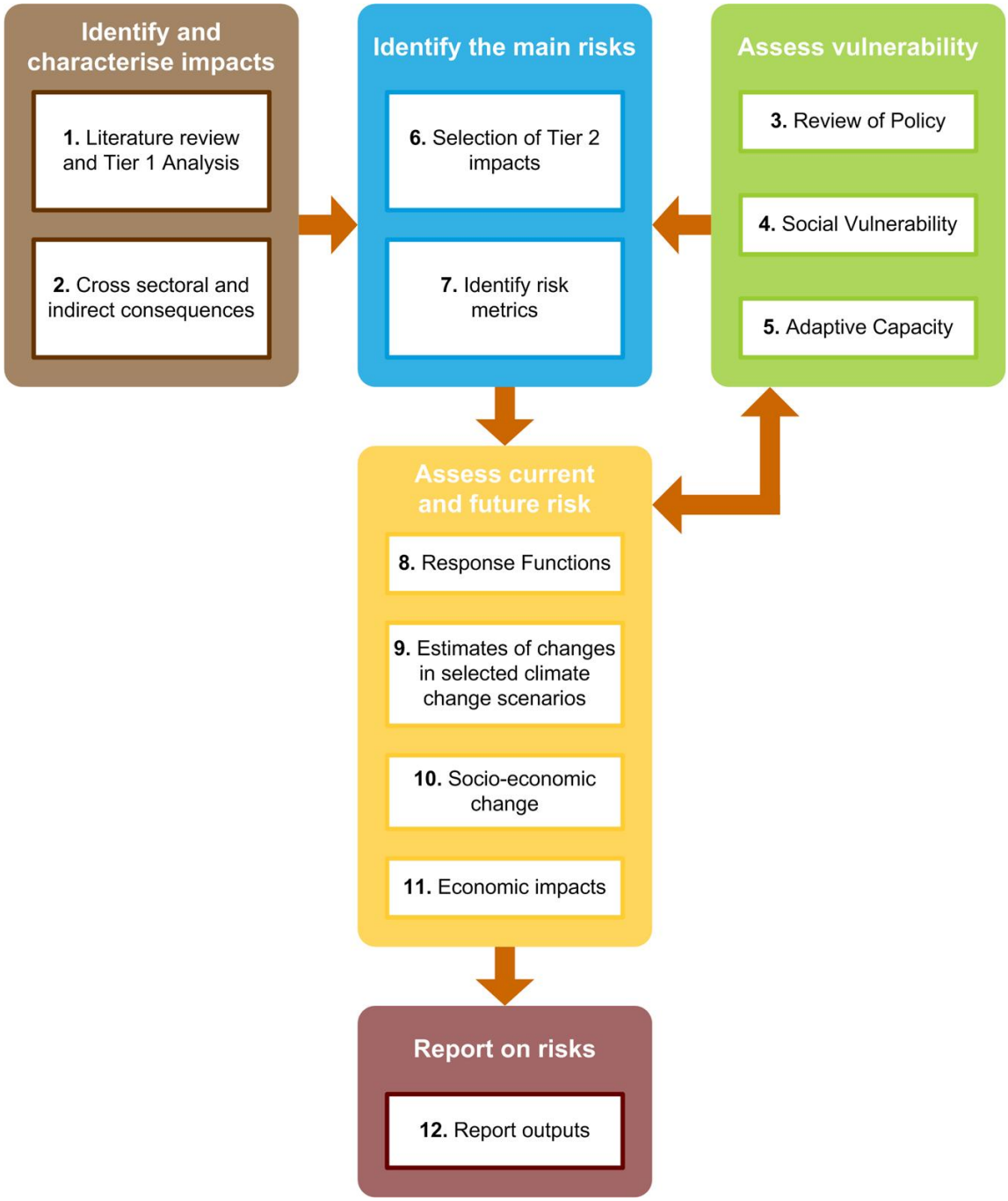


Figure A1.2 **Steps of the CCRA Method (that cover Stage 3 of the CCRA Framework: Assess risks)**

A1.3 Identify and characterise the impacts

Step 1 – Literature review and Tier 1 analysis

This step scoped the potential impacts of climate change on the UK based on existing evidence and collating the findings from literature reviews, stakeholder participation through workshops, correspondence with wider stakeholders and soliciting expert opinion. This work developed the Tier 1 list of impacts (see Appendix 4). The Tier 1 impacts have not been analysed in detail; high level discussion of these impacts is provided in the sector reports.

Step 2 – Cross sectoral and indirect consequences

The Tier 1 lists for the eleven sectors in CCRA were compared and developed further to include cross-sectoral and indirect impacts. This was done by 'Systematic Mapping', which sets out a flow chart to link causes and effects in a logical process. The impacts that were identified in this step were added to the Tier 1 list of impacts.

A1.4 Assess vulnerability

Step 3 – Review of Policy

Government policy on climate change develops and changes rapidly to keep pace with emerging science and understanding of how to respond through mitigation and adaptation. The sector reports include an overview of selected relevant policy as this provides important context for understanding how risks that are influenced by climate relate to existing policies.

Step 4 – Social Vulnerability

The vulnerability of different groups in society to the climate change risks for each sector was considered at a high level through a check list of questions. This information is provided for context; it is not a detailed assessment of social vulnerability to specific risks. Note that this step is different from Step 10, which considers how changes in society may affect the risks.

Step 5 – Adaptive Capacity

The adaptive capacity of a sector is the ability of the sector as a whole, including the organisations involved in working in the sector, to devise and implement effective adaptation strategies in response to information about potential future climate impacts. An introduction into adaptive capacity is given in the sector reports however; work on this is currently ongoing.

A1.5 Identify the main risks

Step 6 – Selection of Tier 2 impacts

The Tier 1 list of impacts for each sector that resulted from Step 2 (see above) was consolidated to select the higher priority impacts for analysis in Tier 2. Firstly, similar or overlapping impacts were grouped where possible in a simple cluster analysis. Secondly, the Tier 2 impacts were selected using a simple multi-criteria assessment based on the following criteria:

- the social, economic and environmental magnitude of impacts
- overall confidence in the available evidence
- the urgency with which adaptation decisions needs to be taken.

Each of these criteria were allocated a score of 1 (low), 2 (medium) or 3 (high) and the impacts with highest scores over all criteria were selected for Tier 2 analysis. The scoring for each sector was carried out based on expert judgement and feedback from expert consultation workshops (or telephone interviews). Checks were carried out to ensure that a consistent approach was taken across all the sectors. The results of the scoring process are provided in the sector reports.

Step 7 – Identifying risk metrics

For each impact in the Tier 2 list, one or more risk metrics were identified. Risk metrics provide a measure of the consequences of climate change, related to specific climate variables or biophysical impacts. For example, in the Water Sector Report one of the impacts identified is 'major drought' due to reduced precipitation. The risk metrics that were identified to measure the consequences of this impact included reductions in summer river flow (Q95), change in water available for public water supply and the population in areas with future deficits. The risk metrics were developed to provide a spread of information about economic, environmental and social consequences. The metrics have been referenced using the sector acronym and a number; for example the Water sector metrics are referenced as WA1 to WA10.

A1.6 Assess current and future risk

Step 8 – Response functions

This step established how each risk metric varied with one or more climate variables using available data or previous modelling work. This step was only possible where evidence existed to relate metrics to specific climate drivers, and has not been possible for all of the Tier 2 impacts. This step was carried out by developing a 'response function', which is a relationship to show how the risk metric varies with change in climate variables. Some of the response functions were qualitative, based on expert elicitation, whereas others were quantitative.

Step 9 – Estimates of changes in selected climate change scenarios

The response functions were used to assess the magnitude of consequences the UK could face due to climate change by making use of the UKCP09 climate projections. This step used the response functions to provide estimates of future risk under three different emissions scenarios (High emissions, A1FI; Medium emissions, A1B; Low emissions, B1; see http://ukclimateprojections.defra.gov.uk/content/view/1367/687/ for further details), three future 30-year time periods (centred on the 2020s, 2050s and 2080s) and for three probability levels (10, 50 and 90 percent, see http://ukclimateprojections.defra.gov.uk/content/view/1277/500/ for further details). The probability levels are cumulative and denote the degree of confidence in the change given; for example 90% suggests that it is thought very unlikely that the change will be higher than this; 50% suggests that it is thought equally likely that the change will be higher or lower than this; and 10% suggests that it is thought very unlikely that the change will be lower than this. For example, 90% does not mean that the change is 90% likely to occur.

All of the changes given in the UKCP09 projections are from a 1961-1990 baseline.

The purpose of this step is to provide the estimates for the level of future risk (threat or opportunity), as measured by each risk metric.

Step 10 – Socio-economic change

It is recognised that many of the risk metrics in the CCRA are influenced by a wide range of drivers, not just by climate change. The way in which the social and economic future of the UK develops will influence the risk metrics. Growth in population is one of

the major drivers in influencing risk metrics and may result in much larger changes than if the present day population is assumed. For some of the sectors where this driver is particularly important, future projections for change in population have been considered to adjust the magnitude of the estimated risks derived in Step 9.

For all of the sectors, a broad consideration has been made of how different changes in our society and economy may influence future risks and opportunities. The dimensions of socio-economic change that were considered are:

- Population needs/demands (high/low)
- Global stability (high/low)
- Distribution of wealth (even/uneven)
- Consumer driver values and wealth (sustainable/unsustainable)
- Level of Government decision making (local/national)
- Land use change/management (high/low Government input).

The full details of these dimensions and the assessment of the influence they have on the sector is provided in the sector reports. Note that this step is different from Step 4, which considers how the risks may affect society; whereas this step considers how changes in society may affect the risks.

Step 11 – Economic impacts

Based on standard investment appraisal approaches (HM Treasury, 2003) and existing evidence, some of the risks were expressed as monetary values. This provides a broad estimate of the costs associated with the risks and is presented in detail in the sector reports. A more detailed analysis of the costs of climate change will be carried out in a study on the Economics of Climate Resilience.

Appendix 2 Magnitude Thresholds and Urgency

The following tables define the magnitude classes used in the assessment, the thresholds used for selected risk metrics and the guidance on the 'urgency of decision' classification (see Defra, 2010b for further details).

Table A2.1 Guidance on classification of relative magnitude: qualitative descriptions of high, medium and low classes

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 ~1000's 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 *~100s 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 river quality affected*	• Small numbers affected • Small reduction in community services • Within 'coping range' *~10s thousands affected etc.*

Note: This provided a guide only. Expert judgement was used in a large proportion of cases.

Table A2.2 Guidance on classification of the 'urgency of decisions'

Class	Urgency
High	• Major policy, investment or other decisions required before 2020[200] 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

[200] 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.

Table A2.3 Thresholds used to classify selected risks

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
AG1a	Changes in sugar beet yield (due to warmer conditions)	t/ha	M	8	9	R	Estimated based on observed sugar beet annual yield data for 1980-2009. Currently average yields are under 8 t/ha but can be much more under the right conditions. See agriculture report.
AG1a	Changes in sugar beet yield (due to warmer conditions)	% change	M	25	50	R	Estimated based on observed sugar beet annual yield data for 1980-2009. Plus and minus 25% is within the normal range 6 to 10 t/ha so of low consequence. A 50% increase would indicate a higher average yield - higher than the last two decades.
AG1b	Changes in wheat yield (due to warmer conditions)	t/ha	M	6	8	R	Estimated based on observed annual wheat yield data for 1960-2007. Although yields can be much higher than 8 t/ha now under the right conditions the data we have used represents the situation at the regional scale on real farms. See agriculture report.
AG1b	Changes in wheat yield (due to warmer conditions)	% change	M	40	80	R	Estimated based on observed annual wheat yield data for 1960-2007. Same logic as sugar beet but the variance in wheat yields is higher, hence the higher percentages.
AG1c	Changes in potato yield (due to combined climate effects and CO_2)	% change	L	0	50	E	Based on weighing up results of analysis and more detailed modelling available in the research literature; Simple analysis suggested changes from -18% to +3% but detailed integrated models suggest increase by 13-16% (see Agriculture Report Section 5.3.3.)
AG2a	Flood risk to high quality agricultural land	Area (ha)	H	< 2x	> 3x	R	Estimated considering costs of flooding, frequency of flooding and increase in flood risk. Project a 3-fold increase in frequent flooding of land for the 2080s Medium emissions scenario
AG2b	Flood risk to horticultural land	Area (ha)	H	< 2x	> 3x	E	Estimated considering costs of flooding, frequency of flooding and increase in flood risk.
AG2c	Flood risk to grassland	Area (ha)	H	n/a	n/a	E	As above but considering that lower quality of land has a lower value

