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A climate change risk assessment for Scotland

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Statement of Use

This report presents the findings of an assessment of climate change risks for Scotland, which has been completed as part of the UK Climate Change Risk Assessment (CCRA).

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

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

Initially, eleven ‘sectors’ were chosen from which to gather evidence: Agriculture, Biodiversity, Built Environment, Business/Industry/Services, Energy, Forestry, Floods and Coastal Erosion, Health, Marine and 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 as part of the UK-wide assessment.

The risk assessment used UKCP09 climate projections to assess future changes to these selected sector risks. Risks were, in general, analysed using single climate variables, for example temperature.

A final Evidence Report draws together information from the eleven sectors (as well as other evidence streams) to provide an overview of risks from climate change to the UK.

This report for Scotland provides a similar overview of risks from climate change to Scotland. The most important risks (or opportunities) for the UK were reviewed with Scottish stakeholders to determine which were important for Scotland. This resulted in some risks being dropped from the list and others being added. Where risks have been added, some of these have been analysed in detail. Those that have not been analysed in detail are discussed within the broader context of risks from climate change to Scotland.
Neither this report nor the Evidence Report aims 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 for the UK, including Scotland, and allow for some comparison between disparate risks and regional/national differences. The results presented here should not be used by the reader for re-analysis or interpretation at a local or site-specific scale.

In addition, as most risks 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).
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 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 is the CCRA report for Scotland and provides evidence to support the Scottish Government’s climate change adaptation programme. It describes and, where possible, quantifies the risks from climate change facing Scotland up until 2100. It is one of a number of reports that have been produced as part of the UK Climate Change Risk Assessment (CCRA).

The CCRA has analysed those impacts and consequences that were considered to be the most important for the UK. A list of the most important impacts and consequences for Scotland has also been developed through a process of consultation with stakeholders. This differs from the UK list, as it takes account of particular features and issues relevant to Scotland. It is these most important impacts and consequences for Scotland that form the basis of this report. Discussion of these builds on the results from the analysis undertaken for the UK with additional information specifically for Scotland.

This report does not attempt to provide a comprehensive discussion of all potential impacts for Scotland, nor does it attempt to identify potential adaptation measures or associated policy for Scotland.

The findings in this report are presented for a range of possible future scenarios and indicate the confidence in the results. Areas where evidence gaps have been identified, either on a UK or more specific Scottish basis have also been identified.

The assessment in this report is based primarily on the UK Climate Projections which were published in 2009 (UKCP09). UKCP09 provides projections of future climate for many overlapping time periods from the present to 2100. This assessment focused on three time periods, namely the 2020s (2010 to 2039), 2050s (2040 to 2069) and 2080s (2070 to 2099). The projections provide the most up to date evidence of potential changes in climate for Scotland but it is important to recognise the limits of our current understanding and relative confidence related to changes in different climate variables (Box ES1).

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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. 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 of the UK CCRA report, 2012) 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 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.

For each epoch, a range of climate change scenarios were considered and ranges of results were presented for each emissions scenario or across the full range of results, including the Low, Medium and High emissions scenarios. For example, by the 2050s under the Medium emissions scenario from a baseline of 1961-1990, projections for Scotland indicate:

**Eastern Scotland**
- An increase in mean winter temperatures of 1.7°C (range 0.6 to 2.9°C).
- An increase in mean summer temperatures of 2.4°C (range 1.1 to 3.9°C).
- An increase in mean winter precipitation of 10% (range 0% to 21%).
- A decrease in mean summer precipitation of 13% (range 27% decrease to 1% increase).

**Northern Scotland**
- An increase in mean winter temperatures of 1.6°C (range 0.6 to 2.8°C).
- An increase in mean summer temperatures of 2.0°C (range 0.9 to 3.4°C).
- An increase in mean winter precipitation of 13% (range 3% to 25%).
- A decrease in mean summer precipitation of 11% (range 24% decrease to 2% increase).

**Western Scotland**
- An increase in mean winter temperatures of 2.0°C (range 1.0 to 3.1°C).
- An increase in mean summer temperatures of 2.4°C (range 1.2 to 3.8°C).
- An increase in mean winter precipitation of 15% (range 4% to 30%).
- A decrease in mean summer precipitation of 13% (range 27% decrease to 1% increase).

In addition, relative to a 1990 baseline, relative sea levels are projected to rise at variable rates around the Scottish coastline, typically ranging between 0.12m to 0.18m by 2050, although noticeably larger rates on some of the Scottish Islands.

These changes have been used to derive estimates of changes in bio-physical systems, for example changes in river flows, aridity and water availability. These have been used together with the climate change projections to assess the potential impacts of climate change.

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1 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.
Specific features that distinguish Scotland from the UK as a whole and, hence, may increase Scotland’s vulnerability to certain consequences of climate change or ability to take opportunities arising from changes in climate include:

- Relatively low temperatures and higher levels of precipitation than other regions of the UK.
- A rich and varied natural heritage.
- Significant areas of agricultural and forestry land.
- A significant number of rural communities reliant on private water supplies and non-mains power supplies.
- A range of hills in the south of the country drained by numerous rivers with a large number of lochs, agricultural areas and forest regions.
- A relatively low-lying agricultural fertile valley in the central belt, containing most of the industrial areas of Scotland.
- A large mountainous region covering the northwest of the country, with a highly indented coastline with exposed islands, high sea cliffs and rocky skerries.
- An abrupt and exposed north coastline with deep nearshore areas.
- Over 790 islands, of which about 100 are inhabited².
- A significant fishing industry, landing over 60% of the total UK catch and accounting for approximately 60% of all Scottish food exports.

For each impact, an assessment has been made of the potential consequences that may occur in the future. The results are presented in terms of the magnitude in the 2020s, 2050s and 2080s, presented with lower and upper estimates where these are available based on the UKCP09 projections.

Therefore, whilst the assessment provides projections of a range of possible changes in risk, the results must not be considered to be estimates of change. The interpretation and use of the results should be as follows:

1. The results provide a guide to the possibility of a risk occurring, its order of magnitude, direction of change and potential timing.
2. The supporting evidence on specific risks illustrates possible future changes.
3. Adaptation actions should recognise the likely direction of change and levels of uncertainty.
4. For the impacts of greatest concern, gaps in evidence should be addressed including the establishment of monitoring and further research where appropriate.

Summary of results

From the results of this assessment, the potentially most significant threats for Scotland from climate change appear to be:

- Changes in soil conditions, biodiversity and landscape as a result of warmer, drier summers.
- Reductions in river flows and water availability during the summer, affecting water supplies and the natural environment.
- Changes in, or loss of, species with specific threats to native species and migration patterns.
- Changes in coastal evolution affecting people, property, infrastructure, landforms, habitats and species.
- Changes to ocean water temperature and quality, affecting the quality of shellfish and the location of commercial fish stocks.
- Increased risk of pests and diseases affecting agriculture and forestry, and the opportunity for new plants to bring associated new pests and disease causing pathogens.
- Increases in flooding both on the coast and inland, affecting people, property, infrastructure, landforms, habitats and species.
- Increase in insurance losses, ICT disruption and transport network disruption resulting from an increase in the occurrence of extreme weather events.
- An increase in the number of people at risk of death, injury or mental health problems as a result of flooding.

The potentially most significant opportunities identified for Scotland from climate change appear to be:

- Changes in crop, grass and forest productivity and land class leading to potential increases in yields. Central, Eastern and Southern Scotland may benefit the most from these changes.
- Increased tourist numbers and longer tourist seasons, providing an opportunity for new businesses and for established businesses to become more profitable.
- A reduction in the number of cold-related deaths and hospital admissions.

There will also be a number of threats or opportunities that will have a far greater or disproportionate impact for Scotland than for the rest of the UK. These include:

- With the majority of soil organic carbon in Scotland, changes in carbon stored in soils will have a more significant impact on priority habitats and provisioning of ecosystem services.
- Specific threats to species or habitats either more common, or predominantly found in Scotland. For example, 70% of the global extent of machair is found in Scotland.
- The threat to the marine fishing industry to Scotland where almost all existing UK marine based finfish aquaculture activity exists.
• A significant opportunity for crops yields due to a general positive effect on land classification and a longer growing season. Wheat yields in particular are anticipated to increase significantly.

• An opportunity due to increased forest productivity.

• An opportunity due to a reduction in the number of cold-related deaths and hospital admissions.

• A magnification of the increased risks faced by the larger number of rural communities in Scotland reliant on (for example) limited transport or communication links or climate impacted businesses (e.g. fishing) etc.

There are close links between the threats and opportunities listed above and others described in this report. They should therefore not be considered in isolation. An integrated approach will be required to mitigate and/or adapt to these threats and opportunities.

**Results by theme**

The results of this assessment were considered under five themes, namely: Natural Environment; Agriculture and Forestry; Business and Services; Infrastructure and Buildings; and Health and Wellbeing. The main potential threats and opportunities identified under these five themes are given below.

**Natural environment**

• Some species may not be able to track their changing climate space.

• Changes in phenology may lead to declines in some species and may affect food webs.

• Changes in species migration patterns may affect species populations and the designated site network.

• Environmental change, such as changes in climate, may disproportionately favour generalist species, which may result in a reduction in overall biodiversity and ecosystem resilience.

• Changes to soil moisture may lead to changes in carbon stored in soils and damage to priority habitats and provisioning ecosystem services.

• Pests and diseases may find a changed climate more favourable and affect provisioning ecosystem services and biodiversity. Invasive non-native species may become more prevalent in Scottish waters.

• Temperature changes and stratification may affect species growth and have negative impacts on ecosystem goods and services such as fish.

• Increased eutrophication of saltwater and freshwater bodies, increasing the number of coastal dead zones.

• A reduction in raw water quality possibly leading to a reduction in the number of water bodies complying with Water Framework Directive objectives.

• Changing water quantity and quality, affecting provisioning and cultural ecosystem services; affecting water supplies and landscape amenity.

• Changes in erosion and accretion may lead to losses of important habitats particularly where landward migration is constrained by coastal defence structures.
Climate Change Risk Assessment For Scotland

- Coastal erosion is a particular problem for Scotland’s inner and developed Firths, which are composed of soft coastlines, and rare habitats such as Machair.
- Saline intrusion may increase leading to changes in ecological communities along the coast, affecting priority habitats and economically important coastal resources and recreational services.
- The composition and range of shallow marine habitats may change as sea levels increase.
- Disease outbreaks may increase, with potential consequences for ecological communities and human health.
- Ocean acidification has already occurred and may negatively affect ecosystem structure, function and goods, in particular commercial shellfish species, in the future.
- An increased risk of wildfire, by the order of 30% to 40% by the 2080s (from a 1980s baseline), with serious implications for habitats and wildlife.
- Societal water demand, if increased due to a warmer climate, may act to jeopardise ecosystem recovery rates, particularly following extended drought periods.
- Tourism may place the natural environment under further pressure.

Agriculture and forestry

- A large increase (in excess of 100%) of wheat yields over the coming century, with little change in yields of rainfed potatoes and overall barley yields.
- Grassland productivity may increase significantly over the coming century, possibly by as much as a half by the 2050s.
- Land classifications are generally anticipated to change, leading to a greater potential range of land use and greater level of productivity. This would allow new areas of land to be farmed with a positive impact on productivity, although potential negative impacts on biodiversity and marginal lands.
- Flooding and coastal erosion of agricultural land is anticipated to increase, potentially reducing the land class of some land. The agriculture land at risk of flooding relative to a 1961-1990 baseline could be expected to increase by up to 100% by the 2050s and 170% by the 2080s.
- Crop and livestock pests and diseases may increase, affecting crop yields, livestock welfare and product quality.
- Warmer weather and increasing levels of carbon dioxide are likely to result in an increase in timber productivity over the coming century, particularly for Sitka spruce.
- Warmer and drier summers could lead to an increased risk of drought. This is projected to increase by an additional 8% by the 2050s from the current loss of 10%. This would affect timber yields, with Sitka spruce the most adversely affected of the main conifer species.
- Pests and diseases pose increasing risks to trees, woodlands and forests. Increasing temperatures would be expected to increase the likelihood of
optimum conditions for pathogen establishment being reached, particularly by the end of the current century.

- An increased risk of wildfires, by the order of 30% to 40% by the 2080s (from a 1980s baseline), with adverse consequences for both timber production and biodiversity.

**Business and services**

- The potential for increases in future flooding is a major risk to business, with the number of non-residential properties at significant likelihood of flooding\(^3\) increasing by at least 40% by the 2050s and by at least 60% by the 2080s. This will affect business premises and supply chains, and disrupt operations. Some smaller companies may not have the resilience to recover. The business sector is also vulnerable to infrastructure failure and disruption.

- The insurance and mortgage markets are likely to be affected by the increased occurrence of extreme events, potentially resulting in greater insurance losses and a reduction in insurance and mortgage business. The mortgage fund at risk due to insurance becoming unaffordable or unavailable may be of the order of £100 million to £800 million by the 2050s. However, opportunities for new markets will also emerge.

- Failure of the financial sector to adequately take account of climate change, resulting in poor financial performance, which could have widespread consequences for business and other sectors.

- The effects of climate change on businesses and the natural environment could have potentially significant effects on tourism. Although many of these could be positive, linked to (for example) warmer weather, there are potentially a number of negative effects as a result of (for example) increased levels of flooding and erosion. This includes a projected reduction in beach area by the 2080s of between 3% and 12%.

- There is an increased risk of erosion to a number of coastal tourist assets. This includes many of Scotland’s golf courses, as well as more than 10,000 ancient and historical sites.

- There is an increased risk to isolated rural communities and businesses from extreme weather events, as they are often reliant on limited transport links and power supplies.

- Pressures on the emergency services may increase as a result of increased flooding, wildfires and other weather related events. The most significant increase in effort relates to flooding, with the level of effort estimated to double by the 2050s, and triple by the 2080s.

- Warming seas are likely to lead to shifts in the distribution of commonly fished species, with some species moving north. This would affect the fishing industry, although there are also likely to be new opportunities as other species move into Scottish waters from the south.

**Infrastructure and buildings**

- The reliance of many communities in Scotland on a limited number of transport links means that increased disruption due to climate change is a

\(^3\) Significant likelihood of flooding is defined here as an annual probability of any form of flooding of 1 in 75 or greater.
major potential impact for many rural communities, with significant effects for many homes and businesses.

- Increased transport disruption due principally to flooding, but also including landslides and other extreme events. This includes an increase of at least 10% to 20% of the length of roads and railways at significant likelihood of flooding, and up to 330km of road impacted by landslide by the 2050s. This will have particular impacts for rural communities, affecting many homes and businesses. However, there will be a decrease in disruption due to snow and ice due to higher winter temperatures.

- A reduced demand for energy in winter for heating and an increased demand in summer for cooling. Household energy consumption is projected to reduce by approximately 6,000GWh/yr for East Scotland, 3,000GWh/yr for North Scotland and 8,000GWh/yr for West Scotland by the 2080s.

- Increased flooding of residential properties is potentially a major consequence of climate change. Although figures for Scotland are not currently available, it is projected that at least 40% more properties could be at significant likelihood of flooding by the 2050s, and at least 60% by the 2080s.

- Northern (Arctic) sea routes may become open in the near future (up to 120 days by the 2050s and 180s days by the 2080s for the Northeast Passage for example) and remain open for longer periods during the Arctic summers. This will benefit Scottish ports from a reduction in certain sea routes.

- A potential reduction in water availability in summer could affect domestic users, industry and business.

- The effects of heat in the urban environment are projected to become increasingly important including both the environment within buildings and the wider urban environment. Green spaces may become less effective at providing cooling, and providing rainwater and runoff drainage.

**Health and wellbeing**

- The projected increase in floods and coastal wave activity would on an annual basis result in a greater proportion of people at risk of death, injury or mental health effects. Although this could result in a significant increase for mental health effects (with up to approximately 800 additional people suffering a mental health effect due to flooding by the 2080s), the projected increase in deaths or injuries due to flooding is small; unlikely to exceed approximately 5 and 100 respectively for Scotland by the 2080s.