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
AG3a/b/c	Risk of crop pests and diseases	n/a	L	n/a	n/a	n/a	No data/thresholds - highly complex and too uncertain to estimate magnitude
AG4	Drier soils (due to warmer and drier summer conditions)	mm	M	225	360	E	Expert view. Values determined by looking at the results and the kinds of deficits that require irrigation.
AG4	Drier soils (due to warmer and drier summer conditions)	% change	M	35	120	R	Estimated based on 'terciles' or modelled results. These could be very misleading as soils that are already dry can't dry as much as wetter soils! Therefore data need to be presented with absolute numbers.
AG5	Increases in water demand for irrigation of crops	Ml/d	M	20	40	R	Estimated - for looking at relative risks at the regional scale (calculated using terciles).
AG5	Increases in water demand for irrigation of crops	% change	M	0	50	R	Estimated - for looking at relative risks but note that large % changes may occur in areas with small volumes of abstraction
AG6	Increases in water demand for livestock	n/a	L	n/a	n/a	n/a	No response function/not analysed further
AG7a	Reduction in milk production due to heat stress	Millions kg/annum converted to £ millions	L	10	100	M	Based on annual costs of lost production and related to the methods table.
AG7a	Reduction in milk production due to heat stress	As above	L	10	100	M	As above
AG7b	Reduction in dairy herd fertility due to heat stress	As above	L	10	100	M	As above
AG8a	Increased duration of heat stress in dairy cows	days	H	n/a	n/a	E	Qualitative view on whether the consequences were low, medium or high considering changes in average climate and heatwaves.
AG8b	Dairy livestock deaths due to heat stress	No./annum	L	n/a	n/a	E	As above noting that the numbers of deaths due to changes in average climate are negligible
AG9	Opportunities to grow new crops	n/a	H	n/a	n/a	E	Expert view based on Sector Report

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
AG10	Changes in grassland productivity	t/ha or % change	M	n/a	n/a	E	The agriculture report shows that increases in yield due to temperature and CO2 could be significant and have a positive economic impacts of £100s millions per annum. However the modelling does not include drought effects so an expert opinion view was taken on the benefits, which were scored as low to medium, although this could potentially be high for small increase in yield (>3%)
AG11	Increased soil erosion due to heavy rainfall	% change in rainfall erosivity	L	ca. +10%	ca. +50%	E	Expert view based on rainfall erosivity calculation. Results vary on a regional basis hence approximate thresholds e.g. indicating >50% increase in most regions
BD1	Risks to species and habitats due to drier soils	% change	M	35	120	R	See AG4
BD2	Risks to species and habitats due to coastal evolution	Area (ha)	M	n/a	n/a	E	Expert view based on a review of areas lost from floods analysis. The areas of valued habitat concerned are small (in the context of a national risk assessment). The areas become more significant for the more extreme scenarios in the 2080s.
BD3	Risk of pests to biodiversity	n/a	L	n/a	n/a	E	Expert view based on literature review. Overall risks are generally anticipated to increase with warmer conditions.
BD4	Risk of diseases to biodiversity	n/a	L	n/a	n/a	E	As above
BD5	Species unable to track changing 'climate space'	n/a	H	n/a	n/a	E	As above
BD6	Environmental effects of climate mitigation measures	n/a	L	n/a	n/a	E	Too uncertain/no thresholds used
BD7	Risks to coastal habitats due to flooding	ha	M	n/a	n/a	E	Expert view based on Sector Report.
BD8	Changes in soil organic carbon	n/a	L	n/a	n/a	E	Expert view based on literature review. Overall risks are generally anticipated to increase with warmer

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
							conditions.
BD9	Changes in species migration patterns	n/a	H	n/a	n/a	E	As above
BD10	Biodiversity risks due to warmer rivers and lakes	n/a	M	n/a	n/a	E	As above
BD11	Generalist species more able to adapt than specialists	n/a	L	n/a	n/a	E	As above
BD12	Wildfires due to warmer and drier conditions	n/a	M	n/a	n/a	E	As above
BD13	Water quality and pollution risks	n/a	M	n/a	n/a	E	As above
BD14	Ecosystem risks due to low flows and increased water demand	n/a	M	n/a	n/a	E	As above
BD15	Increased societal water demand	n/a	0	n/a	n/a	E	Not assessed
BD16	Major drought events	n/a	0	n/a	n/a	E	Not assessed
BE1	Urban Heat Island effect	n/a	H	n/a	n/a	n/a	Too uncertain/no thresholds used
BE2	Increased subsidence risk due to rainfall changes	Number of domestic subsidence incidents per annum	M	34,000	340,000	E	While the original thresholds were lower based on costs, the thresholds were increased following feedback on project reports.
BE3	Overheating of buildings	Total no of days per annum	H	20/30	50/70	E	Two figures are use average for the UK/days in London. Based on expert opinion.
BE5	Effectiveness of green space for cooling	% change in total area	M	10	20	E	View based on Sector Report

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
BE9	Reduction in energy demand for heating	Reduction in household space heating energy consumption	L	10%	20%	R	View based on Sector Report
BU1	Climate risks to investment funds	n/a	L	n/a	n/a	n/a	Too uncertain/no thresholds used
BU2	Monetary losses due to tourist assets at risk from flooding	£ million/ annum	M	n/a	n/a	E	Expert view from Sector Report, using methods table as a guide only
BU3	Risk of restrictions in water abstraction for industry	% loss of turnover	L	n/a	n/a	E	Expert view from Sector Report, using methods table as a guide only
BU4	Risks of business disruption due to flooding	% change in commercial properties at risk	M	20%	50%	R	Expert view from Sector Report. Difficult to classify - hard to say as baseline costs ca. £20 million, which would place at Medium
BU5	Loss of productivity due to ICT disruption	n/a	L	n/a	n/a	n/a	Too uncertain/no thresholds used
BU6	Mortgage provision threatened due to increased flood risk	Value (£) of mortgage fund at risk	L	n/a	n/a	E	Expert view from Sector Report.
BU7	Insurance industry exposure to UK flood risks	Change in annual insurance payout costs (£ million)	M	10%	100%	M	Current risks > £100 million per year and expected to increase
BU8	An expansion of tourist destinations in the UK	Tourist Comfort Index (TCI) scores	L	n/a	n/a	E	Expert view based on Sector Report. The increase reflects rises in temperature

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
BU9	A decrease in output for businesses due to supply chain disruption	n/a	L	n/a	n/a	n/a	Too uncertain/no thresholds used
BU10	Loss of staff hours due to high internal building temperatures	Loss of productivity (%)	M	n/a	n/a	E	Expert view based on Sector Report. This has been scored using expert opinion and the percentage reductions in productivity rather than the potential economic losses. The thresholds are approximately 0.1% and 0.5% of lost productivity using a temperature threshold of 28°C.
EN1	Energy infrastructure at significant risk of flooding	Number of electricity substations	H	1	10	R	This depends on the type of substation affected and the typical number of customers it supplies. Based on the information provided in the Energy Sector Report, these thresholds are relevant only for grid substations. For secondary or domestic substations the thresholds will be higher and for National Grid supply points the thresholds will be lower.
EN1b	Power stations at significant risk of flooding	Number of power stations	M	1	10	R	Similar to substations
EN1b	Power stations at significant risk of flooding	Capacity (MW)	M	100	1000	R	Estimate based on total generation capacity info for UK from Energy Sector report and consideration of how many people are likely to be affected (based on magnitude of consequences table from the Methods Report).
EN2	Energy demand for cooling	Cooling energy demand (MW)	H	100	1,000	R	Estimate based on the historical demand for electricity in the UK and temperature patterns - the highest peaks in demand are around an extra 1000 MW.
EN3	Heat related damage/disruption to energy infrastructure	n/a	L	n/a	n/a	n/a	Not assessed
EN4	Risk of restrictions in water abstraction for energy generation	% change	M	n/a	n/a	E	View based on Sector Report and discussion on reports with Government Departments

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
EN10	Energy transmission efficiency capacity losses due to heat - over ground	Class	H	1	2	C	These thresholds are given in the Energy Sector report
FL1	Number of people at significant risk of flooding	Number of people	H	100,000	1,000,000	M	Estimate based on consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL2	Vulnerable people at significant risk of flooding	Number of properties	M	10000	100000	M	Estimate based on present day figures (39,000 properties) from Flood and Coastal Erosion Sector Report and consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL4a	Agricultural land at risk of flooding	Area (ha)	H	~	~	E	See AG2
FL4b	Agricultural land at risk of regular flooding	Area (ha)	H	~	~	E	See AG3
FL6a	Residential properties at significant risk of flooding	Number of properties	H	50000	500000	M	Estimate based on present day figures (250,000 properties) from Flood and Coastal Erosion Sector Report and consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL6b	Expected Annual Damage (EAD) to residential property due to flooding	£ million	H	10	100	M	Based on magnitude of consequences table from the Methods Report (costs).
FL7a	Non-residential properties at significant risk of flooding	Number of properties	H	100000	200000	E	Expert view based on Sector Report.
FL7b	Expected Annual Damage (EAD) to non-residential property due to flooding	£ million	H	10	100	M	Based on magnitude of consequences table from the Methods Report (costs).
FL8a	Roads at significant risk of flooding	Length of motorway - km	H	10	20	R	Expert view based on Sector Report.
FL8a	Roads at significant risk of flooding	Length of A road - km	H	10	100	R	Expert view based on Sector Report.

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
FL8a	Roads at significant risk of flooding	Length of B road - km	H	100	200	R	Expert view based on Sector Report.
FL8a	Roads at significant risk of flooding	Length of minor road - km	H	500	1000	R	Expert view based on Sector Report.
FL8b	Railways at significant risk of flooding	Length of railway - km	H	10	100	R	Expert view based on Sector Report.
FL10	Water infrastructure at risk of flooding	n/a	H	n/a	n/a	n/a	Not assessed
FL11a	Power stations at significant risk of flooding	Number of power stations	M	1	2	M	Estimate based on consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL11a	Power stations at significant risk of flooding	Capacity (MW)	M	100	1000	M	Estimate based on total generation capacity info for England and Wales from Flood and Coastal Erosion Sector Report and consideration of how many people are likely to be affected.
FL11b	Substations at significant risk of flooding	Number of electricity substations	H	1	4	M	Estimate based on consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL12a	Hospitals at significant risk of flooding	Number of hospitals	M	1	3	M	Estimate based on consideration of magnitude of consequences table from Method Report, specifically number of people affected.
FL12b	Schools at significant risk of flooding	Number of schools	M	n/a	n/a	E	Classified as high due to the number of people potentially affected and using the methods table as a guide
FL13	Ability to obtain flood insurance for residential properties	Number of properties	M	~	~	E	See BU6
FL14a	Agricultural land lost due to coastal erosion	Area (ha)	H	5000	10000	M	Based on magnitude of consequences table from the Methods Report.

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
FL14b	Priority habitats lost due to coastal erosion	Area (ha)	H	50	500	E	Expert view based on Sector Report.
FL15	Flood risk for Scheduled Ancient Monument sites	Area (ha)	H	100	500	E	Expert view based on Sector Report.
FO1a	Forest extent affected by red band needle blight	Class	M	2	3	E	Magnitude classes specified in Forestry Sector Report
FO1b	Forest extent affected by green spruce aphid	Class	M	2	3	E	Magnitude classes specified in Forestry Sector Report
FO2	Loss of forest productivity due to drought	% change	M	10%	20%	R	Based on Sector Report
FO4a	Decline in potential yield of beech trees in England	% change (or is this change *1000m3/yr?)	M	10%	20%	R	Based on Sector Report
FO4b	Increase of potential yield of Sitka spruce in Scotland	Change (*1000m3/yr)	M	10%	20%	R	Based on Sector Report
HE1	Summer mortality due to higher temperatures	Number	H	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
HE2	Summer morbidity due to higher temperatures	Additional patient days per year ('000)	H	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
HE3	Extreme weather event (flooding and storms) mortality	Annual additional (number)	M	10	100	M	Based on magnitude of consequences table from the Methods Report.
HE4a	Mortality due to summer air pollution (ozone)	Annual additional (number)	M	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
HE4b	Morbidity due to summer air pollution (ozone)	Respiratory hospital admissions per year	M	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
HE5	Decline in winter mortality due to higher temperatures	Annual number (reduction)	M	100	1000	M	Current risks > 20,000 deaths per annum
HE6	Decline in winter morbidity due to higher temperatures	Annual patient days avoided per year	M	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
HE7	Extreme weather event (flooding and storms) injuries	Additional number of injuries	M	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
HE9	Sunlight/UV exposure	Number	L	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed. Also baseline information provided in the Health Sector Report
HE10	Effects of floods/storms on mental health	Additional number per year	M	100	1000	M	Based on magnitude of consequences table from the Methods Report, specifically numbers harmed.
MA1	Risk of Harmful Algal Blooms due to changes in ocean stratification	n/a	L	n/a	n/a	n/a	Too uncertain/no thresholds used
MA2a	Decline in marine water quality due to sewer overflows	MPN E Coli 100 g-1 FIL	M	100	1000	E	Magnitude classes specified in Marine & Fisheries Sector Report (qualitative response function), based on case study work
MA2b	Risks of human illness due to marine pathogens	n/a	L	n/a	n/a	n/a	Too uncertain/no thresholds used
MA3	Increased ocean acidification	Change in pH	M	0.1	0.2	R	View based on Sector Report, using methods table as a guide only

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
MA4a	Changes in fish catch latitude/centre of gravity (cod, haddock)	Distance shifted (km)	M	n/a	n/a	n/a	View based on Sector Report, using methods table as a guide only
MA4b	Changes in fish catch latitude/centre of gravity (plaice, sole)	Distance shifted (km)	M	n/a	n/a	n/a	View based on Sector Report, using methods table as a guide only
MA5	Opening of Arctic shipping routes due to ice melt	Number of days	M	30	90	R	View based on Sector Report, using methods table as a guide only
MA6	Northward spread of invasive non-native species	Possible habitat shift (km)	M	n/a	n/a	n/a	Too uncertain/no thresholds used
MA7	Potential disruption to shipping due to rough seas	Probability	L	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
MA8	Potential disruption to breeding of seabirds and intertidal invertebrates	Change in species range	M	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
MA9	Decline in productivity of 'cold water' fish and shellfish stocks	Spawning stock biomass (000s tonnes)	L	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
MA10	Disruption to marine ecosystems due to warmer waters	n/a	M	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
TR1	Disruption to road traffic due to flooding	Class	M	2	3	E	Magnitude classes specified in Transport Sector Report
TR2	Landslide risks on the road network	Class	M	2	3	E	Magnitude classes specified in Transport Sector Report
TR4	Cost of carriageway repairs due to high summer temperatures	Class	M	2	3	E	Magnitude classes specified in Transport Sector Report

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
TR5	Rail buckling risk	Annual number of rail buckles	H	500	5000	M	Number of rail buckles linked to costs using information provided in Transport Sector Report. Then linked this to magnitude of consequences table from the Method Report (costs).
TR5	Rail buckling risk	Annual cost (£000s)	H	10000	100000	M	Based on magnitude of consequences table from the Methods Report (costs).
TR6	Scouring of road and rail bridges		M	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
WA1	Warmer and drier conditions in the South East of England	Normalised variable	M	1	2	R	Thresholds calculated using standard deviation from 1961-90 climate mean, based on South East. Full details in Water Sector Report.
WA2	Lower summer river flows (Q95)	% change	M	-20	-30	R	Thresholds based on expert view.
WA3	Reduction in water available for public supply	Ml/d	M	250	2500	M	Thresholds based on costs calculated using the Method Report.
WA4	Change in household water demand	%	M	5	10	R	Thresholds based on expert view.
WA5	Public water supply-demand deficits	Ml/d	M	250	2500	M	Thresholds based on costs calculated using the Method Report.
WA6	Population affected by water supply-demand pressures	Number of people (000s)	M	30000	60000	R	View based on Sector Report, using methods table as a guide only
WA7	Insufficient summer river flows to meet environmental targets	Number	L	-1000	-2000	R	View based on Sector Report, using methods table as a guide only
WA7	Insufficient summer river flows to meet environmental targets	% change	L	-25	-50	R	View based on Sector Report, using methods table as a guide only
WA8	Number of unsustainable water abstractions (total)	% change	M	-20	-40	R	View based on Sector Report, using methods table as a guide only
WA8a	Number of unsustainable water abstractions (agriculture)	% change	M	-20	-40	R	View based on Sector Report, using methods table as a guide only

Metric code	Risk metric	Unit	Confidence	Low to medium	Medium to High	Type (Based on Method, Relative score or Expert opinion)	Narrative
WA8b	Number of unsustainable water abstractions (industry)	% change	M	-20	-40	R	View based on Sector Report, using methods table as a guide only
WA9a	Potential decline in summer water quality (point source pollution)	%	L	10	50	R	View based on Sector Report, using methods table as a guide only
WA9b	Potential decline in water quality due to diffuse pollution	n/a	L	n/a	n/a	E	View based on Sector Report, using methods table as a guide only
WA10	Combined Sewer Overflow spill frequency	n/a	L	n/a	n/a	E	View based on Sector Report, using methods table as a guide only

Appendix 3 Systematic Mapping

The aim of the systematic mapping was to identify key linkages between causes and consequences and the processes that lead to change. It was largely descriptive and did not seek to quantify the change in anything other than qualitative terms and without reference to specific future scenarios. The systematic mapping was also a process based method that only considered changes that may arise due to climate change. As a consequence, other drivers of change were not considered and risks that are a result of emergent system properties (such as collective societal response to the threat of climate change) were also not considered.

The approach used was a form of forward chaining. Starting with a top level cause (a change in a climate variable) the associated direct bio-physical impacts were identified. These impacts were then the causes for the next level and give rise to a new set of bio-physical impacts or socio-economic consequences, and so on. The mapping exercise focussed on identifying linkages between input variables (causes) and output variables (consequences) and a description of the linking process.

This has produced a network with around 2400 consequences, of which some 1300 are unique sector based consequences (once identical consequences with different attributes have been removed), which after consolidation across sectors were reduced to about 240 generic consequences. Each sector was found to link to all other sectors in some way or other. This highlights the strong interaction between sectors and the complexity of some of the interactions. There were also a number of feedbacks to earlier passes, including some climate drivers. In addition, several impacts recur over several passes.

The resultant mapping provides an extensive resource to explore and better understand many of the key cause-process-consequence links that have been identified for this CCRA. However, the complexity is such that it cannot be easily summarised and needs to be explored interactively. An illustration of the results of a query that produces a diagram small enough to be reproduced is shown in Figure 9.3.

The most frequent cause in all sectors relates to changes in flood waters (whether from inland or coastal sources). This is not unexpected because the initial or secondary impact of several climate variables (e.g. precipitation and sea level) is flooding of some form. This then leads to a number of further impacts (e.g. damage) in later passes. A number of consequences also relate to changes in flood waters, however, it is noticeable that the final consequence of many impacts relates to finance, e.g. capital or operational expenditure and revenue, particularly in the Business sector.

A full account of the systematic mapping is provided in the project report (CCRA, 2011).

Appendix 4 Tier 1 List of Impacts

This table lists all the impacts and consequences identified as part of this assessment, ordered by sector. They are presented by sector for each of the 11 sectors adopted. For each impact or consequence there is a pointer to the Chapter that it relates to.

Note that the impact names are the long titles, used in the Sector Report Tier 1 lists. For the text in the main body of this report and the Tier 2 list (see Appendix 5), names were shortened for ease of use.

Risk metric numbers relevant to each impact, where applicable, are provided so that they may be cross-referenced with the information within the figures and tables used in this report and Appendix 5.

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
Agriculture								
Horticulture	AG9; AG10	Changes in crop development (sowing dates, day length effects, growth rates, earlier springs, flowering dates, yield building, harvest dates). Wide range of consequences dependent upon crop/variety but tendency enhanced performance.						
Horticulture		Changes in crop rotation – influence the range of crop types in a rotation and the number of years e.g. potato rotation may get longer						
Horticulture	AG3	Pest and diseases – air borne pathogens influenced by changes in air temp and humidity – soil borne pathogens by soil temp, soil moisture, and winter kill effects (range of consequences dependent upon pathogen/pest characteristics but tendency will be for enhanced						
Horticulture		Weeds – changes in weed spectrums driven by winter survival, soil conditions, crop competition changes (range of consequences dependent upon species and environment but tendency will be for greater weed activity)						
Horticulture	AG1c	Crop yield – could increase or decrease dependent upon the crop/variety response to the predicted change (e.g. yield of heat/drought/waterlogging stress sensitive species/varieties depressed, yield of less sensitive species/varieties enhanced)						
Horticulture		Crop quality – could increase or decrease dependent upon crop/variety response to the predicted change (as 5 above)						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
Horticulture		Storage quality of outputs – higher temp and relative humidity could affect storability and/or need for storage (refers especially to ambient stored crops, removing field heat may be a bigger problem for many crops if average temps are higher)						
Horticulture		Stress factors – changing temperatures could increase risks associated with frost damage, drought and field water logging (wide range of effects dependent upon crop but tendency will be for deleterious consequences)						
Horticulture		Increase in soil biological activity due to higher temperatures leading to higher rates of organic matter breakdown						
Horticulture		GHG emissions - increased due to enhanced soil biological activity from warmer soils, releasing greater quantities of carbon dioxide, methane, nitrous gases						
Horticulture		Carbon sequestration – higher plant growth rates should sequester more carbon, mitigating some effects of 10 above						
Horticulture		Leaching – increased risk of nutrient and pesticide loss due to more frequent high intensity rainfall events						
Horticulture	AG11	Runoff / erosion risks - increased risk due to more frequent high intensity rainfall events						
Horticulture	AG4	Drought effects (soil moisture availability) – increased risk due to higher evapotranspiration rates combined with reduced summer rainfall						
Horticulture		Water logging effects (seasonal, anaerobic conditions) due to due to more frequent high intensity rainfall events						
Horticulture	AG2b	Flooding – increased risk due to more frequent extreme rainfall events, both in winter and summer						
Horticulture		Salinity – increased risk of inundation of low lying land on coastal regions due to sea level rise						
Horticulture		Trafficability/access/field operations – increased risk due to changing soil conditions (too dry/too wet), particularly in late summer and spring						
Horticulture		Subsidence/landslides – increased risk due to over abstraction						
Horticulture		Agricultural land classification and crop suitability – changes in soil and agroclimatic conditions affecting soil and crop suitability						
Horticulture		Biodiversity / wildlife changes (changes in environmental conditions will influence range of spp supported be that plant, animal, birds, microbial etc)						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
Horticulture		Migration patterns of farmland birds (e.g. already noted in Breckland that succession of mild winters has resulted in an increasing number of traditionally migratory Stone Curlew staying all year)						
Horticulture		Breeding habits / reproductive behaviour of species (e.g. storms could wipe out newly hatched, vulnerable bird spp, stimulating secondary nesting by parents, warmer winters could increase survival rates of late-born young, longer summers could increase life expectancy)						
Horticulture		Air quality – especially GHG – increasing CO_2 levels, good for crop growth but bad for global warming						
Horticulture		Wind effects – changes in direction and speed could influence distribution of pathogens and vectors, higher wind speeds could increase wind erosion of vulnerable soils, lower speeds could reduce dispersal of contaminants						
Horticulture		Water resources –availability for direct abstraction could change due to reduced runoff and recharge, leading to more frequent low flows and licence restrictions						
Horticulture	AG5	Water demand – pattern of irrigation abstraction could change with existing crops needing more water, new crops needing irrigation and seasonal changes in the timing of abstraction						
Horticulture		Water quality – more frequent low flows could increase the micro-biological risks associated with abstraction downstream from sewage treatment works (STWs)						
Horticulture		Heat stress on workers – e.g. changing work patterns, labour costs						
Horticulture		Biodiversity / wildlife changes (changes in environmental conditions will influence range of spp supported be that plant, animal, birds, microbial etc)						
Horticulture		Migration patterns of farmland birds (e.g. already noted in Breckland that succession of mild winters has resulted in an increasing number of traditionally migratory Stone Curlew staying all year)						
Horticulture		Increase in carbon sequestration due to plant growth						
Arable	AG9; AG10	Changes in crop development (sowing dates, day length effects, growth rates, earlier springs, flowering dates, yield building, harvest dates). Wide range of consequences dependent upon crop/variety but tendency enhanced performance.						
Arable		Changes in crop rotation – influence the range of crop types in a rotation and the number of years e.g. potato rotation may get longer						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
Arable	AG3	Pest and diseases – air borne pathogens influenced by changes in air temp and humidity – soil borne pathogens by soil temp, soil moisture, and winter kill effects (range of consequences dependent upon pathogen/pest characteristics but tendency will be for enhanced						
Arable		Weeds – changes in weed spectrums driven by winter survival, soil conditions, crop competition changes (range of consequences dependent upon species and environment but tendency will be for greater weed activity)						
Arable	AG1a; AG1b	Crop yield – could increase or decrease dependent upon the crop/variety response to the predicted change (e.g. yield of heat/drought/waterlogging stress sensitive species/varieties depressed, yield of less sensitive species/varieties enhanced)						
Arable		Crop quality – could increase or decrease dependent upon crop/variety response to the predicted change (as 5 above)						
Arable		Storage quality of outputs – higher temp and relative humidity could affect storability and/or need for storage (refers especially to ambient stored crops, removing field heat may be a bigger problem for many crops if average temps are higher						
Arable		Stress factors – changing temperatures could increase risks associated with frost damage, drought and field water logging (wide range of effects dependent upon crop but tendency will be for deleterious consequences)						
Arable		Increase in soil biological activity due to higher temperatures leading to higher rates of organic matter breakdown						
Arable		GHG emissions - increased due to enhanced soil biological activity from warmer soils, releasing greater quantities of carbon dioxide, methane, nitrous gases						
Arable		Carbon sequestration – higher plant growth rates should sequester more carbon, mitigating some effects of increased GHG emissions, above.						
Arable		Leaching – increased risk of nutrient and pesticide loss due to more frequent high intensity rainfall events						
Arable	AG11	Runoff / erosion risks - increased risk due to more frequent high intensity rainfall events						
Arable	AG4	Drought effects (soil moisture availability) – increased risk due to higher evapotranspiration rates combined with reduced summer rainfall						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
Arable		Water logging effects (seasonal, anaerobic conditions) due to due to more frequent high intensity rainfall events						
Arable	AG2a	Flooding – increased risk due to more frequent extreme rainfall events, both in winter and summer						
Arable		Salinity – increased risk of inundation of low lying land on coastal regions due to sea level rise						
Arable		Trafficability/access/field operations – increased risk due to changing soil conditions (too dry/too wet), particularly in late summer and spring						
Arable		Subsidence/landslides – increased risk due to over abstraction						
Arable		Agricultural land classification and crop suitability – changes in soil and agroclimatic conditions affecting soil and crop suitability						
Arable		Biodiversity / wildlife changes (changes in environmental conditions will influence range of spp supported be that plant, animal, birds, microbial etc)						
Arable		Migration patterns of farmland birds (e.g. already noted in Breckland that succession of mild winters has resulted in an increasing number of traditionally migratory Stone Curlew staying all year)						
Arable		Breeding habits / reproductive behaviour of species (e.g. storms could wipe out newly hatched, vulnerable bird spp, stimulating secondary nesting by parents, warmer winters could increase survival rates of late-born young, longer summers could increase life expectancy)						
Arable		Air quality – especially GHG – increasing CO_2 levels, good for crop growth but bad for global warming						
Arable		Wind effects – changes in direction and speed could influence distribution of pathogens and vectors, higher wind speeds could increase wind erosion of vulnerable soils, lower speeds could reduce dispersal of contaminants						
Arable		Water resources –availability for direct abstraction could change due to reduced runoff and recharge, leading to more frequent low flows and licence restrictions						
Arable	AG5	Water demand – pattern of irrigation abstraction could change with existing crops needing more water, new crops needing irrigation and seasonal changes in the timing of abstraction						
Arable		Water quality – more frequent low flows could increase the micro-biological risks associated with abstraction downstream from sewage treatment works (STWs)						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
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Arable		Heat stress on workers – e.g. changing work patterns, labour costs						
Arable		Biodiversity / wildlife changes (changes in environmental conditions will influence range of spp supported be that plant, animal, birds, microbial etc)						
Arable		Migration patterns of farmland birds (e.g. already noted in Breckland that succession of mild winters has resulted in an increasing number of traditionally migratory Stone Curlew staying all year)						
Arable		Increase in carbon sequestration due to plant growth						
Arable		Changes to levels of pollination affecting crop yield						
Livestock		Changes in crop (grass and fodder crops) development – sowing dates – day length effects – growth rates – earlier springs – flowering dates – yield building – harvest dates						
Livestock		Crop rotations in mixed farming systems						
Livestock	AG3	Plant pest and diseases – air borne pathogens influenced by air temp and humidity – soil/pasture borne pathogens by soil temp, soil moisture, winter kill effects						
Livestock		Weeds – changes in weed spectrums driven by winter survival, soil conditions, crop competition changes						
Livestock	AG1	Crop yield – could increase or decrease dependent upon crop/variety response to changes						
Livestock		Crop quality – could increase or decrease dependent upon crop/variety response to changes						
Livestock		Crop stress factors – high temp/low temp (frost)/drought/waterlogging/humidity						
Livestock	AG2c	Flooding – increased risk due to more frequent extreme rainfall events, both in winter and summer. This will impact on moving animals from in and outdoors and require adequate housing in these emergencies.						
Livestock		Salinity – increased risk of inundation of low lying land on coastal regions due to sea level rise. Coastal livestock systems could be compromised due to land erosion and/or impact of increased salinity of land						
Livestock		Trafficability/access/field operations – increased risk due to changing soil conditions (too dry/too wet), particularly in late summer and spring. Impacts on the ability to graze animals consistently during these periods						