- Higher temperatures may lead to an increase in heat-related deaths in the summer. Projections for the 2050s indicate approximately 100 (range 25 to 285) additional premature deaths as a result of warmer summers by this time, rising to approximately 200 (range 50 to 660) by the 2080s.

- Higher temperatures may lead to a reduction in cold-related deaths in the winter. Projections for the 2050s indicate approximately 550-890 (range 200 to 1,570) premature deaths avoided as a result of milder weather by the 2050s, rising to approximately 800-1,300 (range 330 to 2,330) by the 2080s.
- Hospital admissions are projected to decrease in the winter as a result of warmer weather, of the order of 100 times greater than the number of cold related deaths.
- Hospital admissions are projected to increase in the summer as a result of warmer weather, of the order of 100 times greater than the number of heat related deaths.
- Fuel poverty may reduce due to higher mean temperatures, but due to the influence of other factors, such as fuel prices, employment, etc., as well as the Scottish Governments aim to eradicate fuel poverty by 2016, this is too uncertain to quantify.
- Wetter warmer winters may lead to increased algal and fungal growth in buildings with consequential effects on those vulnerable to asthma and other respiratory diseases.

Results by area

Urban areas

Urban areas are likely to be affected by increases in flooding, a reduction in water availability, an increase in summer heat and milder winters.

Increases in flooding, including flooding from a combination of different sources, would cause increases in disruption to communities, the economy and employment. It would also affect water supplies, wastewater disposal, energy supplies and health services for areas both inside and outside the floodplains. The potential reduction in water availability in the summer would affect all water users including homes, industry and business.

The effects of climate change are likely to be more severe for vulnerable groups, who may be less able to cope with the effects of flooding and the effects of higher temperatures during the summer.

Rural areas

The potential effects of climate change in rural areas include changes to agriculture, the landscape and the rural economy.

Whilst yields of crops, grass and timber may increase, there are threats to agriculture and forests from pests and diseases and drought. Increases in drying and wetting could have adverse impacts on soils, including damage and erosion, although it has not been possible determine the scale of this.

Extreme events could have particularly serious impacts on remote communities including the loss of service connections and flooding of roads. This in turn would affect communities and businesses. The effects of climate change would be more severe for vulnerable groups which, in rural communities, might include the low paid, unemployed and elderly.

Mountainous areas

In mountainous areas the drying out of bogs and other habitats in the summer could lead to a loss of biodiversity and carbon storage. An increase in soil erosion in drier summers and wetter winters could also occur, potentially exacerbated by an increase in summer tourism. These changes would affect the mountain landscape. Biodiversity would also be affected by changes in climatic conditions and habitats, including migration of species to higher altitudes, or even possible loss.
Coastal areas

The coast could be affected by changes to designated habitats and species as a result of coastal squeeze and erosion, particularly on the east coast. Erosion and sea level rise could also damage (or further damage) coastal areas including communities and transport links. Fisheries including shellfish could be affected by sea level rise and changes in water quality. However, the potential opening of Northern (Arctic) sea routes in the summer could give a significant boost for Scottish ports, particularly those in the most northern areas of Scotland.

Tourist resorts on the coast could benefit from a potentially longer tourist season although this would increase pressure on limited natural assets and infrastructure. Threats include the loss of natural assets (particularly beaches) to sea level rise and increases in flooding.

A framework for evaluating risks

There is no single measure of risk that can be used across themes and for different sectors. Some risks can be expressed in monetary terms, but others are more difficult to quantify. In addition, this assessment is concerned with risks for Scotland as a whole, not just for the Scottish Government, and some risks have the potential to 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.

The risks 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 comparison of these different risks, they have been categorised into classes of ‘high’, ‘medium’ and ‘low’ magnitude consequences and ‘high’, ‘medium’ and ‘low’ confidence.4 Details of these classes are provided in Section 4 of this report.

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 policies need to be flexible and adjusted as and when new information becomes available. Therefore, the ‘urgency of decision-making’ has also been classified based on three classes, as defined in Table E.1.

<table>
<thead>
<tr>
<th>Class</th>
<th>Summary urgency description</th>
<th>Short response descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High urgency</td>
<td>• Major decisions required before 2020 that affect future resilience to climate change</td>
<td>Adapt now. Increase capacity.</td>
</tr>
<tr>
<td></td>
<td>• There is a significant shortfall in adaptive capacity</td>
<td></td>
</tr>
<tr>
<td>Medium urgency</td>
<td>• Major decisions required before the 2050s that affect future resilience to climate change</td>
<td>Watch carefully. Promote robustness and</td>
</tr>
<tr>
<td></td>
<td>• There is some shortfall in adaptive capacity</td>
<td>flexibility. Targeted capacity building.</td>
</tr>
<tr>
<td>Low urgency</td>
<td>• No major decisions required prior to the 2050s that affect future resilience to climate change</td>
<td>Wait and see. Monitor and review.</td>
</tr>
<tr>
<td></td>
<td>• There is little or no shortfall in adaptive capacity</td>
<td></td>
</tr>
</tbody>
</table>

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.

4 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.
Considering the criteria of magnitude, confidence and urgency can help to identify important risks that require early adaptation action. On the basis of the findings of the CCRA, we can be most confident that the following three issues require early adaptation action:

- Reductions in river flows and water availability during the summer, affecting water supplies and the natural environment.
- Increases in flooding and diffuse pollution both on the coast and inland, affecting people, health, property, infrastructure, landforms, habitats and species.
- Increased risk of pests and diseases (specifically red band needle blight) affecting forestry.
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1 Introduction

1.1 Overview

It is now widely accepted that the world’s climate is being affected by the increasing anthropogenic emissions of greenhouse gases into the atmosphere, and that even if efforts to mitigate these emissions are successful, the earth is already committed to significant climatic change (IPCC, 2007).

The UK Government and Scottish Government are committed to actions for both mitigation of and adaptation to climate change.

The Climate Change Act 2008 made the UK the first country in the world to set a legally binding framework for reducing emissions, but also creates a framework for building the UK’s ability to adapt to climate change.

Among other actions, the national governments within the UK are all developing programmes for adaptation. To inform these programmes, the Act requires that an assessment of the climate change risks to the UK is prepared on a five year cycle. The first assessment, co-funded by the Scottish Government is due in January 2012 and an updated assessment will be issued every five years. The Climate Change (Scotland) Act 2009 requires the development of an adaptation programme to address risks identified for Scotland in progressive Climate Change Risk Assessments.

The objective of the Climate Change Risk Assessment (CCRA) is to inform UK adaptation policy in 2012, by assessing the current and future risks and opportunities posed by the impacts of climate for the UK to the year 2100. As part of this process the CCRA has produced a number of reports which are outlined below, with the links between the reports summarised in Figure 1.1.

CCRA Evidence Report – This report presents a synthesis of the evidence of current and future climate change risks for the UK as a whole to 2100, based on the findings in the sector reports and other evidence.

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.


Sector Reports – The sector reports document the assessment of risks for each of 11 sectors. 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 Scotland, Wales and Northern Ireland in consultation with stakeholders. These reports present the outputs from the UK-wide assessment from the perspective of each Devolved Administration, supplemented with local case studies. This report is the Scotland Devolved Administration report.
1.2 This report

The purpose of this report is to present the findings of the CCRA for Scotland, and provides the following:

- An overview of the climate change impacts that are currently considered most important for Scotland;
- A discussion of the key issues in Scotland that affect the country’s vulnerability to climate change; and
- A synthesis of the CCRA analysis work on specific climate change impacts and consequences from the perspective of Scotland.

The main sources of evidence used in this report are the eleven sector reports produced by the CCRA project. These are cited in the text by title (e.g. Water Sector Report), and referenced by author in the references as below.
Business, Industry and Services  Anastasi and Baglee, 2012
Biodiversity and Ecosystem Services  Brown et al., 2012
Built Environment  Capon and Oakley, 2012
Health  Hames and Vardoulakis, 2012
Agriculture  Knox et al., 2012
Energy  McColl and Angelini, 2012
Forestry  Moffat et al., 2012
Marine and Fisheries  Pinnegar et al., 2012
Floods and Coastal Erosion  Ramsbottom et al., 2012
Water  Rance et al., 2012
Transport  Thornes et al., 2012

Full details of each of these reports can be found at the end of this report in the reference list. Unless stated otherwise, projections for climate change impacts and consequences quoted in this report are those determined as part of the CCRA sector analysis work. However, all projections need to be treated with caution. The level of confidence that can be placed in the projections is discussed here, but reference should be made to the sector reports in order to understand fully the assumptions made and the level of confidence of specific projections.

This report consists of 6 sections, and the structure is given in Figure 1.2 below.
1.3 **Background**

Scotland is one of four countries of the United Kingdom occupying the northern third of the Island of Great Britain. Sharing a border solely with England to the south, it is bounded by the North Sea to the east, the Atlantic Ocean to the northwest, and, joined by the North Channel, the Irish Sea to the southwest. In addition to the mainland Scotland has over 790 separate islands (although only about 100 of these are inhabited), including the Northern Isles and the Hebrides.

The land area of Scotland is approximately 78,800 km², and from a geographical perspective can be sub divided into four main regions, each with different perspectives in relation to climate change. These are:

- **Highlands and Islands**

  The area broadly covering the Scottish Highlands in the northwest of the country, extending into the Cairngorm mountains as well as the Orkney Islands, Shetland Isles and the Hebrides. The Highlands include the largest mountain ranges of Scotland, including Ben Nevis, the highest peak in the United Kingdom.
• The Grampians

Located in the centre and east of Scotland, the Grampian region contains most of the mountainous Cairngorm region and the low lying fertile land in the East. The Grampian region also contains the large city of Aberdeen which is at the heart of the Scottish oil, gas and fishing industry, as well as the Spey valley which is also home to a great number of whisky distilleries.

• Central Lowlands

This is a relatively low-lying agriculturally fertile valley in the centre of the country situated between the Highlands and Islands and the Southern Uplands. This region contains most of the industrial areas of Scotland including the two largest cities in Scotland, Glasgow (population 590,000) and Edinburgh (population 480,000). In total over half the population of Scotland live in this region.

• Southern Uplands

A range of hills almost 200 kilometres long, the Southern Uplands is the least populous of these areas (although its population density is approximately 4 times that of the Highlands). The region is drained by numerous rivers with a number of lochs, particularly in the west, and has large agricultural areas. There are also large regions of forestry including the Forest of Ae, Mabie Forest and Galloway Forest.

The climate of Scotland is temperate and oceanic, and tends to be very changeable. It is warmed by westerly winds passing over the warm water of the North Atlantic Drift from the Atlantic, and as such has much milder winters, but cooler and wetter summers than other countries on similar latitudes. However, temperatures are noticeably lower than the other regions in the UK assessed as part of the CCRA.

In general, the west of Scotland is usually warmer than the east. This is as a result of the Atlantic Ocean currents and the colder surface temperatures of the North Sea. Rainfall varies widely across the country, with the Western Highlands the wettest, and the lowlands to the east typically the driest. In common with the rest of the UK, heavy snowfall is not common apart from in the more mountainous regions of the Highlands.

Scotland has rich and beautiful flora and fauna, including important populations of seals and internationally significant nesting grounds for a variety of seabirds including gannets (*Morus bassanus*) and most of the UK population of golden eagles (*Aquila chrysaetos*). The natural range of Scots pine forest (*Pinus sylvestris*) in the UK is confined to Scotland, and within these forest areas the Scottish crossbill (*Loxia scotica*), the UK’s only endemic bird species can be found. The flora of the country incorporates both deciduous and coniferous woodland and moorland and tundra species, as well as 70% of the global extent of machair coastal habitat on the Atlantic coast of Scotland.

Scotland has a mixed economy, closely linked to the rest of Europe as well as the wider world. Heavy industry, traditionally the dominant employer in Scotland has suffered a decline (particularly in the more traditional industries such as ship building), although maintained to a certain degree by the petroleum related industries associated with North Sea oil extraction. This has led to a social decline in parts of Scotland, particularly West Scotland where (for example) post-industrial decline and related factors such as material deprivation are often cited as the underlying reason for poor health outcomes (GCPH, 2008).
Primary exports include whisky, aquaculture, electronics and financial services. In addition, fishing which is the major contributor to the local economy in certain rural areas, accounts for around 60% of all Scottish food exports (SDI, 2011).

Edinburgh is the sixth largest financial centre in Europe, and tourism is developing into a key contributor to the Scottish economy, providing about 5% of GDP, and 7.5% of employment. Renewable energy is also a developing economy in Scotland, with the Scottish Government aim of generating the equivalent of 31% of Scotland’s gross annual energy consumption from renewable energy by 2011, rising to 100% by 2020. Most of this is anticipated to come from wind energy. Currently Scotland has more than 60% of the UK wind energy generation capacity, which will rise to 65% by the time sites under construction are completed.

1.4 Climate change impacts

An initial workshop was held in Scotland in March 2010 with a number of stakeholders who covered the range of sectors to be considered in the CCRA. At this workshop, participants were asked to identify specific requirements relevant to Scotland for the CCRA, as well as to help identify any recent studies on climate change impacts that should be considered as part of the CCRA process (particularly in relation to Scotland). The results from this and other workshops were then used in the preparation of scoping reports produced for each sector on a UK basis that were published in April 2010. Each report had a number of specialists who contributed to or reviewed these reports. These formed the basis of the initial list of approximately 700 impacts specific to the UK as a whole (known as the “Tier 1” list of impacts) that were originally reviewed at various sector specific workshops held for nine of the eleven sectors during May 2010. Workshop reports for each sector highlighted which impacts were of greatest concern within their sector where these were identified, as well as any regional specific issues.

Following these workshops, the UK wide assessment of the CCRA produced a consolidated list of priority impacts for the UK as a whole for further analysis based on a scoring methodology (Defra, 2010a), that enabled impacts to be compared across sectors. These were known as the ‘Tier 2’ list of impacts.

It is important to note that the Tier 2 list of impacts was not based on the availability of data; the selection process disregarded how ‘easy’ it was to measure a particular impact. However, once the list of impacts was produced, the next step in the process was to determine whether each impact could be evaluated and measured. The outcome of this process was that approximately half of the impacts were assessed in detail, either fully or semi-quantitatively. The geographical extent of the analysis depended on the availability of suitable data. This varied significantly between England and the other UK countries, with Scotland and Northern Ireland in general being the least data rich.

A second workshop was held in Scotland in September 2010 (CCRA, 2010). The purpose of this workshop was to enable stakeholders to review the list of impacts identified via the sector reports and consultation to date, and to give them a more focussed opportunity to discuss which impacts should be reflected for Scotland in the CCRA. Based on feedback received at the workshop, as well as specific scoring of impacts for Scotland from sector contacts and online feedback, the project team reassessed the Scottish impacts. This rescoring identified 125 impacts that have formed the basis for the impacts that have been considered in this report, and which are

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6 For two sectors Business, Industry and Services and Forestry, sector workshops were not held. Consultation for these sectors was therefore held by telephone interviews with a number of sector specific specialists.
outlined in Appendix A. All of these impacts have been considered in this report, although only 54 were assessed for the UK CCRA. Of the remaining impacts, some were analysed specifically for Scotland (with the results given in Appendix C) and an attempt was made to draw conclusions for the other impacts based on existing evidence and/or case studies. Information on all the Tier 2 list of impacts can be found in the various sector reports (Section 1.2) and the CCRA Evidence Report (CCRA, 2012).

1.5 Key issues raised by stakeholders

A number of key issues were noted by Scottish stakeholders (CCRA, 2010) that were considered to be of particular concern to Scotland. This included the effects of the climate on the natural environment and agriculture, as well as coastal and inland flooding.