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Livestock		Subsidence/landslides – increased risk due to over abstraction. Impacts on upland systems and the management of animals and the land						
Livestock		Threat to some systems that may shift from livestock production to crop. - Agricultural land classification and crop suitability – changes in soil and agroclimatic conditions affecting soil and crop suitability. Improvement of land classification from grass						
Livestock		Biodiversity / wildlife changes (changes in livestock systems will impact on the ability of farmers to maintain different ranges of habitats – threat for current, opportunity for new biodiversity indicators)						
Livestock		Migration patterns of farmland birds						
Livestock		Breeding habits / reproductive behaviour of species						
Livestock		Air quality – especially GHG. Different population dynamics and spread of differing livestock systems will impact on the ability to livestock systems to produce GHG emissions						
Livestock		Wind effects – in exposed pasture based systems (e.g., hill) there may be unfavourable impacts of higher winds on pasture on hills (erosion, quality, competitor plants, lodging)						
Livestock	AG4	Water resources – availability (changing flows, low flows, groundwater recharge) Competition for water from other activities (including agriculture) could limit availability to livestock at critical time						
Livestock	AG6	Water demand – irrigation abstraction (timing, volume). Irrigation less of an issue with many of UK livestock production systems. However for those that may rely on higher energy crops (not grass) it may become an issue						
Livestock		Water quality – low flows, micro-biological risks						
Livestock		Opportunity for improved pasture/fodder quality from currently marginal land categories - - Agricultural land classification and crop suitability – changes in soil and agroclimatic conditions affecting soil and crop suitability. Improvement of land classification						
Livestock		Biodiversity / wildlife changes (changes in livestock systems will impact on the ability of farmers to maintain different ranges of habitats – threat for current, opportunity for new biodiversity indicators)						
Livestock		Migration patterns of farmland birds						

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Livestock		Breeding habits / reproductive behaviour of species						
Livestock		Plant pest and diseases – air borne pathogens influenced by air temp and humidity – soil/pasture borne pathogens by soil temp, soil moisture, winter kill affects						
Livestock		Crop yield – could increase or decrease dependent upon crop/variety response to changes						
Livestock		Crop stress factors – high temp/low temp (frost)/drought/waterlogging/humidity						
Livestock		Loss of native breeds in favour of more breeds more resistant to new disease challenges and/or temperature changes						
Livestock		Changes in livestock breeding season – likely shift in seasonality						
Livestock	AG7a; AG7b	Livestock yield and product quality – livestock performance impacted by changes in feed supply quality and/or unfavourable physiological impacts (intake, fertility, health) by less favourable prevailing weather conditions						
Livestock	AG8	Ability of “weaker” animals (newborns and/or ill animals) to survive in newer weather conditions						
Livestock		Impact on ability to transport during particular weather scenarios of animals due to regulations						
Livestock		Changes in management practices (e.g., periods indoors, shearing) – threat as animals need to be more “managed”, neutral if there is simply a time shift of when current standard farm practices occur in the year						
Livestock	AG3	Livestock pest and diseases –pathogens influenced by air temp and humidity – soil/pasture borne pathogens by soil temp, soil moisture, winter kill effects (threat as conditions may be come more favourable for some pests and diseases, opportunity as the con						
Livestock		Changes in management practices (e.g., periods indoors, shearing) – threat as animals need to be more “managed”, neutral if there is simply a time shift of when current standard farm practices occur in the year						
Livestock		Pest and diseases –pathogens influenced by air temp and humidity – soil/pasture borne pathogens by soil temp, soil moisture, winter kill effects (threat as conditions may be come more favourable for some pests and diseases, opportunity as the conditions may become less favourable						

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Livestock		Use of more on farm energy to help keep animals in their thermo-neutral zone.						
Livestock	AG6	Increase in water use by animals in dry periods						
Livestock		Loss of particular landscapes and associated rural communities, previously managed by livestock keepers (e.g., hill systems)						
Livestock		Human food supply/security						
Livestock		Poaching of fields from livestock traffic						
Livestock	AG8	Livestock stress factors – high temp/low temp and/or humidity – heat stress related to higher temperatures and humidity, cold stress related to lower temperatures exacerbated by wet weather and wind						
Livestock		Livestock stress factors – high temp/low temp and/or humidity – heat stress related to higher temperatures and humidity, cold stress related to lower temperatures exacerbated by wet weather and wind						
Livestock		Ability to provide sufficient resources for animals during extreme events (snow, frost, drought).						
Livestock		Increased costs of energy						
Biodiversity and Ecosystem Services								
Range Shifts	BD5	Increase in species unable to track 'climate space'						
Range Shifts		Increased occurrence of species unable to find suitable microclimate						
Range Shifts		Increased opportunities for new (priority) species						
Seasonal shifts and changes in phenology		Increased asynchrony between a species breeding cycle & its food supply						
Seasonal shifts and changes in phenology		Change in life cycles (esp. insects)						
Seasonal shifts and changes in phenology	BD9	Changes in species migration patterns						
Changes in pests and diseases	BD3	Increased risks from pests						
Changes in pests and diseases	BD4	Increased risks from diseases						
Changes in pests and diseases		Increased risk from novel pathogens						
Changes in interactions & community structure	BD11	Generalist species outcompete specialist species						

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Changes in interactions & community structure		Changing competition between C3 & C4 photosynthesis plants						
Changes in interactions & community structure		Increase in changing interactions due to differences in growth/survival rates						
Changes in interactions & community structure		Change in interactions between trophic levels						
Changes in interactions & community structure		Changes in genetic diversity						
Changes in interactions & community structure		Impacts of changing nutrient supply						
Geomorphological and hydro-ecological habitat change	BD2	Increase in coastal evolution impacting on intertidal, grazing marsh etc.						
Geomorphological and hydro-ecological habitat change		Increased floodplain evolution						
Geomorphological and hydro-ecological habitat change	BD10	Increase in water temperature and stratification of water bodies						
Geomorphological and hydro-ecological habitat change		Decline in snow cover leading to loss of certain habitats						
Geomorphological and hydro-ecological habitat change		Increase in impacts on spawning beds due to high flows						
Geomorphological and hydro-ecological habitat change	BD14	Increase in Biological Oxygen Demand impacts due to low flows						
Geomorphological and hydro-ecological habitat change		Increase in saline intrusion						
Geomorphological and hydro-ecological habitat change	BD1	Increased soil moisture deficits & drying						

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Geomorphological and hydro-ecological habitat change		Increased soil erosion						
Geomorphological and hydro-ecological habitat change		Increased waterlogging						
Habitat disturbance by extreme events		Increase in windthrow during storms						
Habitat disturbance by extreme events	BD7	Increase in major coastal flood/reconfiguration						
Habitat disturbance by extreme events		Increased occurrence of major fluvial floods						
Habitat disturbance by extreme events	BD16	Increase in occurrence of major drought events						
Habitat disturbance by extreme events		Increased loss of niche space						
Habitat disturbance by extreme events	BD12	Increase number of outdoor fires per year						
Changes to ecosystem processes/function		Changes in primary productivity						
Changes to ecosystem processes/function	BD8	Increased detrimental changes in Soil Organic Carbon						
Changes to ecosystem processes/function		Increased rate of decomposition & nutrient cycling						
Changes to ecosystem processes/function		Changes in soil microbial activity						
Indirect effects via land use change		Increased agricultural intensification (i.e. human use of fertiliser) affecting biodiversity						
Indirect effects via land use change		Increase in agricultural abandonment						

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Indirect effects via land use change	BD13	Increased risk of water pollution and eutrophication						
Indirect effects via land use change		Increase in impacts of atmospheric deposition (e.g. N, SO_2, O_3)						
Indirect effects via land use change	BD6	Increased risk to biodiversity from climate mitigation measures (positive/negative)						
Indirect effects via land use change		Changes in priority habitats (BAP habitats) related to coastal defences						
Indirect effects via land use change	BD15	Decrease in water available to the environment due to increased societal water demand						
Built Environment								
	FL6, FL7, FL13, HE3, BU6	Increase in flooding of coastal areas, including coastal archaeology and landscapes, greenspace						
	FL6, FL7, FL13, HE3, BU6	Increase in fluvial flooding of urban areas and buildings						
	FL6, FL7, FL13, HE3, BU6	Increase in pluvial flooding in urban areas						
	FL6, FL7, FL13, HE3, BU6	Increase in flash flooding						
		Soil erosion						
		Increase in landslips						
		Increase in rainwater penetration of buildings						
		Overwhelming of roofs and rainwater goods, particularly in historical buildings						
		Structural damage to buildings						
	FL6, FL7, FL13, HE3, BU6	Increase in surface water discharge from buildings						
		Tree damage/loss						
		Storm damage at construction sites						

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	WA5, WA6	Impacts on water infrastructure, water shortage						
	WA5, WA6	Decrease in water availability						
	BE2	Drought impacts on infrastructure						
		Shortage of water affecting construction						
		Reduced condensation and deterioration						
		Dry conditions in gardens help promote 'urban creep'						
		Increase in tree roots attacking sewerage systems						
	BE5	Change in condition of urban greenspaces						
	FL6, FL7, FL13, HE3, BU6	Flooding during construction and difficulties around unprotected on-site storage of materials						
	FL6, FL7, FL13, HE3, BU6	City inundation						
	FL6, FL7, FL13, HE3, BU6	Flooding of development land						
	BE3	Increase in overheating of buildings						
	BE1	Increase in external overheating in high density areas						
	BE9	Less demand for heating in the winter						
	WA5, WA6	Increase in demand for water in buildings						
		Increase in damage to fabric of some buildings - heat stress						
		Invasions and changes in survival of species leading to changes in species balance, affects strategic and local planning						
		Deterioration of some materials (timber shrinkage, paint)						
		Pest infestation in buildings						
		Increase in fractured stonework and burst pipes, rainwater goods and radiators						
		Less damage to buildings from frost or snow loading						
		Waste management e.g. change to processes, increased vermin activity - negative impact						
		Waste management e.g. change to processes, increased vermin activity - negative impact						
		Increased use of outdoor spaces for informal recreation; variations in use						
		Overheating of construction sites						

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		Waste management e.g. change to processes - opportunity						
		Reduced interruptions to construction processes						
	BE1	Intensification of nocturnal urban heat island effect						
	BE2	Increase in ground movement (heave) and subsidence of clay soils						
		Change in species balance with changed soil conditions						
		Increase in shrinkage of tree roots due to drying and swelling due to rehydration						
		Increase in fire starting or spreading in buildings / increased fire fighting						
		Increase in damp, mould and insect pests in buildings						
		Increase in damp, mould and insect pests in buildings						
		Impact on sulphates in soils						
	BE5	Green spaces become parched						
		Construction site management will be affected e.g. too muddy for heavy machinery						
		Increase in on-site dust generation - construction						
		Air quality affected; changes in the frequency, spatial distribution and concentrations of some airborne allergens such as pollen; increase in frequency and intensity of air pollution episodes during warm seasons (mainly high ground-level ozone concentrations).						
		Increase in the occurrence of plant, equipment, vehicles, etc overheating as well as possible reduction in conductor ratings.						
		Increased run off may mobilise contaminant transport, especially during extreme events.						
		Lightning strikes affecting trees, buildings, power lines, etc.						
		More widespread or more frequent mortality of newly planted trees if severe droughts become more frequent.						
Business, Industry & Services								
	BU1	Financial sector fails to mainstream climate change risk considerations into decision making or only focuses on extreme events, leading to decline in financial performance, credit worthiness, equity, guarantees, plus additional						

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		exposures.						
	BU2	Coastal erosion and flooding of natural and tourist assets (i.e. hotels etc) from sea level rise and storm-surge.						
	BU3	Impact on operations from lack of available water resources either through shortage or competing demands of others (including conflict with other users?).						
	BU4	Sea level rise, coastal inundation and erosion leads to lost assets and increased CAPEX/ OPEX						
	BU5	Operational disruption and reliability of ICT as a result of high temperatures and heatwaves						
	BU6	Flood and coastal erosion impacts on property, impacting mortgages, insurance premiums, etc						
	BU7	Insurance and reinsurance issues for some assets due to frequent impact from extreme events, with risk of additional and larger payouts (at tails of distribution) and financial burden on insurance industry.						
		Incremental climate change may mean that there is an underestimation of decommissioning liabilities and end of life costs. This includes dealing with on-site landfills, for example.						
	BU8	Changing holiday trend leads to new markets						
		Increased air temperature leads to increased energy usage for cooling systems for machinery. Where not possible, machinery may run less efficiently.						
	BU10	Loss of staff hours due to high internal temperatures						
		Seasonal precipitation and water temperature effects wastewater treatment systems						
	BU9	Disruption from flooding of assets, transport links and supply chain						
		Increased scrutiny of investments and loss of reputation due to interplay between environmental, community and climate change pressures						
		Incremental climate change may lead to higher risk of conflict and environmental incidents which could affect environmental and social licence to operate with loss of consumer confidence.						
		Extreme events leading to loss of output through affects across supply chain						

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		Flooding (fluvial or pluvial) affects leads to loss/ temporary failure of assets and delays with increased CAPEX/ OPEX						
		Reliability and security of energy supply may be impacts as a result of heatwave, storms, flood, etc.						
		Increasing temperature will affect the storage and shelf life of some products leading to increased storage management and costs. May also affect supply chains.						
		Milder winters reduced demand for energy (including hydrocarbon based fuels) and impact profits						
		Climate change may affect price and availability of raw product used in food manufacturing						
		Increased frequency of extreme events may lead to price volatility affecting suppliers						
		Reduced precipitation and increased evaporation leads to stress on water resources and declining quality which creates specific conflict with other water users (public and other industries). Important for UK companies overseas.						
		Extreme weather and changes to rainfall patterns impacts storage, supply and disposal of volatile and hazardous chemicals and could cause environmental compliance issues due to accidental and increased diffuse releases of contaminants, changes to pathways						
		Increasing temperatures could affect outdoor workers from heat stress. Also UV exposure on cloudless days.						
		Flash flooding on impermeable ground around facilities may affect local communities downstream and surrounding environmental quality						
		Increased demand for air conditioning leads to additional CAPEX/ OPEX						
		Loss of natural resource that attracts tourists leading to loss of revenue and requirement to shift assets						
		Damage to corporate reputation from increased scrutiny of lack of management of climate change risks						
		ESIA does not take into account climate change, either due to national or lender requirements. Lack of sufficient consideration of climate change may lead to negative reputation, effects on lender/ proponent contracts and increased CAPEX/ OPEX						
		Increased electricity outages and increased levels of competition for energy resource compared with other users demands						

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		Increased frequency of extreme events increase disruption (i.e. road/rail) and reduces opportunity for transport (particularly air and sea) affecting transport of tourists						
		Long-term effects on infrastructure that supports tourism leads to disruption and loss of revenue						
		Incremental climate change leads to litigation between contracted parties and contracts do not adequately foresee and manage climate change risks						
		Extreme weather (including storms, lightning, etc) damaging assets leading to increased CAPEX/ OPEX						
		Extreme events may affect third-party infrastructure and utilities that will lead to reduced production capacity, operational disruption and delays in returning to full production, with potential for financial loss.						
		Increased air and sea temperatures leads to the opportunity of new maritime routes which may provide more economic routes for bulk cargoes.						
		Extreme events may lead to increased insurance costs						
		Increased air temperature leads to changes in consumer demands with increase in sales of products that sell better in warmer weather (opportunity)						
		Water resource abstraction licences revoked or reduced during droughts. May lead to closure or reduced operations due to secondary effects, such as maintaining dust suppression compliance limits.						
		Increased temperatures could affect air quality (e.g. Dust and GL ozone), leading to respiratory issues in exposed workers.						
		Decreased energy costs from reduced indoor space warming in winter						
		Incremental climate change may exacerbate negative impacts on neighbouring communities, with litigation, increased security risks.						
		For UK based multinational, climate change may affect workforce in developing countries.						
		Increased regulation of climate change risk in investment delays commercial arrangements						
		Warmers sea temperatures increases non-native marine species - hazard to swimmers						
		Warmer sea temperature promote algal growth affecting coastal destinations						
		Warmer sea temperature benefits swimming/ coastal tourism						

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		Coastal Tourism increased as temperature rises						
		Increased opportunity (or risk) and demand for outdoor leisure, sport and tourism						
		Increased air temperature leads to changes in consumer demands with reduction in sales of products that sell worse in warmer weather.						
		Extreme weather causes HSE and labour compliance issues, with risk of employer and public liability cover being compromised where climate change not included in HSE risk assessments						
		Increase market for climate resilient property may increase (benefit) property values						
		Increasing temperatures leading to increased maintenance costs (CAPEX/OPEX), arising from thermal stressing of pipe work which leads to leaks, storage tank pressures, etc.						
		Water scarcity leads to effects on procurement of raw agriculture inputs, including animals-based inputs through higher feed prices.						
		Cultivation of fish, shellfish and aquatic plants, dairy and poultry yields particularly vulnerable to climate change lead to increased OPEX, loss of market share through rising costs and loss of revenue.						
		Increased demand for urban green/ blue space as temperatures increase leads to increase sales and additional CAPEX						
		Business opportunity to develop new materials, biotechnology, energy efficiency and carbon capture technology to aid adaptation and transition to low carbon economy						
		Increased product demand and financial gain from increased range of weather-related products (e.g. weather derivatives)						
		Increased opportunities for reinsurance due to increased likelihood of weather related claims						
		Migration of pests and diseases into work area. Potential to affect HSE performance.						
		Work force heat stress leading to operational inefficiency and potential litigation						
		Opportunity for reduced equipment specification and costs from reduced ice loading or cold temperature running requirements						

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		Reduced precipitation will affect runoff and fluvial flows. Insufficient dilution may lead to pollution of water courses and affect local communities and habitats						
		Canal and river navigation difficult to maintain during drought.						
		Increased awareness of climate change means products that are 'greener' and have credible climate change benefits will sell better (opportunity)						
		Increased winter rainfall/ extreme precipitation and soil moisture change through the year may cause subsidence, heave, erosion and landslip with risk to assets, supply chain, etc.						
		More intense rainfall causes rain penetration in buildings affecting structural integrity and value of property.						
		Loss of assets and increased maintenance due to extreme precipitation						
		Extreme events may lead to wholesale and retail energy price volatility						
		Cloud cover increased natural light in buildings leading to lower OPEX/ CAPEX						
		Increased legal exposure and food safety becomes more on an issue in a warmer climate.						
		Increased frequency of lightening strikes						
		Acid mine drainage scenarios become more complicated to manage as groundwater flow regimes change both annually and seasonally						
		Sea level rise reduces air gap on offshore assets leading to closure or CAPEX to raise asset						
		Incremental climate change leads to regulatory regime change in UK which may make UK companies less competitive than less stringent countries. Industry moves abroad.						
		During extreme events emergency response could be compromised leading to evacuation times increased and worker HS issues.						
		Climate impacts on communities may lead to more stringent controls leading to increased risk of litigation.						
		Incremental climate change leading to increased costs of goods and services, and reduced availability of certain raw materials and packaging leading to decreased profit margins						
		Sea level rise and coastal change may affect sector businesses that rely on marine transport and port facilities leading to downtime, loss of productions and HSE						

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		implications						
		Incremental climate change may affect maritime boundaries and enhance geo-political risk to UK companies working overseas.						
		Incremental climate change may lead to an opportunity for diversification of businesses. Diversification of energy mix.						
		Change in bumblebee disease affecting soft fruit industry						
		Availability of calm weather windows						
		Indoor air quality affected by outdoor air quality as buildings ventilated by external air. Also drying of building materials leading to release of solvents.						
		Bacterial growth						
		Reduced damage to infrastructure due to less frost and snow loading						
		Reduced condensation related building damage and deterioration						
		Building drying may lead to damage of some building materials						
		Drier conditions mean increase in fire hazard.						
		Increased lightning strikes could affect tourism; personnel, visitors and assets.						
		Changes in land and marine borne pathogens and pollutants could result in a loss or movement of commercial fish stocks and priority species. Certain commercial plant stocks may also become more vulnerable.						
		The melting of arctic sea ice may allow ships to pass safely on a regular basis though arctic waters.						
		Generation of greater amounts of VOCs, and therefore to increased tropospheric ozone.						
		Water logging effects (seasonal, anaerobic conditions).						
Energy								
		Drier summers, heightened risk of subsidence and heave, leaving structures vulnerable to damage or collapse						
		Cold related damage to infrastructure						
		Increased demand for water supply (pumping, desalinisation, recycling, water transfers) - competition with other major consumers						

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	EN1	Flood risk to infrastructure (plant, substations and underground transmission infrastructure)						
		Changes to heating demand (time spent indoors)						
	EN4	Decreased summer river flow reducing hydro (run of river) or affecting water abstraction for large power stations						
		More frequent spills from dams						
		Higher/lower illumination/ cloud cover change lighting / time indoors.						
		Hydroelectricity availability (large and run of river)						
		Changes in resource available for solar power, PV						
		Decreased winter heating demand / reduced fuel poverty						
		Reduction in cold weather related disruption, and cold related problems for transmission and cables						
	EN3	Overheating of equipment (transformers and transmission lines)						
	EN2	Increased summer cooling demand (including refrigeration)						
		Loss of efficiency in power station cooling process						
	EN2	Higher summer peak electricity supply (reserve margin levels)						
	EN10	Decrease in efficiency of urban power cables beneath the ground surface						
		Change in growing season characteristics of existing vegetation types and changes in the type of vegetation that can grow in a particular area						
		Decrease in efficacy of generation where cooling relies on river water						
		Less air can be drawn into turbines and less fuel can be burned						
		Lifestyle changes such as changed working patterns, with a period of inactivity during the hottest part of the day						
	EN10	Transmission efficiency - lower capacity of electrical transmission as they are derated in order to maintain appropriate operating conditions						
		Higher work for compressors on gas pipelines						
	EN3	Increased incidence of infrastructure problems to electrical transmission grid						
	EN2	Increased inequality for summer cooling availability (‘cooling’ poverty)						
		Changes in geographic distribution of population within the UK						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Changes in biofuels yields, mainly positive (CO_2 fertilisation, extended growing season) although some negative effects						
	EN1	Increased rate of inundation in vulnerable areas, increased area considered vulnerable e.g. UK coastal power station sites						
	EN1	Flooding of transport links						
		Changes in potential for marine renewables (offshore wind, wave, tidal)						
		Increases in wind generation (kWh)						
		Increased wind load factor						
		Storm damage to infrastructure (overhead transmission line (power cuts) from fallen trees, wind damage)						
		Storm damage to wind turbines						
		Maintenance of excavation, cable repairs and pipe work may be more difficult						
		Increases in lightning could decrease the resilience of the electricity networks						
		Increase in coastal and river bed erosion exposing gas infrastructure						
		Changes in heating demand						
		Changes in fuel moisture - faster drying increasing fire hazard.						
		Buildings more likely to overheat; if energy industry buildings (e.g.: power stations) overheat then this impacts on service provision						
Flood and Coastal Erosion								
		A slight increase in the number of mine water outbreak events						
		Change in recreational activities or amenities						
		Change in recreational activities or amenities						
	(BD2, BD7)	Changes to coastal processes						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	City inundation						
	(BD2, BD7)	Coastal squeeze						
	FL8, FL11, FL12 (TR1, TR6, BU5)	Damage to critical infrastructure						
		Damage to reservoirs						