Some specific concerns/comments were also made which were:

- Climate change effects in relation to Scotland place more of an emphasis on rainfall and flooding as opposed to heat and warmer weather compared to the rest of the UK. These are anticipated to be main impacts for Scotland, with the change in future rainfall being of most concern.

- It was perceived that the draft UK CCRA sector reports had not utilized or presented information for Scotland to the same extent as was presented for other parts of the rest of the UK (England in particular).

- It was noted that relative sea-level rise seemed to have been considered as less of an issue for Scotland, even though it was still felt to be important for Scotland.7

- It was suggested that heritage / historic aspects had not been highlighted.

- Impacts on remote and isolated communities were felt to be very difficult to manage and may be quite different from other areas of the UK.

- There were a number of issues raised regarding climate uncertainties and how they could be managed. In particular, confidence regarding wind speed projections was raised as an issue, which are considered as particularly important for Scotland. Also, the assumption that Scotland would become “nicer” in terms of weather due to increased temperatures was challenged with a suggestion that it may end up just being “grey” and “foggy”.

- Confidence around the projected changes, and the response of policy makers and budget decisions was a further issue discussed, and how they could be “future proofed” in the light of possible future risks / conditions.

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7 The effects of isostatic rebound which results in an increase in land levels relative to a fixed datum for Scotland acts to reduce and potentially negate relative rises in sea levels for Scotland. Recent research has indicated that sea-level rise may be a greater issue for Scotland than previously thought for a number of coastal areas (Rennie and Hansom, 2011). However, this paper only considers sea levels up to 2007, and inclusion of records to 2010 would reduce the trends indicated.
1.6 Flooding

It should be noted that the Scottish Environment Protection Agency (SEPA) is currently undertaking a flood risk assessment for Scotland, which has to be finished by December 2011. Limited preliminary results for this assessment were made available by SEPA, which only covers current flood risk. Risks due to flooding have therefore been inferred where it is considered appropriate based on the analysis carried out for England and Wales for the CCRA, and baseline data available for Scotland.

Future work is currently planned by SEPA that should be completed by 2013. This work, in addition to the work due to be delivered by the end of 2011 includes the following, and would be available for use in the next CCRA. This would enable analysis for Scotland to be undertaken that would be similar to that which has been possible for England and Wales this time round.

- National flood hazard and flood risk modelling and mapping covering tidal, river and pluvial flooding. These models will be suitable for climate change assessments.
- Selection of climate change scenarios for assessing potential future flood risk.
- Determination of projected changes in rainfall, river flows and sea level for the selected scenarios.
- Modelling of the scenarios in order to determine potential future risk.

1.7 Policy context

1.7.1 Climate Change Act 2008

The passing of the UK Climate Change Act 2008 signified a world first for a long-term legally binding framework looking into tackling climate change. The UK Climate Change Act 2008 creates a new approach to managing and responding to climate change in the UK by:

- setting ambitious, legally binding targets;
- taking powers to help meet those targets;
- enhancing the UK’s ability to adapt to the impact of climate change;
- establishing clear and regular accountability to the UK Parliament and to the devolved legislatures.

The main provisions in the Act relating to adaptation include:

- A UK-wide Climate Change Risk Assessment (CCRA) that must take place every five years, with this report forming part of the first CCRA;
- A National Adaptation Programme (NAP) which must be put in place and reviewed every five years, responding to the risks identified in the CCRA.

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8 See SEPA website, http://go.mappoint.net/sepa/
9 http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx
10 This covers England and reserved matters.
Adaptation Reporting Powers which enable the Secretary of State to direct “reporting authorities” to prepare climate change adaptation reports.

The Adaptation Sub-Committee of the Committee on Climate Change has been established under the Act to inform and advise the government on the CCRA, the UK Government’s progress in the implementation of the National Adaptation Programme and to provide advice to the Devolved Governments, as required.

1.7.2 Climate Change (Scotland) Act 2009

The Climate Change (Scotland) Act 2009 came into force in August 2009. The Act sets out ambitious targets for the transition of Scotland to a low carbon country. It also establishes the legislative framework to follow the Scottish Government’s ambitions to promote climate change adaptation in a number of ways, namely:

- A Scottish Adaptation Programme which must be put in place and reviewed every five years, responding to the risks identified for Scotland in the UK CCRA.
- An Annual Report on Progress towards implementing the Programme and the requirement to seek independent scrutiny of progress.
- Duties for Public Bodies, requiring them to exercise their functions in the way best calculated to help deliver the Scottish Adaptation Programme and act in a way it considers most sustainable.
- A Land Use Strategy, setting out objectives, proposals and policies relating to sustainable land use.

As required by the Act, the Scottish Government has published guidance to support public bodies in exercising their duties under the Act. This guidance identifies “major players” - public sector organisations that have a larger impact or influence on climate change than others. Included in this list are Scotland’s academic establishments, local authorities, the police and health boards and devolved public bodies; e.g. SEPA, Scottish Natural Heritage, (SNH) and Scottish Water.

1.7.3 Scotland’s Climate Change Adaptation Framework and Sector Action Plans

Scotland’s Climate Change Adaptation Framework is a non-statutory forerunner to the first Adaptation Programme.

The Framework was published in 2009 with an overarching aim to “increase the resilience of Scotland’s communities, and the natural and economic systems on which they depend, to the impacts of climate change”. It has established three pillars of action to achieve this:

1. Improve understanding about the consequences of a changing climate (both challenges and opportunities);
2. Equip stakeholders with the skills and tools needed to adapt; and
3. Integrate adaptation into wider public policy and regulation.

The Adaptation Framework has also established 12 key sectors where adaptation action will be focused. ‘Sector Action Plans’ were published in March 2011, which

have considered existing sources of information and research to identify the key potential impacts of climate change and appropriate actions that can build resilience.

Annual progress reporting on the Adaptation Framework includes details of progress on the Sector Action Plans.

1.7.4 **Scotland’s Policy by CCRA Theme**

*The Natural Environment*

The Scottish Government has devolved responsibility for most environmental policies in Scotland including climate change. The key public bodies relating to climate change adaptation in the Natural Environment in Scotland are SEPA, SNH, Marine Scotland and Forestry Commission Scotland.

**Key public bodies**

The **Scottish Environment Protection Agency**'s (SEPA) main role is to protect and improve the environment and human health. SEPA does this by controlling activities that can cause harmful pollution, by monitoring the quality of Scotland’s air, land and water, and by working to enable those we regulate to comply with legislation. SEPA also has a significant responsibility for Flood Risk Management in Scotland, and for coordinating strategic planning for flood risk, providing flood warnings and giving flood risk advice to land use planning authorities.

Protection and improvement of the water environment is driven through the river basin management planning (RBMP) process. SEPA is the competent authority for river basin management planning and co-ordinates the preparation of the RBMPs, working in partnership with other responsible authorities and water users to achieve this and the objectives outlined in the plans.

SEPA is responsible for producing strategic flood risk management plans under the Flood Risk Management (Scotland) Act 2009 (FRM Act). The FRM Act introduces a joined up and co-ordinated process to reduce flood risk at a national and local level, and aims to reduce the impact of flooding on people, the economy and the environment. Under the FRM Act, SEPA also has enhanced flood warning responsibilities, and additional duties for provision of flood risk advice to land use planning authorities.

Making sure Scotland links river basin management planning and flood risk management processes will help SEPA deliver greater benefits to the water environment and to the communities and businesses affected by flooding. Many actions to restore the water environment can also help mitigate flooding impacts. Better coordination will also help us avoid conflict between the two processes. Furthermore, harnessing the opportunities to integrate these processes will also help us minimise demands on stakeholder time. Management of the water environment, including flood risk management, is best understood, and addressed, at the catchment level.

**Scottish Natural Heritage** (SNH) works to look after Scotland’s nature and landscapes through its advice to Scottish Government and its agencies, local authorities, developers, land managers and others. SNH promotes the benefits of looking after nature, and takes action in partnership with others, for example on protected areas. In relation to climate change, SNH aims to raise awareness of the effects of climate change on nature and to help deliver the contribution that the natural heritage can make in limiting it and adapting to it. For example, SNH encourages the development of healthy ecosystems, with more connection between habitats to allow for species to spread as the climate changes. SNH encourages the use of natural
processes in reducing flood risks, by creating river wetlands or making use of natural coastal defences.

**Marine Scotland** was established in April 2009 bringing together the functions and resources of the previous Scottish Government Marine Directorate, Fisheries Research Services and the Scottish Fisheries Protection Agency ready to deliver integrated management of Scotland’s seas. Marine Scotland is leading the development of the Marine and Fisheries Adaptation Sector Action Plan.

**Forestry Commission Scotland** advises on adaptation for woodland habitats and woodland habitat networks. Forestry Commission Scotland also highlights the value of woodland to reduce riverbank erosion, to complement natural flood management, and to help stabilise slopes liable to landslip. It also advises on changes to forestry practices, including choice of tree species, and ways to manage forests that will increase their resilience to our changing climate.

**Scottish legislation**

The natural environment encompasses all living and non-living things occurring naturally on Earth and therefore has a range of policies and legislation which direct Scottish action. UK and European legislation helps shape and direct policy and plans within Scotland and are an important influence. Scotland’s biodiversity legislation is outlined below.

- In Scotland the Habitats Directive is transposed through a combination of the **Habits Regulations 2010** (in relation to reserved matters) and the **Conservation (Natural Habitats, &c.) Regulations 1994**.

- **Nature Conservation (Scotland) Act 2004**, which reformed the **Wildlife and Countryside Act 1981** in relation to species protection and Sites of Special Scientific Interest. It also requires the Scottish Ministers to publish a biodiversity strategy and a duty on public bodies to further the conservation of biodiversity.

- **Marine (Scotland) Act 2010** which introduces a new system for marine planning which will address climate change objectives and includes a duty to create a network of Marine Protected Areas.

- **Wildlife and Natural Environment (Scotland) Act 2011** which includes provisions on non-native species and on deer management, including codes of practice for each.

The Water Environment and Resource Sector Action Plan identifies key climate change impacts on the water sector as well as ways in which this is already being managed and appropriate actions to improve resilience. The Scottish Government has lead responsibility for water policy in Scotland. For environmental aspects and the production of flood risk management strategies the responsibility lies with SEPA. The main legislation in Scotland includes:

- The **Water Environment and Water Services (Scotland) Act 2003 (WEWS Act)** requires SEPA to work with responsible bodies to prepare RBMPs outlining the flood risk management properties for Scotland. It places responsibility with statutory agencies, businesses, public sector bodies and individuals to the water environment and provides coordination of all water management aspects. The WEWS Act also gave Scottish ministers powers to introduce regulatory controls over water activities, in order to protect, improve and promote sustainable use of Scotland’s water environment (**The Water Environment (Controlled Activities) (Scotland)**)

- The Flood Risk Management (Scotland) Act 2009 introduced a more sustainable approach to flood risk management. The act aims to improve social, economic and natural resilience against flooding for current and future generations.

The Marine (Scotland) Act 2010 together with powers from the marine and Coastal Access Act 2009 gives obligations for marine planning, licensing, nature conservation and an overall integrated approach to management of Scottish territorial seas. Any marine plan must include climate change adaptation and mitigation objectives (Scottish Government, 2010a).

Scottish policy

Supporting the legislation are several frameworks and strategies to aid adaptation.

Scotland’s biodiversity – it’s in your hands (2004) strategy document aims to conserve biodiversity for the health, enjoyment and wellbeing of the people of Scotland now and in the future. The key theme of the strategy is to reinforce the link between people and biodiversity. The strategy follows five ecosystem types: freshwater and wetland, lowland and farmland, marine and coastal, upland and woodlands. The Strategy is being refreshed in 2012 to reflect the new global and EU 2020 targets, and the need to increase resilience to climate change. Scotland’s Climate Change Adaptation Framework Biodiversity and Ecosystem Resilience Action Plan (2009) identifies the following broad areas for action as identified in SNH’s Climate change and natural heritage - SNH’s approach and action plan (2009) (being updated 2012):

- Promotion of natural flood management in catchment planning
- Adaptive coastal management including managed coastal realignment
- Using natural features in urban areas to assist adaptation
- Management of nature conservation sites to take account of changing climate
- Managing species conservation priorities to take account of changing climate
- Reducing pressures on habitats vulnerable to climate change
- Promoting ecological connectivity to assist species movement and make species and habitats more resilient to climate change
- Continuing pressure on non-native species that impact on native biodiversity.

SNH has also produced “Sustaining Nature’s Services: Adopting an ecosystem approach”. An ecosystem approach provides a framework for delivering biodiversity actions at a larger scale that also allows the needs of people to be incorporated as well. “Valuing our Environment: The Economic Impact of Scotland’s Natural Environment” links the importance of the natural environment to Scotland’s economy and highlights the need to use it sustainably to secure Scotland’s future. The Soil Framework for Scotland (2009) and Scotland’s Soil Resource – Current State and Threats (2011) cover climate change impacts on soils and associated biodiversity. The National Planning Framework 2 supports the development of a National Ecological Network. The Land Use Strategy for Scotland ‘Getting the best from our Land’ (2011) provides a high-level framework for integrating these policy commitments within
a series of common principles and proposals, including action relating to climate change adaptation. It is accompanied by an information note on **Applying an ecosystems approach to land use.**

**UK and international legislation**

Key UK wide legislation for the natural environment includes:

- The Offshore Marine Conservation (Natural Habitats, & c.) Regulations 2007 (UK offshore waters only – doesn’t apply to territorial waters).
- UK Marine and Coastal Access Act 2009 (English, Welsh and UK offshore waters only).

Influencing European legislation for the natural environment includes:

- **Directive 2009/147/EC (Birds Directive).** This is the codified version of Directive 79/409/EEC as amended. It includes the designation of sites both on land and in coastal environments as **Special Protection Areas** (SPAs) for birds.

- Council **Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (Habitats Directive), 1992.** This includes the designation of **Special Areas of Conservation** (SACs) both on land and in offshore waters.

- The **Directive 2000/60/EC, the EU Water Framework Directive (WFD) (2000),** which provides guidance on land management. This directive impacts on all land owners and managers through “River Basin Management” and, hence, shaping agriculture, water, forestry, and biodiversity legislation. Additionally, the water quality targets outlined in the WFD become more important during low flows scenarios (European Commission, 2010). The WFD requires member states to implement a series of measures designed to provide for ‘good ecological status’ in water bodies, and to carry out a programme of River Basin Management Planning.

- The **2000 Nitrates Directive (91/676/EEC)**. Through the prevention of pollution of surface and ground waters from agricultural nitrates and promotion of the use of good farming practices, this Directive aims to protect water quality. Several steps are required, including the identification of polluted or threatened waters, the designation of nitrate vulnerable zones (NVZ) and the establishment of action programmes and monitoring systems.

- The **2006 Bathing Water Directive (76/160/EEC)** preserves, protects and improves bathing water quality to ensure it is clean and healthy. The quality of bathing water is summarised in annual reports published by the European Commission.
• The **Floods Directive (2007/60/EC)**\(^{14}\). This entered into force in 2007 and covers the assessment and management of flood risks. Prevention, protection and preparedness are the focus of flood risk management plans, which are produced by Member States in coordination with River Basin Management Plans, ensuring that this Directive is implemented in synchrony with the WFD.

• **Directive 2008/56/EC** on establishing a framework for community action in the field of marine environmental policy - known as the **Marine Strategy Framework Directive (MSFD)**. In particular this requires member states to implement measures to provide for 'good environmental status' in marine environments.

• The **Common Fisheries Policy** which shapes Scottish marine fishing.

Similarly, global conventions help shape the Scottish, UK and European policy and legislation:

• The UN Convention on Biological Diversity (**Biodiversity Convention or CBD**).

• The Convention on Wetlands of International Importance especially as Waterfowl Habitat (**Ramsar Convention or Wetlands Convention**).