			Relevant Chapter(s)					
			Most relevant					
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			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9, WA10)	Dry weather drainage blockage						
	FL13 (BU6, BU7)	Failure of the insurance industry						
		Flooding of contaminated sites and waste management sites						
		Forced movement of population						
		Groundwater flooding						
		Harbours can take in larger ships						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9, WA10)	Increase in surface water flooding						
		Increase in surface water flooding						
		Increase in vegetation in river channels						
	FL14	Increased coastal erosion						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Increased exposure for certain coastlines						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Increased overtopping of coastal defences by waves						
		Increased pumping costs (land drainage)						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Increased risk of inland river flooding						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Increased tidal flooding - population flooded						
		Inland erosion and accretion, leading to loss of river banks, blockages and consequent flooding.						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9, WA10)	Intra-urban flooding						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Land lost (area flooded or submerged)						
	FL15	Loss of archaeological or cultural importance						
	(BD2, BD7)	Loss of ecosystems						
	(BU2, BD7)	Loss of natural assets (beach/dune)						
	(BD2, BD7)	Loss of wetland						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Major sea level rise, > 1 metre						
		May delay onset of flood season						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	More frequent operation of flood barriers, leading to reduction in reliability and increased chance of failure.						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	More overtopping of defences leading to more defence failures. Drying of flood banks in summer leading to increased chance of failure						
		More summer convective storms and flooding						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Permanent sea breaches						
	(BD2, BD7)	Reduction in ecosystem services						
		Reduction in snow related flood events						
		Resettlement						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Restriction or tide-locking of drainage outfalls						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9)	Salinity intrusion						
	FL1, FL2, FL4, FL6, FL7 (HE3, HE7, HE10, BU2, BU4, BU9, WA10)	Sewer flooding						
		Slippage risk to soil dams						
		Tidal flooding threatening the stability of estuaries shores						
Forestry								
		Increase in productivity of some species e.g. for biomass production						
		Denser canopies						
		Serious damage to trees for example stem increment of beech; serious damage to tree stands						
		Oxidation of peatlands						
		Increase in grass and forest fires / increased fire fighting						
		Decrease in snow damage (although the remaining snow may be 'wetter' and cause more damage						
	FO2	Drought during period of woody growth						
	FO2	Newly planted trees threatened						
		Increase in localised flooding, channel scour, soil erosion and landslipping						
		Water tables raised enough to kill tree roots						
		Waterlogging of soils						
	FO4	Limits the current range of tree species that can be grown on droughty soils						
	FO4	Changes in species suitability						
	FO1b	Damaging effects of pests exacerbated						
	FO4	Migration of tree species/loss of native tree species in southern England						
		Biodiversity loss						

			Relevant Chapter(s)					
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			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Potential reduction in some of the damaging effects of pests						
		Loss of habitat (although very little woodland at risk from saline incursion						
		Increase in 'weed' species						
		Winter chilling requirements for flowering or seed germination not met						
		Increase in emission of volatile organic compounds from trees						
		Earlier budburst leading to increased damage by late frosts						
		Reduction in winter cold damage (although reduced hardening could reverse this benefit)						
		Reduction in cold-associated mortality of insect pest, deer and squirrel populations						
		Potential for range of new species						
		Increase in delayed or incomplete winter hardening						
	FO1a	Increase in pests and disease and activity						
		Catastrophic windthrow						
		Loss of mature woodland habitat						
		Possible reduction in the window for lifting nursery stock						
		Change in soil organic carbon						
		Increase in invasive flora and fauna						
		Urban green spaces become parched and therefore have reduced cooling capacity						
		Changes in lifestyle patterns and the natural environment affecting tourism visits and movements within the UK.						
Health								
	HE1	Increased summer mortality						
	HE5	Reduced winter mortality						
		Exposure of medicines (or other medical and laboratory materials) to high temperatures during storage and transit (most licences specify storage below 25°C).						
	HE9	People encouraged to spend more time in the sun						
		Multiplication of pathogenic micro-organisms						
		Increase in water-borne diseases (Cryptosporidiosis) in people using surface waters (inland and coastal) for recreational purposes						
		Longer pollen season and more days with high pollen concentrations						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Increase in vector reproduction, parasite development and bite frequency						
		Exacerbation of food-borne disease (no acclimatisation) (food poisoning, campylobacteriosis, salmonellosis, Salmonella Typhimurium infections and Salmonella Enteritidis infections)						
	HE4	Changes in air quality and increase in frequency and intensity of air pollution episodes during warm seasons (mainly high ground-level ozone concentrations)						
	HE2	Additional effects from extremes (heatwaves) - morbidity impacts						
		Cases of malaria may become more common (this is unlikely to become a serious public health concern in the UK)						
	HE2	Increased summer morbidity						
		Increased algal or fungal growth in existing buildings						
		Disruption to building maintenance work						
		ICT server overheating in Primary Care Trusts (PCTs) and hospitals						
	HE6	Reduced winter morbidity						
		Decline in frequency and intensity of winter air pollution episodes						
		Other (food, diet, water, etc)						
		Increase in outdoor activities/ recreation leading to exercise and lifestyle benefits						
		Fewer traffic accidents						
		New disease (or disease boundaries)						
		Deterioration in the quality of surface waters						
		Flooding leading to negative impact on raw water quality						
		A significant rise in demand for emergency medicine (including ambulatory emergency care)						
		Social disruption, injuries, deaths, disability, migration, homelessness and food shortages						
		Buildings and other NHS infrastructure may not be resilient to these events						
		Health care staff performance compromised						
		Patient recovery in hospitals may be compromised						
	HE3	Extreme weather risk to elderly (over 75), especially those who are socially isolated or living on their own						
	HE3	Extreme weather risk to elderly (over 75), especially those who are socially isolated or living on their own						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		More traffic accidents						
		Increased strain on mobile care and support services						
		Flooding of property						
	HE3	Flood risk – fatality/injury						
	HE10	Flood risk – psychological wellbeing and mental stress						
		Flood risk – other e.g. spread of communicable diseases						
		Flooding leading to physical damage of NHS infrastructure and buildings, and disruptions in transportation of patients, medical staff and supplies						
	HE9	People encouraged to spend more time in the sun						
	HE9	Increase in cataracts						
		Increase in indirect human exposure to agricultural contaminants including certain pesticides, fertilizers, bacteria and viruses (magnitude of the increases highly dependent on contaminant type)						
	HE9	Delay in the rate of recovery of the stratospheric ozone layer						
Marine & Fisheries								
		Reduced capacity of oceans to absorb CO_2						
	MA3	Growth, reproduction and shell formation of many invertebrate species (e.g. molluscs, echinoderms, crustaceans) impacted.						
	MA3	Habitat-forming calcifying species impacted (e.g. coldwater corals)						
		Potential impacts on noise transmission						
		Potential impacts on tourism in overseas territories (coral reefs)						
		Slowing of Ocean Carbon Sinks						
		Exacerbation of coastal and marine eutrophication						
		Decreased tourism / increased disruption to facilities such as marine leisure provision						
		Reduced dilution of pollutants or pulsed release from diverse sources						
		Increased coastal and marine pollution						
		Erosion of land						
		Increased frequency of extreme high-water-level events						
		Increased levels and amounts of coastal flooding and damage (including damage to Ports and Coastal Infrastructure)						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Coastal squeeze						
	MA4	Changes in distribution, migration, recruitment and growth rate						
		Saline intrusion of coastal aquifers / river catchments						
	MA6	Increase in invasive species						
		Earlier stratification and onset of the spring plankton bloom in UK seas						
	MA6	Marine invasion by non-native species						
		Increased demand for offshore resources (aggregates extraction) to cater for increased coastal defence measures						
	MA4 / MA8	Changes in species migration and connectivity in life cycles						
	MA1	Increase in the frequency of harmful algal and jellyfish blooms						
		Coastal Power Stations may become unfeasible due to thermal outputs						
	MA2	Altered balance between aquatic borne disease hosts and pathogens						
	MA4	Shifts in populations of fish; increases in warm water species; decreases in many cold-water species.						
		Shifts in timing and populations of warm and colder water plankton						
	MA5	Reduction in Arctic sea ice / increase in icebergs / more fog						
		Increased tourism						
		Availability of cooling water for power stations impacted						
	MA5	Increased shipping and opening up of new trade routes through the Arctic / Port Development in the north						
		Impact on the behaviour of animals - more sluggish or skittish manner (sometimes a function of temperature or light levels)						
	MA1; MA2	Human illness associated with increased presence of marine Vibrio. spp. / harmful algal blooms / sewage-borne pathogens						
		Sustainability of key habitats and protected regions						
		Regionalised changes in localised currents						
		Cultured species become more susceptible to disease						
	MA2	Establishment of exotic diseases in animals						
	MA2	Decreased presence of certain diseases						
	MA9	Breeding season/spawning behaviour of fish disturbed						
		Habitat loss for beach-nesting birds, mammals, etc						

			Relevant Chapter(s)					
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			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Decline in sand eel populations in the Northern Atlantic and Irish Sea						
		Other physiological processes affected such as gametogenesis						
		Increase the extent and level of participation in watersports						
	MA10	Stratification of water column with depth						
		Changes in the 'habitability' of sites/coastlines for traditional aquaculture species						
		Calmer surface conditions and more settled underwater conditions						
		Thermal stress experienced by intertidal cultivated species						
		Increased wave heights						
		Increased exposure for certain coastlines						
		Decreased tourism						
		Increased scour around legs and supports of offshore installations						
		Increased scour						
		Increased frequency of extreme high-water-level events						
		Impact on the structural stability of offshore wind and wave farms						
		Coastal geomorphology changes e.g. shifts in sandbanks						
		Continued extension and retraction of ranges for intertidal species						
		Increased release of contaminated sediment or storm water containing untreated sewage (CSO)						
	MA9	Variability in year class strength of fish						
		Increased opportunities for wind farms						
		Storm damage to ports and coastal infrastructure						
	MA10	Re-suspension of nutrients and impacts on plankton						
		Vulnerability of offshore structures - oil and gas						
	MA1; MA2	Increase in harmful algal blooms, shellfish borne pathogens and marine eutrophication						
		Delays, closures, disruption to port activities / infrastructure and cargo						
		Increased sedimentation of navigation channels						
	MA9	Storm mortality and loss of nests for birds						
		Damage / site relocation for cultured aquatic species / sites						
		Damage to offshore cabling						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Increase in safety at sea issues (shipping, spillages etc)						
		More difficult to access offshore resources (e.g. aggregates)						
		Increased danger to shipping						
		Laying of offshore power cables						
	MA10	Increased intensity of coastal upwelling currents and atmospheric deposition of micro nutrients						
		Reduction in the calm weather windows available for dredging aggregates						
		Increased equipment failure						
		Impact the ability of fishing boats to access resources						
		Increased potential for renewables industry (e.g. tidal stream, waves, barrages)						
		Leaching of contaminants from previously stable disposal sites						
	MA7	Disruption to ferry services and shipping						
Transport								
	TR1	Increased flooding of infrastructure						
	TR1	Increased road submersion and underpass flooding						
	TR1	Increased flooding of underground rail networks						
	TR1	Pluvial flooding around London Underground						
		River flows affect river transport						
		Changes in incidence of road or rail speed restrictions or service delays						
	TR2	Increase in earthworks failures; Increased landslides and undercutting; rail track blockages, particularly in cuttings						
	TR2	Increased erosion of foot paths and cycleways						
		Rising water tables affecting underground infrastructure						
		Greater opportunities for walking and cycling, particularly in summer						
		Poor driving conditions - increased number of accidents						
		Reduction in visibility causing problems for aircraft take-off and landing						
		Prevention of road repairs						
		Increases in delays for air take-off and landing						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
	TR1	Flooding of coastal infrastructure. Increased rate of inundation in vulnerable areas, increased area considered vulnerable, increased corrosion of track, points and signals and overhead line equipment in vulnerable areas, road infrastructure.						
		Flooding of coastal infrastructure. Increased rate of inundation in vulnerable areas, increased area considered vulnerable, increased corrosion of track, points and signals and overhead line equipment in vulnerable areas, road infrastructure.						
	TR4	Increased thermal loading on road pavements						
		Reduced winter maintenance costs for road & rail						
		Improved working conditions for personnel in cold environments						
	TR5	Increased incidence of rail buckling						
		Increased passenger discomfort, customer and staff heat stress. Increased driver discomfort/heat exhaustion e.g. London Underground						
	TR5	Overheating of equipment both on infrastructure and trains/underground.						
		Overheating of equipment both on infrastructure and trains/underground.						
	TR2	Increased subsidence (road, rail, waterway embankment stability)						
		Less need for heating on transport in winter						
		Increased demand for air conditioning (cooling) and energy use on public transport/ road vehicles						
		Overheating of car engines						
	TR4	Increased rutting on roads						
	TR4	Changes in incidence road or rail speed restrictions or service delays						
		Reduced winter protection (gritting)						
		Reduced icing of rails, points and overhead cables (see also impact under increased average wind speed)						
		Reduced number of blockage incidence, improved safety on platforms						
		Changes in travel demand (e.g. increased tourism or recreational activity)						
	TR4	Melting of airport runway surface (above 45°C)						
		Older planes may struggle to take off in time (not issue for new planes)						

			Relevant Chapter(s)					
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			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Reduction in cold weather related disruption, speed restrictions and accidents - improvements in road safety						
		Increase in amount of aviation fuel needed						
		Higher density altitudes affecting aviation: reduced engine combustion efficiency; increased runway lengths required						
	TR2	Impact on maintenance regimes due to degradation, soil shrinkage/subsidence etc.						
		Decrease in weather interference to construction activities						
		Reduction in winter travel problems on average could lead to inadequate preparation for extreme events						
		Aircraft payloads may have to be reduced for take-off owing to the lower air density.						
	TR5	Failed air conditioning on rail vehicles						
		Increased incidence of damage (e.g. to bridges, signs, etc)						
		Increased damage to infrastructure (e.g. electric network for rail including power lines, signalling and electric equipment), damage or blocking of road or rail lines or (tree fall) etc						
		Day-to-day running of ports affected						
		Increase in problems for suspension bridges, high-sided vehicles and construction cranes						
		Changes to annual patterns of leaf fall.						
		Increased disruption of marine transport (commercial and passenger)						
		Catastrophic loss of a vessel						
		Increase in 'wear and tear' of aircraft during take-off and landing						
		Increase in interference to asphalting and concreting as wind-chill cools the surface too quickly						
		Changes in timing of winter maintenance regimes						
		Changes to Insurance cover/premiums						
		Changes in incidence of road or rail speed restrictions or service delays, or airport restrictions						
		Condensation or sublimation from high humidity leading to possible aircraft engine starting problems and wing-icing						
		Increased opportunities for design of new generation vehicles to cope with climate change						
		Change in wind chill factor.						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Loss of coastal land due to erosion (e.g. landward migration of beaches and cliffed coastlines) as sea levels rise and wave energy increases with potential erosion of ports						
		Lightning strikes affecting trees, buildings, power lines, etc.						
		High winds at Ports increased storminess						
Water								
	WA2	Lower river flows, particularly in the summer						
		Change in average reservoir yields						
		Increased soil erosion and sediment movement						
		Lower summer groundwater tables						
	WA2	Lower river flows, particularly in the summer						
		Change in groundwater recharge - shorter recharge period						
	WA5	Supply-demand deficit						
	WA10	Sewer flooding (see floods worksheet)						
	EN4	Reduction in hydro-electric power generation						
	BD1, BD14-16	Change in habitat condition and ability to support species						
	WA7, WA8	Meteorological and hydrological drought affecting water supply/demand						
		Reduced water volumes into supply thus less dilution of pollutants						
		Reduction in volume of sewer base flow						
		Change in pipe bursts/leakage						
	FL10	Flooding of critical infrastructure and damage (water/waste water treatment works, reservoir embankments) - see floods worksheet						
		Increased opportunity for winter storage						
	WA9	Deterioration in water quality						
		An increase in the incidences of cryptosporidium in water						
		Deposition of sediments						
		Settlement of sediments and H_2S in water supply system						
	WA10	"Shock" first flush loads in sewer system						
	EN4	Opportunity for greater hydropower production						
	WA7, WA8	Localised summer droughts exacerbated						
		Dams will be more prone to siltation from increased soil erosion						

			Relevant Chapter(s)					
			Most relevant					
			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Build up of contaminants in water distribution system						
		Reduced financial rating of UK water companies						
	WA4	Higher demand from agriculture (see agriculture report)						
	WA4	Increased water demand						
	EN4	Decrease in (cool) water available for cooling and generation						
	WA4	Large increase in the demand for water						
		Affect MEICA (Mechanical, Electrical, Instrumentation, Controls, Automation) plant - increased rate of deterioration						
		Pest issues						
		Increase in evaporation loss from open water sources (reservoirs)						
		Increase in evaporation losses from wetlands						
	BD10	Increase in water temperature						
		Algal growth						
		More efficient water/waste water treatment processes						
		Increased algal growth						
		Discolouration due to impact on chemical processes						
		Increased sludge related disease						
		Water-borne diseases						
		Increased recreation and demand for water-intensive products and activities						
		Contamination of water sources through recreational activity						
		Greater microbial action, odour, gases at sewage treatment works						
		Greater microbial action causes chlorine depletion						
		Increased risk to water supply infrastructure near the coast						
		Saline intrusion of (the lower reaches of) rivers and coastal aquifers						
		Saline incursion - extension of tidal limits in rivers						
		Reduced navigation in summer due to low flows, reduced in winter due to high flows						
		Extreme flood leading to dam failure						
	WA9	Increased UV in water bodies						
		Less freeze damage to pipes						
		Lower infiltration in sewer systems						

			Relevant Chapter(s)					
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			Less relevant					
			Little relevance					
Sub-Sector (if applicable)	**Risk Metric(s) (if applicable)**	**Impact (or consequence) Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health and Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**
		Increase in dilution of pollutants due to high flows						
		Change in the geography of demand on water infrastructure (sewerage) due to population movements						

Appendix 5 Tier 2 Risk Metrics

This table lists the risk metrics identified as part of the CCRA assessment, ordered by sector. The yellow boxes indicate the relevant themes for each risk metric. Section numbers are provided where information on the risk metric can be found. Some risk metrics are referred to in numerous places, in which case the most relevant section is provided here. Section numbers in bold highlight the sections that are in general most relevant to that particular risk metric.

Risk metric unique codes are provided here and in Appendix 4 so that the association between the Tier 1 impacts and the risk metrics can be identified.

		Most relevant section						
Unique code	**Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health & Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**	**Sector Report Only**
Agriculture								
AG1a	Changes in sugar beet yield (due to warmer conditions)		**4.2.3**	5.6.1			8.3.5	
AG1b	Changes in wheat yield (due to warmer conditions)		**4.2.3**	5.6.1			8.3.5	
AG1c	Changes in potato yield (due to combined climate effects and CO_2)		**4.2.3**	5.6.1			8.3.5	
AG2a	Flood risk to high quality agricultural land		**4.3.3**				8.3.1	
AG2b	Flood risk to horticultural land		**4.3.3**					
AG2c	Flood risk to grassland		**4.3.3**					
AG3	Risk of crop pests and diseases		**4.3.4**				8.2.3	
AG3b	Crop disease using 'rust' as marker for wheat							Y
AG3c	Crop disease using 'blight' as marker for potato							Y
AG4	Drier soils (due to warmer and drier summer conditions)		**4.3.2**					
AG5	Increases in water demand for irrigation of crops		**4.5**					
AG6	Increases in water demand for livestock							Y
AG7a	Reduction in milk production due to heat stress		**4.2.2**					
AG7b	Reduction in dairy herd fertility due to heat stress		**4.2.2**					
AG8a	Increased duration of heat stress in dairy cows		**4.2.2**					
AG8b	Dairy livestock deaths due to heat stress		**4.2.2**					
AG10	Changes in grassland productivity		**4.2.1**				**8.2.5**	
AG11	Increased soil erosion due to heavy rainfall		**4.3.3**					
AG9	Opportunities to grow new crops		**4.4**					

		Most relevant section						
Unique code	**Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health & Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**	**Sector Report Only**
Biodiversity and Ecosystem Services								
BD1	Risks to species and habitats due to drier soils						**8.2.1**	
BD2	Risks to coastal species and habitats due to sea-level rise	3.3.2					**8.2.1**	
BD3	Risk of pests to biodiversity						**8.2.3**	
BD4	Risk of diseases to biodiversity		**4.3.4**				**8.2.3**	
BD5	Species unable to track changing 'climate space'						**8.2.1**	
BD6	Environmental effects of climate mitigation measures			5.4.2			**8.3.3**	
BD7	Risks to coastal habitats due to flooding	3.3.1					**8.2.1**	
BD8	Changes in soil organic carbon						**8.2.5**	
BD9	Changes in species migration patterns						**8.2.2**	
BD10	Biodiversity risks due to warmer rivers and lakes	3.2.9					**8.2.4**	
BD11	Generalist species more able to adapt than specialists						**8.2.4**	
BD12	Wildfires due to warmer and drier conditions	3.2.7	**4.3.5**		**6.4.3**		**8.2.6**	
BD13	Water quality and pollution risks						**8.2.6**	
BD14	Ecosystem risks due to low flows and increased water demand						**8.3.5**	
BD15	Increased societal water demand							Y
BD16	Major drought events							Y
Built Environment								
BE1	Urban Heat Island effect				6.1.1	**7.3.1**		
BE2	Increased subsidence risk due to rainfall changes					**7.2.3**		
BE3	Overheating of buildings			**5.2.1**	6.1.1	**7.2.2**		
BE5	Effectiveness of green space for cooling				6.1.1	**7.3.2**	**8.3.4**	
BE9	Energy demand for heating			**5.2.1**	6.1.1	**7.4.3**		
Business, Industry & Services								
BU1	Climate risks to investment funds			**5.4.1**				
BU2	Monetary losses due to tourist assets at risk from flooding			**5.4.2**		7.2.1	8.3.6	
BU3	Risk of restrictions in water abstraction for industry			**5.2.3**				
BU4	Risks of business disruption due to flooding			**5.2.2**				
BU5	Loss of productivity due to ICT disruption			**5.3.3**		**7.7**		
BU6	Mortgage provision threatened due to increased flood risk			**5.4.1**				
BU7	Insurance industry exposure to UK flood risks			**5.4.1**				
BU8	An expansion of tourist destinations in the UK			**5.4.2**				

		Most relevant section						
Unique code	**Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health & Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**	**Sector Report Only**
BU10	Loss of staff hours due to high internal building temperatures			**5.2.1**		7.2.2		
BU9	A decrease in output for businesses due to supply chain disruption			**5.3.1**				
Energy								
EN1	Energy infrastructure at significant risk of flooding			**5.3.3**		**7.4.1**		
EN1b	Power stations at significant risk of flooding					See FL11a		Y
EN2	Energy demand for cooling			**5.2.1**		**7.4.3**		
EN3	Heat related damage/disruption to energy infrastructure			**5.3.3**		**7.4.2**		
EN4	Risk of restrictions in water abstraction for energy generation					7.6.2		
EN10	Energy transmission efficiency capacity losses due to heat - over ground			**5.3.3**		**7.4.2**		
Floods & coastal erosion								
FL1	Number of people at significant risk of flooding				**6.2.5**			
FL2	Vulnerable people at significant risk of flooding				**6.2.5**			
FL4a	Agricultural land at risk of flooding		See AG2					Y
FL4b	Agricultural land at risk of regular flooding		**4.3.3**				8.3.1	
FL6a	Residential properties at significant risk of flooding				**6.4.1**	**7.2.1**		
FL6b	Expected Annual Damage (EAD) to residential property due to flooding					**7.2.1**		
FL7a	Non-residential properties at significant risk of flooding			**5.2.2**		7.2.1		
FL7b	Expected Annual Damage (EAD) to non-residential property due to flooding			**5.2.2**		7.2.1		
FL8a	Roads at significant risk of flooding					**7.5.1**		
FL8b	Railways at significant risk of flooding					**7.5.2**		
FL10	Water infrastructure at risk of flooding							Y
FL11a	Power stations at significant risk of flooding			**5.3.3**		**7.4.1**		
FL11b	Substations at risk of flooding (tidal and fluvial)					**7.4.2**		
FL12a	Hospitals and schools at significant risk of flooding				6.1.2	**7.2.1**		
FL12b	Hospitals and schools at significant risk of flooding					**7.2.1**		
FL13	Ability to obtain flood insurance for residential properties				**6.3**	7.2.1		
FL14b	Priority habitats lost due to coastal erosion						**8.2.1**	
FL14a	Agricultural land lost due to coastal erosion							

		Most relevant section						
Unique code	**Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health & Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**	**Sector Report Only**
FL15	Flood risk for Scheduled Ancient Monument sites					**7.2.1**		
Forestry								
FO1a	Forest extent affected by red band needle blight		**4.3.4**				**8.2.3**	
FO1b	Forest extent affected by green spruce aphid		**4.3.4**				**8.2.3**	
FO2	Loss of forest productivity due to drought		**4.3.1**					
FO4a	Decline in potential yield of beech trees in England		**4.2.4**				8.3.5	
FO4b	Increase of potential yield of Sitka spruce in Scotland		**4.2.4**				8.3.5	
Health								
HE1	Summer mortality due to higher temperatures				**6.2.1**			
HE2	Summer morbidity due to higher temperatures				**6.2.2**			
HE3	Extreme weather event (flooding and storms) mortality				**6.2.5**			
HE4a	Mortality due to summer air pollution (ozone)				**6.2.7**			
HE4b	Morbidity due to summer air pollution (ozone)				**6.2.7**			
HE5	Winter mortality due to higher temperatures				**6.2.3**			
HE6	Winter morbidity due to higher temperatures				**6.2.4**			
HE7	Extreme weather event (flooding and storms) injuries				**6.2.5**			
HE9	Sunlight/UV exposure				**6.2.8**			
HE10	Effects of floods/storms on mental health				**6.2.6**			
Marine & Fisheries								
MA1	Risk of Harmful Algal Blooms due to changes in ocean stratification	3.3.3			**6.2.9**		**8.2.3**	
MA2a	Decline in marine water quality due to sewer overflows				**6.2.9**		**8.2.6**	
MA2b	Risks of human illness due to marine pathogens				**6.2.9**		**8.2.3**	
MA3	Increased ocean acidification	3.3.4					**8.2.6**	
MA4	Changes in fish catch latitude/centre of gravity (cod, haddock, plaice)			5.3.2			**8.3.2**	
MA5	Opening of Arctic shipping routes due to ice melt			**5.3.1**		**7.5.3**		
MA5	Arctic ice melt due to higher temperatures	**3.3.6**						
MA6	Distribution of marine alien/invasive species						**8.2.3**	
MA7	Potential disruption to shipping due to rough seas					**7.5.3**		

		Most relevant section						
Unique code	**Name**	**Biophysical**	**Agriculture & Forestry**	**Business**	**Health & Wellbeing**	**Buildings & Infrastructure**	**Natural Environment**	**Sector Report Only**
MA8	Potential disruption to breeding of seabirds and intertidal invertebrates						**8.2.1**	
MA9	Decline in productivity of 'cold water' fish and shellfish stocks			5.3.2				
MA10	Disruption to marine ecosystems due to warmer waters	**3.3.5**					**8.2.4**	
Transport								
TR1	Disruption to road traffic due to flooding			5.2.2		**7.5.1**		
TR2	Landslide risks on the road network			5.3.1		**7.5.1**		
TR4	Cost of carriageway repairs due to high summer temperatures					**7.5.1**		
TR5	Rail buckling risk					**7.5.2**		
TR6	Scouring of road and rail bridges			5.3.1		**7.5.2**		
Water								
WA1	Warmer and drier conditions in the South East of England	**3.2.5**						
WA2	Lower summer river flows (Q95)	**3.2.8**						
WA3	Reduction in water available for public supply			**5.2.3**	6.1.1	**7.6.1**		
WA4	Change in household water demand				6.1.1	**7.6.2**		
WA5	Public water supply-demand deficits			**5.2.3**	6.1.1	**7.6.2**		
WA6	Population affected by water supply-demand pressures				6.1.1	**7.6.2**		
WA7	Insufficient summer river flows to meet environmental targets						**8.2.6**	
WA8	Risk of unsustainable water abstraction (total)					**7.6.2**		
WA8a	Risk of unsustainable water abstraction for agriculture		**4.5**	**5.2.3**				
WA8b	Risk of unsustainable water abstraction for industry					See WA8		Y
WA9a	Potential decline in summer water quality (point source pollution)						8.2.6	
WA9b	Potential decline in water quality due to diffuse pollution						8.2.6	
WA10	Combined Sewer Overflow spill frequency				**6.2.9**	**7.6.3**		

Appendix 6 Technical Glossary

This glossary of standard terms used in the CCRA is based mainly on IPCC and UKCIP definitions. Terms without citations were developed specifically for the CCRA.