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**Agriculture and Forestry**

**Agriculture**

The agriculture sector is administered and managed in different ways according to devolved responsibilities. Defra has responsibility for agricultural policy at a UK Government level, but agricultural policy for Scotland is devolved to the Scottish Government.

Agriculture in Scotland operates within the overall context of the European Union’s **Common Agricultural Policy** (CAP) as well as other European policies. The CAP has a role to play in facilitating adaptation by helping farmers to adapt their production to the changing climatic situation and to provide wider ecosystem services dependent on land management (European Commission, 2009). CAP will be reformed after 2013 and the EU has indicated that a greater emphasis will be given to promoting adaptation measures at farm level. The CAP has identified three priority areas for action to protect and enhance the EU’s rural heritage: Biodiversity and the preservation and development of 'natural' farming and forestry systems, as well as traditional agricultural landscapes; water management and use; dealing with climate change\(^{15}\).

CAP currently supports climate change adaptation through the **Scotland Rural Development Programme** (SRDP). This is a £1.5 billion programme of economic, environmental and social measures designed to develop rural Scotland\(^{16}\). It includes measures to address economic and social goals as well as environmental measures. It is outcome-focused and primarily aims to deliver a Greener Scotland. It brings together a wide range of formerly separate support schemes including those covering the farming, forestry and primary processing sectors, rural enterprise and business development, diversification and rural tourism. The Crofting Counties Agricultural Grants Scheme (CCAGS) provides assistance towards improving and sustaining the viability of croft businesses.

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\(^{15}\) [http://ec.europa.eu/agriculture/envir/index_en.htm](http://ec.europa.eu/agriculture/envir/index_en.htm)

UK agriculture is also shaped by other EU directives that influence land management, such as the Water Framework Directive (WFD) and the Nitrates Directive.

The Water Framework Directive (WFD) has an impact on agriculture through the control of pollution, especially that occurring due to diffuse discharge via runoff and leaching, and water abstraction. Agricultural practices which can contribute to pollution discharge include fertilization of crops, slurry spreading and the spraying of pesticides. The WFD requires farmers to carefully manage land and farm practices to meet the targets of a good ecological status for all water bodies.

The Nitrates Directive (91/676/EEC) also influences land management. It requires the identification of areas where groundwaters have high nitrate concentrations or are thought to be at risk of nitrate contamination. Areas associated with such groundwaters are designated as Nitrate Vulnerable Zones (e.g. Lower Nithsdale) within which Action Programmes must be established in order to reduce and prevent further nitrate contamination.

Forestry

In Scotland, forestry policy is set within the broad context of growing the economy in a sustainable way to raise quality of life. The Scottish Forestry Strategy's core principles are based on sustainable development and social inclusion, achieved through a culture of ‘forestry for and with people’ and delivered in well managed forests and woodlands that integrate effectively with other land uses and businesses (Scottish Executive, 2006).

Seven key policy themes have been chosen to deliver the vision above:

- Using forestry, and adapting forestry practices, to help reduce the impact of climate change and help Scotland adapt to its changing climate.
- Getting the most from Scotland’s increasing and sustainable timber resource.
- Strengthening forestry through business development to underpin sustainable forest management and support economic growth and employment across Scotland.
- Improving the quality of life and wellbeing of people by supporting community development across Scotland.
- Making access to, and enjoyment of, woodlands easier for everyone - to help improve physical and mental health in Scotland.
- Protecting the environmental quality of our natural resources (water, soil and air), contributing to and improving our scenery, and helping to make the most of our unique historic environment.
- Helping to restore, maintain and enhance Scotland’s biodiversity, and increasing awareness and enjoyment of it (Scottish Executive, 2006).

Scottish forestry policy seeks to encourage effective integration with other land uses, and with sectors such as energy, transport, health, water, education and tourism, to get the most out of these key themes.

Forestry policy in Scotland recognises the specific role of forests in tackling climate change, and has identified several actions for Forestry Commission Scotland, namely:
- Protecting and managing existing forests through sustainable forest management, conserving carbon stocks, and minimising woodland removal (Scottish Government, 2011a).

- Creating new woodland to capture carbon, produce wood and help adaptation. There is a policy to increase the tree planting rate to 10,000 ha per year and a proposal to consider increasing this rate towards 15,000 ha per year (Scottish Government, 2011a).

- Adapting to climate change by planning and managing forests and woodlands in a way that minimises future risks from climate change, for example through the creation of forest habitat networks, and using different timber species, including hardwoods, or silvicultural systems.

- Promoting the use of sustainably produced wood for energy and construction.

- Reducing the forestry sector's carbon footprint.

- Raising awareness and understanding of climate change and how forestry can make a positive contribution.

- Measuring progress (Forestry Commission Scotland, 2009).

The **Scottish Land Use Strategy** also proposes action for climate change adaptation which is relevant to forests and the forestry sector. A review of Scotland's approach to the CAP, including the role of Scotland's Rural Development Programme in supporting climate change objectives through forestry measures, is being undertaken in the lead up to the next Rural Development Programme period which starts in 2014.

An analysis of preparedness for adaptation in the Scottish forestry sector considered that it has 'a strong platform to start from' based on existing policies and their likely, near-future, development.

Forest legislation is guided by the Forestry Act 1967. Scottish forestry policy is determined by Forestry Commission Scotland on behalf of the Scottish Government. The Scottish Forestry Strategy's core principles are based on sustainable development and social inclusion, achieved through a culture of 'forestry for and with people' and delivered in well managed forests and woodlands that integrate effectively with other land uses and businesses (Scottish Executive, 2006).

The **Climate Change Action Plan (2009-2011)** (Forestry Commission Scotland, 2009) describes what the Forestry Commission will do to increase the adaptation measures and response to the challenges of climate change. This strategy encapsulates all areas where forestry is relevant to climate change including increasing carbon sequestration, ecological adaption, increasing the knowledge of species adaption and planting natural woodlands that promote biodiversity.

The Scottish Forestry Strategy is the Scottish Governments framework for taking forestry forward through the first half of this century and beyond. The focus is on people interaction, providing a high quality business and enhancing the natural environment (Scottish Executive, 2006).

**Business and Services**

Although it is for businesses themselves to mainstream adaptation into their strategies, the Scottish Government, Scottish Enterprise, Highlands & Islands Enterprise, SEPA and the Adaptation Scotland can support businesses in this. The Scottish
Government’s Economic Strategy (2011) highlights the need for the potential risks and opportunities posed by climate change impacts to be taken into account.

The Business and Industry Sector Action Plan sets out the key climate change issues and challenges and planned work to strengthen resilience of Scottish businesses to the impacts of climate change.

Adaptation Scotland provides free advice and support to help business adapt to climate change, including ‘Adapting to Climate Change: A Guide for Businesses in Scotland’ and a series of information notes to help small businesses.

“Secure and Resilient: A Strategic Framework for Critical National Infrastructure in Scotland” includes an aim to minimise the disruption to the Scottish public and business community by ensuring that relevant consequence management plans are in place, which may aid adaptation.

Government, SEPA, Scottish Enterprise and Highlands & Islands Enterprise have a responsibility to continue to increase businesses’ awareness and develop policy to direct them accordingly.

Infrastructure and Buildings

The Scottish Government provides a framework for infrastructure and the built environment for devolved matters, including planning, transport policy, architectural policy and building regulations. Scottish Enterprise, Highlands & Islands Enterprise, Transport Scotland and SEPA work together in areas such as renewable energy, sustainable construction, transport infrastructure and environmental management to support and facilitate the achievement of the Scottish Government framework for infrastructure and the built environment.

Adaptation to climate change through spatial planning is an integral part of the long term development strategy set out in the second National Planning Framework (NPF2). Scottish Planning Policy (SPP) sets the need to tackle climate change as a principal challenge of sustainable economic growth. Sustainable flood management and urban drainage are also key aspects of planning policy in Scotland. The role of green infrastructure in helping to adapt to climate change is also recognised in the Scottish Government planning policy (Green Infrastructure: Design and Placemaking, Scottish Government, November 2011). The Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005 identifies structure and guidance for dealing with emergency situations outlining the responsibilities at ground level and providing direction on the organisation and implementation of emergency efforts.

Scottish Ministers are responsible for the building standards system in Scotland with the key purpose of protecting the public interest, creating building regulations and preparing technical guidance to ensure both domestic and non-domestic buildings are safe, efficient and sustainable. Energy performance and reduction of carbon emissions are key aspects of built environment policy in Scotland. One of the aims under the Building (Scotland) Act 2003 is furthering the achievement of sustainable development. A key aspect of the guidance supporting the Act focuses on a reduction in carbon footprints and the achievement of sustainable development in new buildings and current building stock.

The Scottish Government is supported by Historic Scotland, SNH, SEPA and the Forestry Commission in promoting and highlighting actions to help prepare Scotland to adapt to climate change in the built historic environment as well as the associated

natural environment. The key agencies and Scottish Government have prepared a resources and guidance pack, *Planning and Climate Change: Key Agency and Scottish Government Resources and Guidance*\(^\text{18}\) to assist in embedding climate change issues into planning processes including development plans. The National Trust for Scotland has identified a range of climate change impacts on both natural and built heritage, and recognises that Historic Scotland should be supported to carry out research on introducing acceptable adaptation measures for historic buildings, appropriate management and maintenance techniques and craft skills.

The *Flood Risk Management (Scotland) Act 2009* will lead to improved information on flood risk in the form of flood risk and hazard maps (by 2013) and flood risk management plans (by 2015). These will inform planning authorities when they prepare development plans and determine specific planning applications. Frameworks have been developed including *Secure and Resilient: A Strategic Framework for Critical National Infrastructure in Scotland* and *Choosing our future: Scotland’s sustainable development strategy*. A number of initiatives that focus on making the construction industry in Scotland “greener”, more sustainable and resilient to extreme weather events are ongoing.

Transport policy in Scotland is guided by the *National Transport Strategy* which sets out the Scottish Government’s priorities for transport in Scotland. Transport Scotland is the Scottish Government national agency directly responsible for the trunk road network. They also lead on Scottish strategy and policy for transport overall, along with responsibility for overseeing the rail franchise requirements and providing outputs from Network Rail through the *High Level Output Specification*\(^\text{19,20}\). Elements of transport infrastructure management are devolved to country level including Transport Scotland, the Welsh Government and the Northern Ireland Executive, who operate and manage the main road networks in those countries, setting their own policy for each devolved administration.

The *Climate Change (Scotland) Act 2009* sets an ambitious interim target to reduce Greenhouse Gas (GHG) emissions by at least 42% by 2020. In support of this target, the *Scottish Energy Sector Action Plan*\(^\text{21}\) sets out how to ensure that Scotland is well placed to maximise the opportunities presented by climate change and minimise the resulting negative impacts.

**Health and Wellbeing**

In the UK, the Department of Health leads the health and social care sector, which includes the National Health Service (NHS), the social care sector and arm’s length bodies (ALBs) (e.g. the Health Protection Agency).

With few exceptions, such as the regulation of medicines, public health and healthcare are devolved to the Scottish Government under the *Scotland Act 1998*. The Scottish Government Health Directorate provides the central management of the NHS in Scotland, and oversees the work of the 14 territorial NHS boards that plan and deliver health services.

The introduction of the new *Public Health Etc (Scotland) Act* in 2008 improved the ability of the Government and the public health community to respond to the health challenges posed by climate change. More specifically, the Scottish Government’s

\(^{18}\) http://www.scotland.gov.uk/Topics/Built-Environment/planning/modernising/cc/Climatechange

\(^{19}\) http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/adaptation/AdaptationFramework/SAP/Transport/KeyPolicies

\(^{20}\) The Scottish Transport Sector Action Plan only considers trunk roads, not all roads (see also Section 4.5.1)

Health and Wellbeing Sector Action Plan looks to existing sources of information and research to identify the key issues in adapting to the consequences of climate change for the health and wellbeing of the Scottish population and on the healthcare sector. The Action Plan considers the effects of temperature, extreme weather events, water quality etc., and provides an indication of the broad range of work planned over the coming years to strengthen resilience to the impacts of climate change in these areas. It also considers what the health sector can do to help other sectors and wider society adapt.

The Energy Assistance Package, which is administered by the Energy Saving Trust in Scotland, provides advice on how to cut energy bills and make homes warmer and on provisions whereby vulnerable groups might qualify for extra income, discounted energy rates, free insulation or a new central heating system.

The Department of Health (2010) also outlines the connection between public health and wellbeing and climate change and sustainability. It recognises the need to promote readiness in the NHS to deal with any negative impacts on physical and mental health that may be caused by climate change. This includes plans to introduce Warm Deal grants to reduce fuel poverty by providing insulation for homes which may reduce stress and anxiety by 50%. Additionally, targeting those at risk from flooding would provide information on how to prepare and deal with events.
2 Climate variability and change in Scotland

2.1 Current climate

The climate of Scotland is temperate and oceanic, and tends to be very variable geographically. It is warmed by the North Atlantic Drift from the Atlantic, and as such has much milder winters, but cooler and wetter summers than other countries on similar latitudes. However, temperatures are noticeably lower than the other regions in the UK assessed as part of the CCRA.

Some of the main characteristics of Scotland’s climate and how these compare with other parts of the UK are summarised below:

- **Mean annual air temperatures** – Mean annual temperatures differ significantly over Scotland, and are generally lower than the rest of the UK. These vary from approximately 0°C over the mountainous regions of Ben Nevis, to 9.4°C to 9.7°C in coastal areas such as Ayrshire, Bute and Kintyre. Elsewhere in the UK, mean annual temperatures reach over 11°C in Cornwall and the Channel Islands.

- **Maximum air temperatures** – July or August is the warmest month with a mean daily maximum temperature of 19-20°C in low areas to less than 16°C elsewhere. These compare to 22.5°C in the London area. Instances of high temperatures more common in the rest of the UK are relatively rare, with the record high for Shetland for example only 25°C.

- **Minimum air temperatures** – January and February are the coldest months, with the mean daily minimum temperatures varying between less than -3°C on the mountainous areas of the west to 2°C on west facing coasts. However, very low temperatures can be experienced in Scotland, with the UK record low of -27.2°C being shared between two Scottish locations.

- **Frost** – The average number of days with frost in Scotland differs widely based on location. Air frost varies from less than 25 days a year in the Hebrides to more than 90 days a year over the higher ground of the Lammermuir Hills and the Grampians. Ground frost varies from less than 60 days per year to over 150 days per year with a similar distribution as for air frost. These are typically of greater number with a wider range than for the rest of the UK.

- **Mean annual precipitation** – Much of the west of Scotland is exposed to the rain-bearing westerly winds, particularly the Western Isles and the west coast. As a result, most of the western half of the region has an average annual rainfall of at least 1700 mm. The highest average annual rainfall occurs over the higher, west-facing slopes, with the wettest area being to the northwest of Fort William (over 4000 mm per year, the largest in the UK). Over the lower lying islands the average is less than about 1600 mm whilst along the coasts of East Lothian, Fife and the Moray Firth, it is only about 700 mm. These values can be compared with annual totals of around 500 mm in the driest parts of Eastern England.
• **Snowfall** – Over most of Scotland, snowfall is confined to the months November to April, although upland areas often have brief falls in October and May. On average, the number of days with snow falling varies from less than 10 per year in the Hebrides to over 100 days over the Grampians. The number of days with snow lying has a similar distribution, with less than 5 in the western islands and along the west coast, but over 60 days over the higher ground of the Grampians. On the highest summits, such as Ben Nevis, snow cover typically persists for 6 or 7 months each year. These averages can be compared with the coasts of South West England where less than 3 days per year have lying snow.

• **Wind** – The western and northern parts of Northern Scotland are, on average, the windiest in the UK, being fully exposed to the Atlantic and closest to the passage of areas of low pressure. Upland areas typically have over 20 days of gales\(^{22}\) per year, with the Hebrides having over 25 days. Most inland areas average around 5 days per year.