Adaptation - Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities (IPCC, 2007). There are various types of adaptation, such as:

- **Autonomous adaptation** – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation (IPCC, 2007).
- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC, 2007).
- **Maladaptation** - Any changes in natural or human systems that inadvertently increase vulnerability to climatic hazards; an adaptation that does not succeed in reducing vulnerability but increases it instead. It can also cover spending a disproportionate amount of effort and investment on adaptation beyond what is required (ASC, 2011).
- **No regret (adaptation) options (or measures)** - Adaptation options (or measures) that would be justified under all plausible future scenarios, including the absence of man-made climate change. A no regret option could be one that is determined to be worthwhile now (in that it would yield immediate economic and environmental benefits which exceed its cost), and continue to be worthwhile irrespective of the nature of future climate. (Willows and Connell, 2003)

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 (modified from the IPCC (2007) report to support the project's focus on management of future risks).

> **Natural Adaptive Capacity** – The ability of a species or natural system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (modified from the IPCC, 2007 definition to focus on the natural environment).

Anthropogenic - Resulting from or produced by human beings. (IPCC, 2007)

Baseline - The baseline is the state against which change is measured. It might be a 'current baseline', in which case it represents observable, present-day conditions. It might also be a 'future baseline', which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines. (IPCC, 2007)

Capacity - A combination of all the strengths and resources available within a community, society or organisation that can reduce the level of risk, or the effects of a disaster. Capacity may include physical, institutional, social or economic means as

well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability. (UN/ISDR**,** 2004)

Capacity building - In the context of climate change, capacity building is developing the technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of adaptation to, mitigation of, and research on climate change, and in the implementation of the Kyoto Mechanisms, etc. (IPCC, 2007)

Climate – The climate can be described simply as the 'average weather', typically taken over a period of 30 years. More rigorously, it is the statistical description of variables such as temperature, rainfall, snow cover, or any other property of the climate system (ASC, 2011).

Climate Change - Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere, ocean or in land use (ASC, 2011).

Climate Change Scenario - A coherent and internally-consistent description of the change in climate by a certain time in the future, using a specific modelling technique and under specific assumptions about the growth of greenhouse gas and other emissions and about other factors that may influence climate in the future. (Willows and Connell, 2003)

Climate space - The geographical area which is suitable for a particular species, based on the climate parameters within which the species can survive and reproduce. Climate space does not take into account other factors, such as topography, food or water availability that might impact upon the species actual geographical range (realised range).

Climate Variability - Climate variability refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also climate change. (IPCC, 2007)

Confidence - The degree to which the findings of the assessment are considered valid, based on the type, amount, quality, and consistency of evidence, as well as the degree of agreement on the evidence.

Consequence - The end result or effect caused by some event or action. Consequences may be beneficial, neutral or detrimental. A detrimental consequence is often referred to as an impact. May be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected). (Willows and Connell, 2003).

Global Climate Models (GCMs) – Models that describes important physical elements and processes in the atmosphere, oceans and land surface that make up the climate system. These can be used to estimate the effects of greenhouse gas emissions on the global climate. See Regional Climate Models.

Greenhouse gas - A number of anthropogically produced and naturally occurring gases whose presence in the atmosphere traps energy radiated by the Earth. Carbon dioxide is the most important greenhouse gas. (Willows and Connell, 2003)

Gross Domestic Product (GDP) - The monetary value of all goods and services produced within a nation. (IPCC, 2007)

Hadley Centre Coupled Model version 3 (HadCM3) – A coupled climate model that has been used extensively for climate prediction, detection and attribution, and other climate sensitivity studies. HadCM3 was one of the major models used in the IPCC Third and Fourth Assessments.

Hazard - A situation or event with the potential to cause harm. A hazard does not necessarily cause harm. (Willows and Connell, 2003)

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

Likelihood - The chance of an event or outcome occurring, usually expressed as a probability. We cannot associate likelihood with specific changes in climate risks, therefore likelihood is not used in this assessment. Instead we consider potential risks for a range of plausible scenarios.

Mitigation - Action to reduce the sources (or enhance the sinks) of factors causing anthropogenic climate change, such as greenhouse gases.

Mitigation (in context) - In the context of risk management, any action to reduce the probability and magnitude of unwanted consequences; see Armstrong (2001). Hence, adaptation to climate change is a strategy undertaken to mitigate the risk associated with future changes in climate. In climate change policy, mitigation refers specifically to the reduction in greenhouse gas emissions, which is an example of risk management. (Willows and Connell, 2003)

Model - In its broadest sense, a representation of how a system works, or responds to inputs, and may be used as a basis of risk assessment, analysis or management by decision-makers. A model may be anything from a conceptual framework through to a fully parameterised and validated numerical representation of a system implemented on a computer. (Willows and Connell, 2003)

Monetisation – Provision of indicative monetary costs (per year) of potential economic, social and environmental consequences. For the CCRA, the monetisation exercise has focused on the effect on overall human welfare. The intrinsic value of elements of the natural environment is not captured, nor is the variation in social vulnerability considered.

Parameter - Strictly, a fundamental property of a system (or model), the value of which, together with the structure of the system (or model), determines the relationship between system components (or variables). However, the term has a variety of common usages and it is often used synonymously with variable (e.g. a climate or water quality parameter). (Willows and Connell, 2003)

Pathway - Provides the connection between a particular hazard (e.g. storm-force winds) and the receptor (e.g. insurance company premiums) that may be 'harmed'. The pathway may include the track of the storm, the location of domestic dwellings, nature of roofing materials, the level of consequent insurance claims. (Willows and Connell, 2003)

Percentile - A percentile is a value on a scale of zero to one hundred that indicates the percentage of the data set values that is equal to or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (10th) percentile may be used to refer to the threshold for the upper (lower) extremes. (IPCC, 2007)

Probability - is used to describe the chance or relative frequency of occurrence of particular types of event, or sequences or combinations of such events. These events

may be discrete or described by a continuous variable. An example of a discrete event is the probability that a particular location experiences flooding on one or more occasions during any year. The maximum depth of flooding experienced during each such event is an example of a continuous variable, which can take a range of values with different probabilities. The nature of the probability may be determined by reference to an underlying theory, or be described based upon supporting observations. (Willows and Connell, 2003)

Projection - Any description of the future and the pathway that leads to it. A specific interpretation of a 'climate projection' refers to a climate model-driven estimate of future climate. (Willows and Connell, 2003). Projections are distinguished from predictions in order to emphasise that projections involve assumptions – concerning, for example, future socio-economic and technological developments that may or may not be realised – and are therefore subject to substantial uncertainty. (IPCC, 2007)

Receptor - The entity that may be harmed by a particular set of hazardous events. (Willows and Connell, 2003)

Regional Climate Models (RCMs) – High resolution climate models that cover a limited area of the globe, typically 5,000 x 5,000 km. These are comprehensive physical models, usually including the atmosphere and land surface components of the climate system, and containing representations of the important processes within the climate system. See Global Climate Models.

Reinsurance - The transfer of a portion of primary insurance risks to a secondary tier of insurers (reinsurers); essentially 'insurance for insurers'. (IPCC AR4, 2007)

Residual (climate) risk - The risk that remains after risk management and adaptation to (e.g.) climate. (Willows and Connell, 2003)

Resilience - The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change. (IPCC, 2007)

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

Return period - The expected mean time between occurrences that **equal or exceed** a particular defined, usually extreme or unusual event. Often used to express the frequency of occurrence of the event (which is 1/return period). Estimates of return periods are subject to uncertainty, such that consecutive events may occur at intervals greater or smaller than the average return period. (Willows and Connell, 2003)

Risk – combines the likelihood an event will occur with the magnitude of its outcome. In the CCRA risks are presented as threats, with adverse costs or damages, or opportunities that may benefit specific sectors; the magnitude of risk is evaluated in social, economic or environmental terms using 'risk metrics', e.g. the costs of damage, number of people affected or areas of land affected by a specific climate effect.

Potential risk - Due to the difficulties of defining the likelihood related to future emissions scenarios, changes in climate and socio-economic factors, the assessment focuses on the magnitude of risks for a wide range of plausible scenarios. We refer to this as the 'potential risk' as the range of outcomes presented is dependent on specific combinations of emissions scenarios, climate and socio-economic change.

Perceived risk - Refers to the observation that the individual or public perception of risk may differ from the perception gained by a risk assessor as a result of a technical risk assessment. (Willows and Connell, 2003)

Risk Assessment - the structured analysis of risks to provide information for decision making. Risk assessment usually relates to a particular exposure unit which may be individual, population, infrastructure, building or environmental asset etc. The process usually involves identifying hazards that could have an impact, assessing the likelihoods and severities of impacts, and assessing the significance of the risk; related to the magnitude and likelihood of the risk in this case (adapted for this assessments' definition of risk from the UKCIP glossary, 2011)

Risk evaluation - A component of risk assessment in which judgments are made about the significance and acceptability of risk. (Willows and Connell, 2003)

Risk identification - The process by which hazards are recognised and characterised. In the case of climate change risk assessment, risk identification is a deliberate procedure to review, and it is hoped, anticipate possible hazards. Risks associated with climate variability can in general be identified from past experience of climate. (Willows and Connell, 2003)

Risk Management - The implementation of strategies to avoid unacceptable consequences. In the context of climate change adaptation and mitigation are the two broad categories of action that might be taken to avoid unacceptable consequences (Australian Greenhouse Office, 2003).

Risk screening - Following initial identification of hazards and risks, risk screening is the process by which it is determined which risks should be investigated in more detail. Risk screening is usually based on ranking or scoring methods. (Willows and Connell, 2003)

Robustness - The ability of a system to continue to perform satisfactorily under load. (Willows and Connell, 2003)

Scenario - A coherent, internally consistent and plausible description of a possible future state of the world, usually based on specific assumptions. (Willows and Connell, 2003)

Sensitivity - The degree to which a system is affected, either adversely or beneficially, by climate variability or change.

Socio-economic scenarios - Scenarios concerning future conditions in terms of population, Gross Domestic Product and other socio-economic factors relevant to understanding the implications of climate change. (IPCC, 2007)

Stakeholder - People, including organisations, who have an investment, financial or otherwise, in the consequences of any decisions taken. (Willows and Connell, 2003)

System - The social, economic and physical domain within which risks arise, produce consequences, and in which risks are managed. An understanding of the way in which a system may behave is an essential aspect of understanding and managing risk. In particular it is important to identify mechanisms and thresholds by which the system may fail when loaded, and the processes that provide opportunities for risk management decisions. (Willows and Connell, 2003)

Systematic mapping - The identification of links between causes and effects and the processes that lead to change. For the CCRA, this looked at climate variables, direct socio-bio-physical impacts and then both direct and indirect consequences within sectors and between sectors.

Systems analysis – The analysis of bio-physical or socio-economic systems. For the CCRA, this took the form of systematic mapping.

Threshold - A property of a system or a response function, where the relationship between the input variable and an output or other variable changes suddenly. It can be

important to identify thresholds, and other non-linear relationships, as these may indicate rapid changes in risk. (Willows and Connell, 2003)

UKCP09 range - The UK Climate Projections (UKCP09) provide probabilistic projections of climate change for the Low, Medium and High emissions scenarios and for seven overlapping time periods. The CCRA used projections near the upper and lower ends of the UKCP09 range for each emissions scenario, as well as the central projections. Rather than being used as an indicator of the likelihood of particular outcomes, these were interpreted as plausible scenarios illustrating a range of possible changes. The CCRA does not assign probabilities to any future projections or risks.

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 - The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. (IPCC, 2007)

Weather - Refers to the state of the atmosphere, across space and time, with regard to temperature, cloudiness, rainfall, wind, and other meteorological conditions (ASC, 2011).

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