• **Sunshine** – The sunniest places in Scotland are in the east, where on the coast of Fife they average 1500 hours per year. Other coastal places, for example in East Lothian and the Solway coast average more than 1400 hours but sunshine averages are lower elsewhere, and are lowest over the mountains; the West Highlands and Shetland for example average less than 1100 hours per year. The sunniest places on mainland UK are along the south coast of England, with over 1750 hours each year on average, whilst the Channel Islands enjoy over 1900 hours.

More detailed information about Scotland’s current climate can be found on the Met Office website.\(^{23}\)

### 2.2 Recent climate trends

Climate trends across Scotland were assessed in SNIFFER, (2006) for the period 1961 to 2004. This section highlights the main findings that were identified in this report based on best estimates, with the complete modelled figures given in Appendix B. These trends are assessed by the three regions North, West and East Scotland, shown in Figure 2.1.

In all cases the seasons have been assessed as follows:

- **Spring** - March, April, May
- **Summer** - June, July, August
- **Autumn** - September, October, November
- **Winter** - December, January, February

\(^{22}\) A gale is defined as a mean wind speed of 34 knots (about 39mph) or more over any consecutive period of ten minutes or longer in a day.

\(^{23}\) http://www.metoffice.gov.uk/climate/uk/
- **Average annual temperature (Appendix B, Figure B1)** – These were noted to increase for all seasons for all regions. Increases were typically at least 1°C for the spring, summer and winter, and approximately 0.7°C for the autumn.

- **Maximum temperatures (Appendix B, Figure B2)** – These were noted to increase for all seasons for all regions. Increases were about 10% greater than for the average annual temperatures given above.

- **Minimum temperatures (Appendix B, Figure B3)** – These were noted to increase for all seasons for all regions. Increases were about 10% less than for the average annual temperatures given above. It should be noted that since this report was issued, there have been two exceptionally cold winters, namely 2009/10 and 2010/11. The winter of 2010/11 was the second coldest since 1985/86\(^24\).

- **Daily Temperature Range** – The temperature range was noted to increase for the spring, autumn and winter seasons by approximately 0.24-0.30°C, 0.24-0.46°C and 0.30-0.45°C respectively, with increases greatest in the north, and least in the east. There was no detectable trend for the summer season for all regions.

\(^{24}\) www.metoffice.gov.uk/climate/uk/2011/winter.html
• **Heating degree days**\(^{25}\) ([Appendix B, Figure B4]) – These were noted to have reduced by approximately 9% for the north, and 11% for the east and west regions.

• **Growing degree days**\(^{26}\) ([Appendix B, Figure B5]) – Growing degree days were noted to have increased by approximately 22% for all regions.

• **Length of the growing season**\(^{27}\) ([Appendix B, Figure B6]) – This was noted to have increased by approximately 32% in the north and east and about 37% in the west.

• **Growing season start and end dates** ([Appendix B, Figure B7]) – The growing season was noted to have started earlier by approximately 20 days for the north and east regions, and 22 days for the west region and ended about 12 days later for the north and east regions, and 14 days for the west region.

• **Extreme temperature range** ([Appendix B, Figure B8]) – The extreme temperature range was noted to have shown no change in the north, yet a 3°C decrease in the east and a 2°C decrease in the west.

• **Length of summer heatwaves and winter cold spells** ([Appendix B, Figure B9]) – The number of heatwave days was noted to have increased by approximately 6 days in the north and east and by 4 days in the west. The number of cold spells was noted to have reduced by approximately 6 days in the north and 8-9 days in the east and west.

• **Air frost** ([Appendix B, Figure B10]) – The number of days of air frost was noted to have reduced by approximately 30% in the spring, 33% in the autumn, 20% in the winter in the north and east, and 25% in the west. December 2010, after this report was issued, was the coldest December across the UK in over 100 years\(^ {24}\).

• **Ground frost** ([Appendix B, Figure B11]) – For the spring, the number of ground frost days was noted to have decreased by approximately 11, 9 and 8 days respectively in the north, east and west regions. For the summer, this was approximately 3 days for the north, and 1-2 days for the east and west. For the autumn this was approximately 8 days for the north and 4 days for the east and west. For the winter, this was approximately 8 days for the north and east, and about 10 days for the west.

• **Early and late season frosts** – First ground frosts were noted to occur between 3-12 days later and late frosts between 12 and 24 days earlier for Scotland as a whole. This typically increased the frost free season by approximately 15-35 days for Scotland.

• **Average precipitation total** ([Appendix B, Figure B12]) – Average precipitation was noted to have increased variably for all regions for all seasons. These were greatest in the winter, typically increasing by over 36% in the east, and 60-70% in the north and west. The only noted decrease was an approximate 7% reduction in the north in the summer.

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\(^{25}\) This is the day-by-day sum of the mean number of degrees by which the air temperature is less than 15.5°C; so called as it provides an indication of heating demand.

\(^{26}\) This is the day-by-day sum of the mean number of degrees by which the air temperature is more than 5.5°C.

\(^{27}\) This is the period bounded by daily mean temperatures of greater than 5°C for more than 5 consecutive days and daily mean temperatures of less than 5°C for more than 5 consecutive days (after 1 July).
Snow cover (Appendix B, Figure B13) – Snow cover was noted to decrease by approximately 28% in the north and east and over 40% in the west in the spring. For the autumn, the decrease was 70-80%. Snow cover in the winter months was noted to decrease by approximately 26-37%, least in the north and greatest in the west.

Days of heavy rain each year (Appendix B, Figure B14) – The number of days of heavy rain was noted to have increased by approximately 1-2 days in the spring. The summer showed a decrease of approximately 1 day in the north and east with a 1 day increase in the west. No noticeable trend was noted in the autumn, apart from a 3-4 day increase in the east. Winter days of heavy rain where noted to have increased noticeably, approximately 8 days in the north and west, and 3-4 days in the east.

Number of consecutive dry days (Appendix B, Figure B15) – The number of consecutive dry days was noted to show little discernable trend apart from a slight (1 day) increase in the east.

Average rainfall intensity (Appendix B, Figure B16) – The number of days per year where 1mm or more of rain fell was noted to increase by approximately 7-8%.

Maximum five-day rainfall (Appendix B, Figure B17) – The maximum five-day rainfall amount was noted to have increased by approximately 17% in the north and by approximately 25% in the east and west.

Average pressure at sea level (Appendix B, Figure B18) – The change in average sea level air pressure was noted to show little variation for the spring, summer and autumn months for all regions (less than 1hPa). For the winter, there was a reduction of about 3 hPa in the north, and approximately 1-2 hPa in the east and west.

Average wind speed each year – There has been no detectable trend in average wind speeds over the last 40 years.

Days of gales each year – There has been no detectable trend in the number of gales over the last 40 years.

Sunshine hours (Appendix B, Figure B19) – The percentage changes in sunshine hours are variable across Scotland. Typically there has been a 3-7% increase in the spring, no noticeable trend in the summer, and an 11-18% increase in the autumn. For the winter, the change in sunshine hours is very dependant on region, with a 13% increase in the east, yet a 5% decrease in the north and no discernable trend in the west.

Cloud cover – There has been no detectable trend in the amount of cloud cover over the last 40 years.
2.3 Climate projections

Based on the UKCP09 projections\(^{28}\), the future climate in Scotland is likely to result in:

- Higher temperatures in summer and winter
- Increased winter rainfall, but a decrease in summer rainfall
- More heavy rainfall days\(^{29}\) in summer and winter
- A rise in relative sea level

The tables presented in the sections below show the UKCP09 projections for Scotland that have been used in the CCRA analysis. These are presented for three time periods termed the 2020s, 2050s and the 2080s, for the Low, Medium and High emissions scenarios relative to a 1961-1990 baseline. Results are also presented for three probability levels termed the p10, p50 and p90 corresponding to the lower, central and upper estimate of the projections. Temperature and precipitation projections are presented for the three UKCP09 administrative regions in Scotland. Further details on the time periods, emission scenarios and probability levels are given in Defra (2010a).

The projections provide information on climate as averages for a 30-year time period in the future. The modelling approach does consider climate variability, but as the outputs are presented as 30-year averages they do not provide projections of climate variability at the shorter time scales (e.g. seasonal, annual and decadal). When examined at shorter time scale, due to these shorter-term variabilities, the observed changes may differ (larger or smaller) than those suggested by the 30-year averages.

Other potential changes in the climate include:

- More frequent and more intense extreme rainfall events
- More extreme events (e.g. flood, heat) and a greater magnitude of extremes
- Increases in sunlight and UV radiation
- Small change in frequency or intensity of winter storms (although this has a high degree of uncertainty - see Section 2.3.4)\(^{30}\)
- Small change in summer or winter wind speeds or number of windy days (although this has a high degree of uncertainty – see Section 2.3.4).

Specific data for changes in wind speed or the number of windy days were not provided in UKCP09\(^{31}\). Therefore, the CCRA has not undertaken quantitative estimates of their impacts.

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\(^{28}\) Using the central estimates for the medium emissions scenario.

\(^{29}\) Days with a rainfall amount greater than 25mm.

\(^{30}\) Depressions (cyclones) or low pressure areas, not thunderstorms.

\(^{31}\) Since the initial launch of UKCP09, probabilistic projections of wind speed have been produced (Sexton and Murphy, 2010). However, projections are highly uncertain and it is not known whether they are likely to increase or decrease.
2.3.1 Temperature

Temperatures are projected to increase for Scotland. Mean annual increases of 1.1°C to 3.4°C (Eastern Scotland), 1.0°C to 3.1°C (Northern Scotland) and 1.2°C to 3.6°C (Western Scotland) are projected by the 2050s and 1.4°C to 5.1°C (Eastern Scotland), 1.3°C to 4.7°C (Northern Scotland) and 1.5°C to 5.5°C (Western Scotland) by the 2080s from the 1961-1990 baseline (Table 2.1). Increases in mean seasonal temperatures are typically projected to be lower in the winter and spring months and higher in the summer and autumn months (Tables 2.3 to 2.6).

Table 2.1 Temperature change (baseline 1961-1990): Mean annual temperature rise (°C)

<table>
<thead>
<tr>
<th>Emissions scenario</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
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<tbody>
<tr>
<td></td>
<td>p10</td>
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<td>p90</td>
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<td></td>
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<tr>
<td>Low</td>
<td>1.1</td>
<td>1.9</td>
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</tr>
<tr>
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<td>0.6</td>
<td>1.2</td>
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Table 2.2 Temperature change (baseline 1961-1990): Annual maximum temperature rise (°C)

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### Table 2.3  Temperature change (baseline 1961-1990): Mean Winter (DJF) temperature rise (°C)

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### Table 2.4  Temperature change (baseline 1961-1990): Mean Spring (MAM) temperature rise (°C)

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### Table 2.5  Temperature change (baseline 1961-1990): Mean Summer (JJA) temperature rise (°C)

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Table 2.6 Temperature change (baseline 1961-1990): Mean Autumn (SON) temperature rise (°C)

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2.3.2 Rainfall

Mean annual rainfall is likely to reduce slightly for Scotland. However, the projections are dependent on season with projected increases in winter precipitation and projected decreases in summer precipitation. The pattern of change may not be the same across Scotland. From the 1961-1990 baseline, by the 2050s the projections show there could be a mean annual increase or decrease of around 6% for Eastern Scotland and 6-8% for Northern Scotland and Western Scotland (Table 2.7). Tables 2.8 to 2.11 show the seasonal changes for each region.

Table 2.7 Precipitation change (baseline 1961-1990): Annual mean change (%)

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### Table 2.8  Precipitation change (baseline 1961-1990): Mean Winter (DJF) change (%)

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### Table 2.9  Precipitation change (baseline 1961-1990): Mean Spring (MAM) change (%)

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### Table 2.10  Precipitation change (baseline 1961-1990): Mean Summer (JJA) change (%)

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Table 2.11 Precipitation change (baseline 1961-1990): Mean Autumn (SON) change (%)

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2.3.3 Relative Sea Level

The effects of relative sea-level rise in Scotland have been moderated by isostatic rebound effects since the end of the last Ice Age. Although long-term rates of land uplift peak around Glasgow at 1.6 mm/yr (Shennen and Horton, 2002), present rates are now far lower peaking at 0.6 mm/yr (Bradley et al., 2009) again around Glasgow. When compared with rates of current sea level rise, all areas are experiencing relative sea level rise over at least the last few decades.

Projections for relative sea-level rise in Edinburgh with respect to 1990 levels for the Low, Medium and High emissions scenarios based on results presented by UKCP09 are shown in Table 2.12 below. The table shows, for example, that there is projected to be a 2.6-25.2 cm increase by 2050 and a 5.1-43.6 cm increase by 2080 for the Medium emissions scenario. Projections with respect to the 1990 baseline for other locations around Scotland are shown in Table 2.13. These show little variation on the Scottish mainland, yet noticeable variations for some of the Islands (e.g. Lerwick on Shetland and Stornoway on Eilean Siar). These projected rises in sea level would have consequential impacts on the flood risk around the coast, which is discussed in Section 3.2.13.

Table 2.12 Relative sea-level rise (1990 baseline) for Edinburgh (cm)

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<td>p5</td>
<td>p50</td>
<td>p95</td>
<td>p5</td>
</tr>
<tr>
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<td>4.3</td>
<td>8.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Medium</td>
<td>0.9</td>
<td>5.7</td>
<td>10.6</td>
<td>2.6</td>
</tr>
<tr>
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<td>1.3</td>
<td>7.5</td>
<td>13.7</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Note: These are estimates of relative sea level changes (i.e. including isostatic adjustment).
Table 2.13 Relative sea-level rise for several locations (1990 baseline) for the Medium emissions scenario (cm)

<table>
<thead>
<tr>
<th>Location</th>
<th>2020 p5</th>
<th>2020 p50</th>
<th>2020 p95</th>
<th>2050 p5</th>
<th>2050 p50</th>
<th>2050 p95</th>
<th>2080 p5</th>
<th>2080 p50</th>
<th>2080 p95</th>
<th>2095 p5</th>
<th>2095 p50</th>
<th>2095 p95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinburgh</td>
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<td>5.7</td>
<td>10.6</td>
<td>2.6</td>
<td>13.9</td>
<td>25.2</td>
<td>5.1</td>
<td>24.4</td>
<td>43.6</td>
<td>6.7</td>
<td>30.5</td>
<td>54.3</td>
</tr>
<tr>
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<td>1.7</td>
<td>6.6</td>
<td>11.5</td>
<td>4.3</td>
<td>15.6</td>
<td>26.9</td>
<td>7.7</td>
<td>27.0</td>
<td>46.2</td>
<td>9.8</td>
<td>33.6</td>
<td>57.4</td>
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<tr>
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<td>5.4</td>
<td>16.7</td>
<td>28.0</td>
<td>9.3</td>
<td>28.6</td>
<td>47.9</td>
<td>11.6</td>
<td>35.5</td>
<td>59.3</td>
</tr>
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<td>10.8</td>
<td>15.7</td>
<td>12.7</td>
<td>24.0</td>
<td>35.3</td>
<td>20.3</td>
<td>39.6</td>
<td>58.8</td>
<td>24.5</td>
<td>48.3</td>
<td>72.1</td>
</tr>
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<td>Ullapool</td>
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<td>45.5</td>
<td>8.9</td>
<td>32.8</td>
<td>56.6</td>
</tr>
<tr>
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<td>12.8</td>
<td>6.9</td>
<td>18.2</td>
<td>29.5</td>
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<td>50.2</td>
<td>14.3</td>
<td>38.2</td>
<td>62.0</td>
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<tr>
<td>Tobermory</td>
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<td>5.5</td>
<td>10.4</td>
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<td>13.4</td>
<td>24.7</td>
<td>4.4</td>
<td>23.6</td>
<td>42.9</td>
<td>5.8</td>
<td>29.7</td>
<td>53.5</td>
</tr>
<tr>
<td>Millport</td>
<td>0.1</td>
<td>5.0</td>
<td>9.9</td>
<td>1.1</td>
<td>12.4</td>
<td>23.7</td>
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<td>22.2</td>
<td>41.5</td>
<td>4.2</td>
<td>28.0</td>
<td>51.8</td>
</tr>
</tbody>
</table>

Note: These are estimates of relative sea level changes (i.e. including isostatic adjustment).

However, based on the methodology developed for the Environment Agency’s Thames Estuary 2100 study (TE2100, 2007), UKCP09 have developed a High++ (extreme) scenario range for sea level rise that provides an additional amount of change above the likely range of current models as a result of faster melting of ice sheets (see Floods and Coastal Erosion Sector Report). This gives a sea level rise around the UK of 0.93-1.90m.32 Although this scenario does not have an assigned probability, the consequences for this sea level rise are discussed in the report, particularly for the areas at greatest risk of flooding namely the Firths of Forth and Tay, the Moray Firth, parts of the inner Firth of Clyde and the coast of Argyll, and the Solway Firth (SNIFFER, 2008). However, it should be noted that it is thought unlikely that the upper end of the High++ range will be realised during the current century33.

2.3.4 Wind and storm conditions

Surface wind speed

There is a perception that winds and storms will increase in the future as a result of climate change. Winds were not originally covered by UKCP09 as the required data was not available from other climate models used in the UKCP09 methodology. However, guidance produced as a result of additional work undertaken subsequent to the main UKCP09 projections (Sexton and Murphy, 2010) states that by the 2050s:

- Projected changes in summer wind speed covers both positive (higher wind speeds) and negative (lower wind speeds) changes. Generally for the UK, projected wind changes are skewed towards negative changes, although slightly positive changes are projected for Scotland. This is consistent with the poleward shift of the storm track in summer.
- Projected changes in winter wind speed are approximately symmetrical around near-zero change.
- The largest uncertainty ranges are over Scotland.

On this basis, it has been assumed by the CCRA that it is unlikely that there will be a noticeable change in average or extreme wind speeds in Scotland, but it is recognised that there is a high degree of uncertainty regarding this.

32 http://ukclimateprojections.defra.gov.uk/content/view/1849/500/
33 http://ukclimateprojections.defra.gov.uk/content/view/2008/500/
However, this guidance was produced as a result of additional work undertaken subsequent to the main UKCP09 projections. The results (as for all UKCP09 products) are subject to the caveat that the current generation of climate models used to produce them could be missing a key process liable to change the projections. The next set of climate model projections being generated around the world for the IPCC Fifth Assessment Report should improve representation of the effects of the stratosphere on surface climate and assessment of these models will enable modellers to reassess the current results for surface wind speeds (Sexton and Murphy, 2010).

**Offshore winds and waves**

UKCP09 does not provide offshore wind and wave projections, and little research has been carried out into past trends in wind speeds and waves heights and (or) wind and wave directions. Research that has been carried out appears to be based on secular trends, and unlike sea levels (see Section 2.3.3), it is unlikely that any firm conclusions can be made relating to global changes with time (Hames, 2006). Research into past trends in wave heights has proved to be inconclusive, and decadal variability is high. Although Carter and Draper (1988) indicated that over the period 1960 to 1986 wave heights had shown a notable increase, since the 1990s wave heights have levelled off probably as a result of the North Atlantic Oscillation as indicated for example in Alexandersson et al., (2000).

On this basis, as well as the UKCP09 Marine and Coastal Projections report (Lowe et al., 2009), which suggests little change in seasonal and extreme wave heights around the Scottish coastline, it has been assumed by the CCRA that it is unlikely that there will be a noticeable change in mean or extreme offshore wave heights for Scotland.

**Storms**

Storms can be defined differently depending on the publication. UKCIP02 defines storms as depressions or low pressure areas, identified and tracked using mean sea level pressure data and an analysis program. UKCP09 uses two different methods, one of which is similar to that used in UKCIP02. Key findings for the storm projections are (Murphy et al., 2009):

- UKCIP02 showed an increase in the future number of winter depressions attributed to a southward shift in the North Atlantic storm track.
- Within the UKCP09 projections there is little evidence of a change in the frequency or intensity of storms in the UK.
- There are uncertainties associated with both the position and strength of the present day storm tracks and these contribute to the large uncertainties in the future predictions of storms.

On the basis of the conclusions drawn by Murphy et al., 2009, it has been assumed by the CCRA that there it is unlikely that there will be a noticeable change in storms in Scotland.

**Surge**

Surge, the increase in sea levels above the predicted tide levels are projected to show a small increase over the rest of this century. Current projections indicate a rate of increase not more than 0.9 mm/year for return period events up to 50 years\(^{34}\), indicating that a 50 year surge in the 2080s will increase by less than 7cm. This would probably result in increased extreme sea levels around the Scottish coast.

\(^{34}\) [http://ukclimateprojections.defra.gov.uk/content/view/1855/500/](http://ukclimateprojections.defra.gov.uk/content/view/1855/500/)
3 Impacts on bio-physical systems

3.1 Introduction

In order to assess the consequences of climate change, it is first necessary to consider how climate change may affect bio-physical systems\textsuperscript{35}, for example the water cycle and soil systems. This is indicated for example in Figure 3.1 below which shows the direct bio-physical impacts that leads to a number of cause-consequence links, leading to a final impact of an effect on capital or operational expenditure\textsuperscript{36}.

Figure 3.1 Sample systematic map showing some agriculture links to “Capital or Operational Expenditure”

Some of the main impacts of climate change on bio-physical systems are as summarised below.

1. Reduced summer rainfall and higher summer temperatures, leading to:
   a. Lower runoff and low river flows in summer,
   b. Increase in aridity\textsuperscript{37} in summer leading to drying of soils and reduced moisture availability,
   c. Increase in frequency and severity of summer droughts.

\textsuperscript{35} The initial impacts of a climate variable (such as temperature or rainfall) are on biological or physical elements of the environment. These are referred to as “bio-physical impacts”.
\textsuperscript{36} Figure 3.1 is a sample figure from the systematic mapping exercise that was carried out for the CCRA to explore and better understand many of the key cause-process-consequence links. Full details of this analysis, and the tool developed are given in CCRA, 2011.
\textsuperscript{37} A measure of the dryness of an area based on rainfall and temperature (see Water Sector report).
2. Increased winter rainfall (and intense summer storms), leading to:
   a. Higher runoff and higher river flows in winter,
   b. Increase in wetness in winter leading to increased waterlogging and increased risk of landslip,
   c. Increase in flooding in winter and from intense rainfall events in summer,
   d. Increase in erosion of soils and sediment movement in rivers.
3. Rising temperatures, leading to:
   a. Increase in number of growing degree days and longer growing season,
   b. Increase in number of cooling degree days,
   c. Decrease in number of heating degree days,
   d. Increase in water temperatures.
4. Sea-level rise, leading to:
   a. Increase in coastal flooding,
   b. Increase in coastal erosion,
   c. Loss of beaches and coastal features.
5. Combined effects of all climate drivers:
   a. Changes to vegetation and species,
   b. Changes to the landscape,
   c. Changes to the built environment and society.

Estimates are presented below of the likely magnitude of the main bio-physical impacts for Scotland, based on UKCP09 projections and results from the CCRA analysis. Impacts relating to rainfall refer to the river basins in Scotland, which are shown below in Figure 3.2.

The consequences of these bio-physical impacts for the Natural Environment; Agriculture and Forestry; Business and Services; Infrastructure and Buildings; and (human) Health and Wellbeing are discussed later in Section 4.
3.1.1 Lower runoff and low river flows in summer

Summer rainfall is projected to decrease by approximately 12% (range 29% decrease to 6% increase) by the 2050s from the 1961-90 baseline, Section 2.3.2. This will result in reduced river flows and less available moisture.

Low flows in rivers were assessed by considering the change in the flow rate exceeded 95% of the time, termed the Q95 flow\(^{39}\). Considering Table 3.1, this flow rate is projected to reduce for Scotland (i.e. low flows will get lower). These projections relative to the 1961-90 baseline for the central estimate of the Medium emissions scenario indicate no change to an 8% reduction by the 2020s, a 12% to 23% reduction by the 2050s, and a 19% to 30% reduction by the 2080s\(^{40}\).

\(^{38}\) The Tweed river basin, similar to the Solway river basin straddles the English border. However, as the Tweed river basin, unlike the Solway river basin is predominantly in Scotland, it is considered for the basis of this report as being solely in Scotland.

\(^{39}\) The flow rate that is exceeded 95% of the time.

\(^{40}\) These figures are based on all 10 river basins. This includes the Solway river basin that is partly in Scotland.
### Table 3.1 Change in Q95 by UKCP09 river basin region (Scotland)

<table>
<thead>
<tr>
<th>Region</th>
<th>Low Emissions</th>
<th>Medium Emissions</th>
<th>High Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10 (wet)</td>
<td>p50 (mid)</td>
<td>p90 (dry)</td>
</tr>
<tr>
<td>Solway (part in England)</td>
<td>2020</td>
<td>16</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>1</td>
<td>-14</td>
</tr>
<tr>
<td>Argyll</td>
<td>2020</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>4</td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td>2080</td>
<td>-1</td>
<td>-14</td>
</tr>
<tr>
<td>Clyde</td>
<td>2020</td>
<td>11</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>-3</td>
<td>-17</td>
</tr>
<tr>
<td></td>
<td>2080</td>
<td>-8</td>
<td>-22</td>
</tr>
<tr>
<td>Forth</td>
<td>2020</td>
<td>10</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>-2</td>
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</tr>
<tr>
<td></td>
<td>2080</td>
<td>-7</td>
<td>-19</td>
</tr>
<tr>
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<td>2020</td>
<td>3</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>-5</td>
<td>-16</td>
</tr>
<tr>
<td></td>
<td>2080</td>
<td>-10</td>
<td>-19</td>
</tr>
<tr>
<td>North Highland</td>
<td>2020</td>
<td>7</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>-2</td>
<td>-14</td>
</tr>
<tr>
<td></td>
<td>2080</td>
<td>-7</td>
<td>-17</td>
</tr>
<tr>
<td>Orkney and Shetland</td>
<td>2020</td>
<td>7</td>
<td>-5</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
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<td>-7</td>
<td>-17</td>
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<td>2020</td>
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<tr>
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</tr>
<tr>
<td></td>
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<tr>
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<td>-8</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>-7</td>
<td>-21</td>
</tr>
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### 3.1.2 Aridity and summer droughts

Increases in aridity in the summer will cause drying of soils and reduced moisture availability, with consequences for the natural environment, agriculture, forestry and water use. The projected change in relative aridity\(^{41}\) for Scotland is shown in Table 3.2. Relative aridity has been used by the CCRA as an indicator of relative dryness compared to the baseline figures for temperature and rainfall between 1961 and 1990. The relative aridity projections indicate that the average relative aridity could increase to about 1.1 (range 0.5 to 1.9) by the 2020s, 1.9 (range 0.9 to 3.4) by the 2050s and 2.6 (range 1.1 to 5.2) by the 2080s\(^{42}\). The projections for a dry High emissions scenario in the 2080s give an average relative aridity of about 4.7 in Scotland. This indicates that future major droughts may be very severe events, far more so than droughts experienced to date.

Projections for the frequency and severity of summer droughts have not been made in the CCRA. However an assessment of the potential increase in drought conditions can be made based on changes in relative aridity.

---

\(^{41}\) Aridity is usually measured based on a relationship between precipitation and temperature. Details of the relative aridity score used for the CCRA analysis can be found in the Water Sector report.

\(^{42}\) These figures are based on the average p50 medium emissions scenario projections for all river basin areas.
### Table 3.2 UKCP09 relative aridity scores for the Scottish river basins

<table>
<thead>
<tr>
<th>PROJECTED RELATIVE ARIDITY BY UKCP09 BASIN</th>
<th>Low Emission</th>
<th>Medium Emission</th>
<th>High Emission</th>
</tr>
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<tbody>
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<td></td>
<td>p10 (wet)</td>
<td>p50 (mid)</td>
<td>p90 (dry)</td>
</tr>
<tr>
<td></td>
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<td>p50 (mid)</td>
<td>p90 (dry)</td>
</tr>
<tr>
<td></td>
<td>p10 (wet)</td>
<td>p50 (mid)</td>
<td>p90 (dry)</td>
</tr>
<tr>
<td>Solway</td>
<td>0.56</td>
<td>1.08</td>
<td>1.66</td>
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<tr>
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<td>1.08</td>
<td>1.67</td>
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<td></td>
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<td>1.07</td>
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<td>1.08</td>
<td>2.77</td>
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<td>1.77</td>
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<td>0.52</td>
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<td>1.78</td>
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<td>0.52</td>
<td>1.05</td>
<td>1.63</td>
</tr>
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<td>1.74</td>
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<td>1.77</td>
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<td>1.82</td>
<td>3.00</td>
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<td>Orkney and Shetland</td>
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#### 3.1.3 Snowmelt

Snowmelt often magnifies the impact of winter rainfall (extreme events and seasonal flow patterns), with the combined effect being known to produce many of the largest floods on Scotland's main rivers such as the Tay, Dee, Spey, Ness, Tweed and Clyde. Very occasionally, snowmelt alone may produce floods without significant accompanying rainfall (SNH and Institute of Hydrology Scotland, undated). However, for high level catchments, snow can regulate flows by storing and releasing water slowly; reducing flow peaks and increasing low flows (see Appendix C3).

Probabilistic projections of snowfall rate were not provided in UKCP09 (although these were provided by UKCIP02). In the absence of this data, UKCP09 Briefing Report (Jenkins et al., 2009) refers to typical reductions of 65-80% over mountain areas and 80-95% elsewhere by the 2080s under the Medium emissions scenario (averaged over the 11 members of the Met Office Hadley Centre RCM ensemble) relative to the 1961-90 baseline. On the basis of such reductions, and, in combination with milder winters, the likelihood of snowmelt floods is expected to decrease, although flow variations for high level catchments is likely to increase (Kay et al., 2011).

A projected reduction in snow and snowmelt would also impact on species distribution and abundance.

#### 3.1.4 Runoff and higher winter river flows

The most damaging floods in Scotland occur when slow-moving frontal storms come in off the Atlantic. These can last for up to 72 hours and sometimes increase flood flows as they melt lying snow (see Section 3.1.3). Less frequent storms of an easterly or northerly origin can generate floods along the east coast. Floods associated with
persistent high groundwater levels are virtually unknown in Scotland (Evans et al., 2004).

The climate scenarios in UKCP09 project increases in winter rainfall which would lead to:

- Greater volumes of runoff and higher river flows.
- Increased catchment wetness leading to increased problems of waterlogging.
- Increased flooding both from rivers and surface water (this could also be caused by intense summer rainfall events).
- Increased spill frequency and volumes from combined sewer overflows (CSOs).

Recent research by Kay et al., (2011) indicates that peak river flows in Scotland could increase by 15% to 37% by the 2080s relative to the 1961-90 baseline. These increases will not be consistent across Scotland, with increases on the west coast much higher than the east coast. Although projections for the 2020s and 2050s are not available, comparison against projections for England and Wales indicate flow increases in the region of 5% to 10% by the 2020s and about 20% by the 2050s.

Projections of the change in frequency of heavy rainfall events for Glasgow were analysed in the Water sector for the CCRA. Figure 3.3 shows the change in these events from a 1961-1990 baseline to the 2080s for the Medium emissions scenario. These suggest that heavy rainfall events could increase in depth, with these increases most likely to occur in the winter months. These increases are most noticeable for events which exceed 30mm of rainfall in a 6 hour period, although short duration heavy rainfall events (>10 mm in one hour, >20 mm in three hours) could increase or decrease. These short duration events, which are relevant for CSO spill frequency, suggest that CSO spill frequencies could either increase or decrease for Glasgow.

![Figure 3.3 Change in frequency of heavy rainfall events between the 1961-90 baseline and the 2080s for the Medium emissions scenario for Glasgow](image-url)
3.1.5 Waterlogging of soils and landslip

Increases in intensity and duration of rainfall in winter are likely to lead to poaching as well as more frequent and extended periods of waterlogging. This will tend to lead to more frequent and larger areas of inundation of high grade (floodplain) agricultural land, with consequences for agricultural productivity (Johnson et al., 2009), although warmer drier summer periods would be expected to reduce periods of waterlogging.

Risk and frequency of landslip will also increase as a result of wetter winters affecting forestry regions and roads. This is of particular concern in Scotland where many of the significant forests are on steep topography and where there have been a number of significant landslides on roads in recent years.

Waterlogging was not assessed in detail as part of the UK CCRA, however the effect of waterlogging on the number of workable days on land has been considered specifically for Scotland (see Appendix C2). The risk of landslips for trunk roads only was considered within the Transport Sector, and results of this analysis are presented in Section 4.5.1.

3.1.6 Increase in flooding from rainfall

Changes in rainfall patterns are likely to cause an increase in flooding, both from rivers and surface water. SEPA are required under the Flood Risk Management Act (2009) to take account of climate change when assessing flood risk. Based on climate change projections, it is understood that flooding from both rivers and surface water are likely to increase and ongoing research by SEPA will assess this in more detail. For this report, the assessment of flooding from rainfall has been assessed qualitatively based on the assessment carried out for the CCRA for England and Wales.

3.1.7 Soil erosion

Increased rainfall intensities may increase soil erosion rates. There are also concerns that increases in summer drought could damage soil structure and also influence erosion rates. In effect, 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, with accompanying losses of soil carbon.

Evidence on current rates of erosion come from field scale studies, monitoring of suspended sediment in rivers and detailed modelling studies. Recent research has modelled soil loss in Scotland due to grazing and climate change (Lilly et al., 2009).

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43 Breaking up of land causing surface water damage as a result of (for example) livestock hooves.
44 http://www.scotland.gov.uk/Topics/Environment/Water/Flooding/FRMAct
Figure 3.4  Modelled estimates of annual sediment yields in Scotland for different levels of dwarf shrub cover - a. 100% cover, b. 80% reduction in cover, c. difference attributable to heavy grazing
Source: Lilly et al., 2009

‘Rainfall erosivity’ has been used by the CCRA as an indicator of the potential for rainfall to cause soil erosion. The concept is based on the energy in rain drops and it is highly correlated with rainfall intensity. Erosion rates are likely to increase with an increase in intensity of rainfall events or the number of intense rainfall events in a year (more details are given in the CCRA Evidence Report, CCRA 2012). Calculations were completed for four sites across the UK for the 2080s, Medium emissions scenario. For the selected site in Scotland, rainfall erosivity may increase by 56% (23% to 58%)45.

3.1.8 Growing degree days and growing season

Growing degree days (GDD) – the day-by-day sum of the mean number of degrees by which the air temperature is more than 5.5°C.

Growing season length – the period bounded by daily mean temperatures of greater than 5°C for more than 5 consecutive days and daily mean temperatures of less than 5°C for more than 5 consecutive days (after 1 July).

An increase in the number of growing degree days and a longer growing season will probably result in a reduction in frost and an increase in the frost free season. This would be expected to have a positive effect on the development of crops and on food production, although vernalisation for some crops could be reduced and some pests

45 These figures are based on p50 projections for the medium emissions scenario.
and diseases may be more likely to survive winters and/or potentially thrive more in warmer summers.

For the baseline period of 1961 to 1990, GDDs were between 100 and 200 in Northern Scotland, increasing to about 400 in Southern Scotland. These are projected\textsuperscript{46} to increase by up to 200 by the 2020s, 400 by the 2050s and 400-600 by the 2080s. An increase in GDDs would influence the growing season and time to maturity of agricultural crops. In general, it is anticipated that growing seasons will get longer.

3.1.9 Primary production

Primary production (plant growth) is influenced by a number of climatic factors, including levels of carbon dioxide in the atmosphere and changes in temperature, precipitation and solar radiation. Optimum rates of primary production are expected to increase in temperate ecosystems with warmer temperatures and higher levels of atmospheric CO\textsubscript{2} concentrations. However, water availability and soil nutrient supplies may limit production, even offsetting favourable conditions.

Projections for grassland productivity have been produced for the CCRA as an indicator of primary production, due to the importance of this crop in areas such as Scotland. Further details can be found in Section 4.3.1.

3.1.10 Heating and cooling degree days

Cooling degree days (CDD) – the day-by-day sum of the mean number of degrees by which the air temperature is more than 22\textdegree C.

For the baseline period of 1961 to 1990, the average number of CDDs for Scotland was less than 25. Throughout Scotland the CDDs are projected\textsuperscript{47} to increase over the rest of this century, however this won’t be significant, and only the most southern parts of Scotland are projected to have more than 25 CDD by the 2080s.

Heating degree days (HDD) – the day-by-day sum of the mean number of degrees by which the air temperature is less than 15.5\textdegree C.

For the baseline period of 1961 to 1990, the number of HDDs for Scotland was typically between 3000 and 4000 in Northern Scotland and between 2500 and 3000 in Southern Scotland. These are projected\textsuperscript{48} to decrease by about 500-600 by the 2020s, 700-1000 by the 2050s and more than 1000 by the 2080s. This means that Glasgow, for example, may experience an approximate 40% decrease in HDDs by the end of this century.

Although in general the confidence in both CDD projections and HDD projections is considered relatively high, the relatively uncertainty in future CDDs may be greater.

3.1.11 Thermal humidity

Temperature is only one of the factors that influence thermal comfort; it is a combination of temperature and humidity and, to a lesser extent wind and solar radiation, which have a direct impact on thermal comfort and ‘heat stress’ for animals.

\textsuperscript{46} Based on 11 member RCM climate projections; UKCP09 projections are not available. The confidence in these projections is relatively high.

\textsuperscript{47} Based on 11 member RCM climate projections; UKCP09 projections are not available.

\textsuperscript{48} Based on 11 member RCM climate projections; UKCP09 projections are not available.
and plants (see Section 4.3.1) and human health (see Section 4.6.2) during extreme heatwaves.

The thermal humidity index (THI)\textsuperscript{49} combines temperature with relative humidity to give an index that describes thermal discomfort.

For the baseline period of 1961 to 1990, the maximum monthly average THI values for Scotland are between 50 and 72. The projected values\textsuperscript{50} for THI for the 2020s remain unchanged, but the range reduces to between 60 and 72 by the 2050s and 2080s\textsuperscript{51}.

\subsection*{3.1.12 Water temperature and quality}

It is expected that increases in air temperatures would lead to a rise in water temperatures. The extent of freshwater warming, particularly of the entire water column, is highly dependent on a number of other factors including flow velocity, evaporation rates, depth of the water column and the amount of shade (provided by surrounding vegetation, for example).

The changing balance of seasonal precipitation is likely to have a direct impact on solute and sediment transport. Examples of potential changes in processes due to climate include:

- Increases in nitrate leaching in winter months due to increases in precipitation, infiltration in soils and recharge of groundwater;
- Similarly, changes in phosphorous 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 the nutrient and pesticide transport will only increase where its availability is not limited. Other factors, such as land use and technology, may be more important than climate in future time periods. The potential consequences of changing patterns of solute transport include changes in water quality at the basin scale, ecological status and the requirements for water treatment.

\subsection*{3.1.13 Coastal flooding and erosion}

The projected increases in sea levels for Scotland would result in an increase in the level of extreme sea levels, leading to more frequent and severe coastal flooding and loss of low lying land. This is demonstrated in Figure 3.5 below for a number of locations around the Scottish coastline. This indicates for example that around Greenock, a sea level with a current return period\textsuperscript{52} of 100 years will have a return period of approximately 9-10 years if eustatic\textsuperscript{53} sea levels increase by 0.5m, a level projected to be reached around the 2090s for this location for the central estimate of

\textsuperscript{49} Also referred to as the temperature humidity index
\textsuperscript{50} Based on 11 member RCM climate projections; UKCP09 projections are not available. The confidence in these projections is medium.
\textsuperscript{51} Where the THI range is less than 72 this indicates no stress to cattle.
\textsuperscript{52} The return period of a sea level is the average period of time between which the sea level of interest is reached or exceeded.
\textsuperscript{53} The absolute change in sea levels to a fixed datum, independent of changes in local land levels.
the Medium emissions scenario. Although the effects of isostatic rebound mean that relative sea levels will rise at different rates around the coast, the change in return periods with time will vary little. By the 2050s and 2080s therefore, the current 1 in 100 year sea level will be in the region of a 1 in 40 year and 1 in 10 year event respectively. However, these effects may be more pronounced for the islands such as the Shetland Isles where relative sea levels are rising at a much greater rate than locations on the mainland54.

Small increases in relative sea levels as noted in Figure 3.5 will therefore have significant effects on the return period of coastal flooding events. This would be expected to cause more frequent coastal flooding, and increase coastal erosion rates on those stretches of the coastline that are susceptible to erosion (i.e. soft coastlines). In this respect, the combined effects of increased flooding and erosion are likely to present land managers with considerably more challenges than have been experienced in the recent past.

![Figure 3.5](image)

**Figure 3.5** Change in return period and time periods these are projected to be reached by for a 100 year event for different rises in mean sea levels and time periods (based on the central estimate of the Medium emissions scenario). Locations shown are approximate.

### 3.1.14 Sea temperature, salinity, stratification and circulation

The three main parameters that determine the marine climate are temperature, salinity and circulation. The following summarises the main findings of the UKCP09 marine and coastal projections relating to these parameters, as well as stratification55. These are based on one future scenario that might be realised under the Medium emissions scenario (see CCRA, 2012).

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54 It should be noted that the time periods shown on Figure 3.5 are for the current projections from UKCP09. Research by Rennie and Hansom (2011) indicate that the time periods indicated in Figure 3.5 may occur earlier than shown. However, this paper only considers sea levels up to 2007, and inclusion of records to 2010 would reduce the trends indicated by Rennie and Hansom (2011).

55 [http://ukclimateprojections.defra.gov.uk/content/view/825/500/](http://ukclimateprojections.defra.gov.uk/content/view/825/500/)
Sea surface temperature
The seas around the UK are projected to become 1.5 to 4°C warmer, depending on location. Increased temperatures can cause shifts in species types 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.

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 (and therefore density differences in the ocean) may disrupt ocean currents which can have devastating consequences for the climate as a whole.

Circulation
Projected changes in the open ocean (especially the circulation) are particularly uncertain due to the limitations of the ocean model used. Circulation patterns are likely to be as variable in time and space in the future as they are today, being mainly controlled by the complex topography of the seabed around the UK, as well as by highly variable tides, winds and density differences (which depend on the distributions of temperature and salinity). Changes in circulation may have impacts on a range of physical and biological processes in the marine environment.

Stratification
Seasonal stratification\textsuperscript{56} 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. An increase in the duration of stratification of the water column in the future could encourage and enhance the development of harmful algal blooms.

3.1.15 Ocean acidification
Although oceanic pH has varied throughout history, the concern is that reductions in pH observed are occurring much faster than at any time during the last 55 million years. As atmospheric concentrations of CO\textsubscript{2} continue to rise in the future, increased absorption by the oceans may accelerate oceanic acidification. Both modelled and observational data suggest that oceanic absorption of CO\textsubscript{2} has already decreased oceanic pH by 0.1 units since 1750.

The CCRA has assessed ocean acidification in a quantitative manner using the relationship derived between atmospheric loading of CO\textsubscript{2} and oceanic uptake and dissolution resulting in decreased pH. The reduction in pH of the North Sea has been projected to exceed on average 0.1 pH units in the next 50 years, due to inputs of atmospheric CO\textsubscript{2} into the marine system. Based on a worst case scenario, it has been estimated that there could be a total decline of 0.5 pH units below pre-industrial times by 2100 (Marine and Fisheries Sector Report). However, ocean pH can be affected by localised conditions and in some coastal locations pH can vary as much as 1.0 pH units due to complex riverine mixing and biological input.

\textsuperscript{56} The layering of warmer waters over colder waters
Another important aspect to consider is the effects of increased ocean acidification on the ocean’s ability to take up further CO$_2$. From the mid-1990s to 2005, the North Atlantic reduced its uptake of CO$_2$ by half; however it is not yet clear whether climate change is the cause (Defra, 2010c).

3.1.16 CO$_2$ levels

The balance between carbon in the atmosphere and in storage (in soils and the oceans) has a significant impact on the consequences of climate change and the mechanisms that are causing it. For example, more carbon in the atmosphere would lead to an increase in plant productivity (affecting agriculture and forestry) but would also contribute to increases in global temperatures and acidification of the oceans.

Whilst no quantified estimates have been made in this report on the climate change impacts of CO$_2$ levels in the atmosphere and in storage, this is recognised as an important issue (see for example Section 4.2.1).

3.2 How Scotland might change

A summary of the way in which climate change is likely to impact on the environment in Scotland is given in this section. The impacts are considered in more detail in Chapter 4 based on the findings of the CCRA analysis.

3.2.1 Changes to vegetation and species

Warmer drier summers would affect both natural biodiversity and human interventions including agriculture and forestry. Wetter winters would result in wetter soils and increased waterlogging. This would affect biodiversity, agriculture and forestry.

Marine species may be affected by increases in water temperature and other projected consequences of climate change, for example increased acidification of seawater or changes in circulation patterns.

These impacts are discussed in Sections 4.2 (The Natural Environment) and 4.3 (Agriculture and Forestry).

3.2.2 Changes to the landscape

Increases in temperature and wetter winters and drier summers would lead to changes to the landscape, for example through affecting processes such as soil erosion and flooding. Changes will also result from human attempts to mitigate against climate change by (for example) developing renewable energy or increasing the amount of carbon locked up in soils and vegetation, and the way that we adapt to the changing climate in planned and unplanned ways.

The combined influence of these direct, mitigation and adaptation effects are likely to be greatest in lowland and coastal landscapes reflecting the dominance of land management, settlement and land use in shaping landscape character, and the likely impacts of changing sea levels. In the uplands landform is a more dominant factor. Here, with the exception of developments such as renewable energy generation and related infrastructure, change may be gradual and subtle.
Impacts on the landscape have not specifically been addressed in the CCRA although inferences on the likely effects can be made from the analysis and discussion presented in Section 4, particularly Sections 4.2 (The Natural Environment) and 4.3 (Agriculture and Forestry). An assessment of the impacts of climate change on Scottish landscapes was also looked at by Land Use Consultants (2010), and where appropriate conclusions from their report are included in the relevant sections.

Figure 3.6 below shows the changes due to climate that have occurred since the original land classification for Scotland in the 1970s, as well as the projected changes in the 2050s based on the UKCIP02 Medium-High emissions scenario (also Section 4.3.1). Since the original land classification, there have been some subtle, yet important changes. Regions classified as ‘cold-wet’ have decreased, whilst ‘mild-wet’ regions have increased, with some even becoming ‘mild-very wet’ in the west. By contrast, in the east, a new ‘warm-dry’ region has considerably expanded, including the Borders, Angus and Moray areas. The changes for the 2050s future scenario are much more pronounced. The west continues to comprise mainly ‘mild-wet’ regions, with most of the ‘cold-wet’ regions lost from the uplands.

3.2.3 Loss of beaches and coastal features

Sea-level rise has had a dramatic effect on Scotland's coastline for millennia. Given the anticipated increases in sea-level rise in the coming decades, we can expect considerable changes to occur to parts of our coastal zone and the land uses which occupy it. Recent investigations (Ball et al., 2009) have identified the more vulnerable areas of Scotland's coastline. Of particular concern is the low-lying land fringing the eastern firths, but few areas are expected to be completely free from change. As all areas of Scotland are experiencing relative sea-level rise, all soft coasts are expected to adjust to the changing processes. In many cases this will lead to recession and coastal squeeze resulting in reduced areas of intertidal habitats. These impacts and their effects are discussed in Section 4.2.3.

Areas at particular risk will be low lying coastal settlements with soft defences (e.g. sand dunes) and areas such as the Orkney Isles and Western Isles where sea level rises relative to land levels are at their greatest (see Section 2.3.3).
4 Risk assessment

4.1 Summary of approach

This section describes the main consequences of the bio-physical impacts described in Chapter 3 and direct consequences of climate effects described in Chapter 2.

The following sections discuss the climate change impacts and consequences for Scotland under the following themes:

- 4.2 The Natural Environment
- 4.3 Agriculture and Forestry
- 4.4 Business and Services
- 4.5 Infrastructure and Buildings
- 4.6 Health and Wellbeing.

This chapter focuses specifically on the Tier 2 list selected for Scotland following the process described in Section 1.4. Further information regarding other impacts and consequences can be found in the various sector reports. The Tier 2 list for Scotland is provided in Appendix A.

The climate change impacts and consequences have been assessed based on the results of the CCRA analysis. The approach to risk analysis is described in the CCRA Method Report (Defra 2010a). As the CCRA is interested in the scale of impact rather than the direction, potential positive as well as negative impacts were assessed, and were considered with equal weight. The analysis is described in the eleven sector reports, as listed in Section 1.2.

In addition, some further analysis work was carried out for six Scottish specific impacts, which are outlined with the results in Appendix C. Case studies or additional narrative, using published results where available, were also used to assess other impacts that are considered important for Scotland but had not been assessed as part of the UK-wide analysis.

The Scotland Tier 2 impacts in Appendix A are listed by Sector. However, these have been allocated to one or more themes in this section of the report. For example, there is no specific theme for ‘water’, but elements of the Water Sector appear in all of the themes.

To help identify impacts within this report and across the CCRA, different impacts have been given different impact, or risk metric numbers (e.g. BD1). Risk metrics are measures of the consequences of climate change. Where metrics were not originally identified for the UK CCRA, they have been given a sub-number ‘r’ for reference purposes (e.g. BDr1, etc).

At the end of each theme there is a summary figure similar to the one shown below (see Box 4.1). The figure presents the estimated scale of the consequences for Scotland (both threats and opportunities) of each impact ranging from low to high. By presenting these for the three time slices of the 2020s, 2050s and 2080s, this gives an indication of how the risk may change over time.
Box 4.1 Summary figure example

Risk metric number
Tier 2 impacts for Scotland
Scale of consequences for each time slice
Method
i.e. Whether the assessment is based on:
Q – quantified analysis
IJ – informed judgement

Opportunities
AG1b/4 Changes in wheat and spring barley yield (due to warmer springs)
AG25/51/52 Agricultural land classification and crop suitability
AG10 Changes in grassland productivity
AG21 Waterlogging effects (annual)
AG1c Changes in potato yield (due to combined climate effects and CO₂)
GN4 Changes in global trading patterns
AG66 Human food supply from domestic agriculture

Threats
AG2/4/4 Flood risk to high quality agricultural land
WA5 Public water supply-demand deficits
AG1e Changes in winter barley yield (due to wetter winters)

Key for colour coding:
- 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

Confidence
i.e. How confident we are that these consequences will occur.

Coverage
i.e. Whether the assessment is based on:
S - analysis specific to Scotland
UK – analysis that is UK-wide

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<td>AG1c Changes in potato yield (due to combined climate effects and CO₂)</td>
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<tr>
<td>AG1e Changes in winter barley yield (due to wetter winters)</td>
<td></td>
<td></td>
<td>Too uncertain</td>
</tr>
</tbody>
</table>

Where the magnitude of the consequences of an impact has been quantified, the scaling is based on the central estimates for the Medium emissions scenario for the 2020s, 2050s and 2080s. These impacts are identified by a Q for quantified. The majority of impacts, however, have had to be assessed using informed judgement and these are identified by an IJ.

Some impacts are too difficult to assess at the present time, either because the science is not sufficiently well advanced yet to understand the scale of the consequences or the inherent uncertainty is too great. These are included in the figure for completeness, but have a grey bar.

Some impacts were quantified at the Scotland scale as part of this UK-wide analysis, others have been quantified as part of the additional analysis work for Scotland. In both cases these are identified with an S for Scotland. Other impacts were only

Note: In some cases, the Tier 2 impact names are shortened in the summary figures for convenience. The full impact names are given in Appendix A.
quantified at the UK scale, but are equally valid for Scotland as for the rest of the UK, and these have been identified with a UK.

It is important to stress that all projections presented in these figures are simply best estimates based on current understanding and we understand some impacts better than others. Therefore, there is a further column provided that gives an indication of how much confidence we have in whether the consequences will occur ranging from low to high.

Consequences can be considered as high, medium or low depending on four different criteria, as listed below. The cost per year has been estimated based on a monetisation exercise, which is described in Appendix D. However, this alone does not determine whether the consequence is high or not. If any one of these four criteria scores high, then the consequences are shown as high in the figure.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>People affected (number)</td>
<td>&gt; 100,000</td>
<td>100,000 – 10,000</td>
<td>&lt;10,000</td>
</tr>
<tr>
<td>Deaths per year (number: increase or decrease)</td>
<td>&gt; 1,000 / year</td>
<td>1,000 – 100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Cost per year (increase or decrease)</td>
<td>&gt; £100 million</td>
<td>£100 – 10 million</td>
<td>&lt; £10 million</td>
</tr>
<tr>
<td>Environmental impact (positive or negative)</td>
<td>Widespread and potentially large</td>
<td>Locally large; Widespread but not large</td>
<td>Local</td>
</tr>
</tbody>
</table>

Unless indicated otherwise, the projections and relevant discussion of climate change risks in this report have been drawn from the eleven CCRA sector reports (see Section 1.2). Each section identifies which reports have mainly been used, and if the reader wants further information, this will be found in the relevant sector report.

4.2 The Natural Environment

Scotland has some of the most spectacular landscape in the UK, with extensive mountainous areas covering approximately 50% of its land area, numerous freshwater and sea lochs and large areas of forest, moorland and peatlands, making it home to globally important habitats and species.

Most of the coastline of Scotland is unspoilt by development and tourism, with large areas of cliffs, beaches and estuaries. Approximately 11% of the land area of Scotland is designated as Sites of Special Scientific Interest (SSSI), 1.5% as National Nature Reserve (NNR), and 13% as National Scenic Areas (NSA). There are currently 51 Ramsar sites designated as important wetlands in Scotland, covering a total area of about 313,500 hectares as well as (as of March 2010) a total of 391 Natura 2000 sites. These comprise 245 Special Areas of Conservation (SACs) and 148 Special Protected Areas (SPAs), accounting for approximately 10% of Scotland’s land surface.

Scotland has a rich and varied natural heritage, with significant areas rich in different species and habitats. The most significant of these occur in Argyll, the Breadalbane Hills, the Central Highlands, Mull and Skye. Scotland contains 65 of the 169 habitats listed within the European Commission’s Habitats Directive, including some for which Scotland is globally important. The rest of the UK adds only a further 15 such habitats (Miles et al., 1997). The flora of Scotland includes over 1,600 vascular plants, more than 1,500 lichens and nearly 1,000 bryophytes. Examples of habitats of conservation importance, and also distinctive to Scotland include boreal Caledonian forest, heather...
moorland and coastal machair, as well as specialist montane species such as Norwegian mugwort (*Artemisia norvegica*), icy rock moss (*Andreaea frigida*) and alpine lady-fern (*Athyrium distentifolium*), which may lose physical space in a warmer climate.

The fauna of Scotland includes 62 species of wild mammals, including a population of wild cats (*Felis silvestris grampia*) and important numbers of grey and harbour seals (*Halichoerus grypus* and *Phoca vitulina*). Many populations of moorland birds, including black grouse (*Tetrao tetrix*), red grouse (*Lagopus lagopus scotica*) and capercaillie (*Tetrao urogallus*) are in Scotland, with internationally significant nesting grounds for seabirds such as gannets and most of the UK population of golden eagles. Ospreys (*Pandion haliaetus*) have re-colonised Scotland during the last 50-60 years, and white-tailed eagles (*Haliaeetus albicilla*) have recently been re-introduced. The Scottish crossbill, the only bird unique to Britain, is found only in native Scots pine forest areas.

Scotland’s seas are among the most biologically productive in the world; it is estimated that the total number of Scottish marine species exceeds 40,000. Included in the country’s ocean inventory are the Darwin Mounds, an important area of cold water coral reefs discovered in 1988. Inland, nearly 400 genetically distinct populations of Atlantic salmon (*Salmo salar*) live in Scottish rivers. Of the 42 species of fish found in the country’s freshwaters, half have arrived by natural colonisation and half by human introduction.

To assess the impacts of climate change on the natural environment, this Chapter has been considered under four sections namely terrestrial, freshwater, coastal and marine. In some cases the impacts assessed encompass more than one section.

### 4.2.1 Terrestrial

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Biodiversity and Ecosystem Services Sector Report and Forestry Sector Report.

Climate change could lead to changes in terrestrial biodiversity and ecosystem functions, which would not only affect the natural environment, but would also have knock-on impacts for society and the economy.

**Impacts on species and community structure**

**Changes in climate space**

The geographical location where different species are able to survive is, in part, associated with climate, particularly temperature. As temperatures increase the geographical locations where species are able to survive shift; usually northwards and with increasing altitude. Unless species are able to adapt to the new climate in situ, they shall be forced to move, following their changing ‘climate space’. Some species may not be able to track their changing climate space and will therefore be threatened by climate change. Barriers to movement include fragmentation of habitat, often caused by agriculture and other land uses. Other, biological barriers include the availability of suitable habitat, the ability to disperse, reproduction and life-cycle traits, dependence upon the other species within its community and its inherent ability to adapt to its surroundings. Species at the southerly limit of their range in Scotland and

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57 Water availability is also a very important climate factor in species distribution.
those currently confined to high altitude areas are particularly at risk\textsuperscript{58} for example, the large heath (\textit{Coenonympha tullia}) and scotch argus butterflies (\textit{Erebia aethiops}) (Franco \textit{et al.}, 2006). Also see impacts in the Cairngorms National Park below. Habitats that are considered to be at particular risk from changing climate space include heather moorland, peat bogs, woodlands (see Section 4.3.2) and montane plant communities (Land Use Consultants, 2010). Species least at risk from changing climate space are those with a predominantly southern distribution in Scotland. These species are projected to gain additional climate space in Scotland. They include species such as the nuthatch, which is already spreading through southern Scotland and the large skipper (\textit{Ochlodes sylvanus}), a butterfly which is projected to spread from the south-west (SNH, 2010).

The implication of changes in species ranges is the changes to species interactions and community composition that may subsequently occur. Whilst this ability to change is an essential part of an ecosystems’ ability to adapt to changing environmental conditions, the loss of particular species or interaction integral to the system may lead to loss of ecosystem function. For example, wood ants (\textit{Formica exsecta}, \textit{Formica sanguinea}, \textit{Formica aquilonia} and \textit{Formica lugubris}) which influence the distribution, abundance and community structure of many other species of invertebrate and plant species are keystone species; their loss would have a major affect on other species population and ecological process within their ecosystems (discussed in more detail in Section 4.2.4). Loss of ecosystem functions may lead to major disruption or loss of ecosystem services, such as loss of species of provisioning\textsuperscript{59} or cultural\textsuperscript{60} value.

Due to the difficulty in isolating a single driving force behind a particular species range in the UK, the ability of species to track their climate space has not been analysed in the CCRA but is assessed as a significant threat for Scotland (although there will also be opportunities for new species). The current evidence base from some well-recorded species as described above suggests that this impact is already occurring but the implications for the wider functioning of the ecosystem remain uncertain. Modelling suggests that the effects of climate change are projected to become increasingly apparent in the future, especially if the current state of habitat fragmentation is not reversed by the introduction of landscape-scale measures to improve connectivity, diversity and extent of priority habitats within the designated site network and through the wider landscape. This risk may ultimately affect species that provide important ecosystem services to humans, such as pollinators, but changing interactions between species is a source of considerable uncertainty. The strong influence of anthropogenic changes on species populations also means that it is difficult to assess how climate change will affect species distribution.

\begin{center}
Case Study : Climate Change in the Cairngorms National Park
\end{center}

The Cairngorms National Park (CNP) is Britain’s largest national park; it covers 4,528 km\textsuperscript{2}, almost twice the size of the Lake District. It is a mountainous area, containing the largest continuous areas of land above 1000m in the UK and most of Scotland’s highest summits (Gordon and Wignall, 2006). Famed for its mountainous landscape, the CNP is the most extensive area of arctic-alpine habitat in Britain and is home to 25% of Britain’s threatened birds, animals and plants including the Scottish crossbill, the only bird unique to Britain. The golden eagle, osprey, capercaillie, red squirrel (\textit{Sciurus vulgaris}), wild cat, water vole (\textit{Arvicola amphibius}), otter (\textit{Lutra lutra}),

\textsuperscript{58} Although species will generally respond to a warming climate by moving up an altitudinal gradient, certain climatic variables other than temperature may be more important for some species. Crimmins \textit{et al.}, (2011) for example highlighted observations in North America of species moving downhill in response to climate change, as a result of the changing water balance.

\textsuperscript{59} Provisioning services are a type of ecosystem service and can be described as the products obtained from ecosystems.

\textsuperscript{60} Cultural services are a type of ecosystem service and can be described as the non-material benefits people obtain from ecosystems.
freshwater pearl mussel (*Margaritifera margaritifera*) and lamprey are among other important species found in the CNP. Nearly 40% of the CNP is set aside for conservation purposes under local, national and European designations (CNPA, 2010). The forests of the Cairngorms contain remnant Caledonian pine forest and also include a rare kind of pinewood found only in Scotland and Norway. Heather moorland covers much of the CNP and the rivers, loch and marshes found there are among the cleanest in Scotland (CNPA, 2010).

**Figure 4.1 Western capercaillie**

*Changes in climate in the Cairngorms National Park*

East Scotland’s average yearly temperature over the last 50 years has already risen by approximately 1°C. There are fewer days with air or ground frost; precipitation has increased in winter, but decreased in summer; snow cover has declined and the growing season has lengthened (see Chapter 2).

*Impacts to the Cairngorms National Park*

The change in climate experienced have several consequences, including more frequent and severe flooding, summer droughts and reduced snow sports. These changes coupled with the changes in temperature also impact on species distribution and abundance (CNP, 2007).

The survival of species within the Cairngorms largely depends upon their ability to track their climate space. Other pressures on the local habitats are extremely important, for example, grazing. Modelling indicates that the climate space for characteristic species of montane heath, such as stiff sedge and the ptarmigan will mostly remain in the CNP. However, montane habitat will reduce in total area, bowing to an increase in neutral grassland habitat (Berry *et al.*, 2005). A species’ ability to move uphill not only depends upon factors such as its ability to disperse, available suitable soil/graze/prey type and space availability, but it also relies on its ability to successfully compete against other species in the new area. In the case of the CNP, aggressive plants like bracken, broom and coarse grasses may also move with their climate space, uphill and
out-compete the arctic-alpine species (Shaw and Thompson, 2006).

Average snow cover has already decreased by a third (from 1961/62 to 2004/05 (SNIFTER, 2006), see also Section 2.2); an increase in temperature of just 2°C could reduce lying snow by up to 90% (Shaw and Thompson, 2006). Species such as the snow bunting (*Plectrophenax nivalis*) rely directly on snow cover to trap insects throughout the winter, so that they are able to feed on them. Furthermore, snowmelt in the spring triggers the emergence of many flying insects, such as crane flies, *en masse*. The clouds of emerging insects are frequented by dotterel (*Charadrius morinellus*), wheatear (*Oenanthe oenanthe*), golden plover (*Pluvialis apricaria*) and other hill birds which need food at this time of year to feed their broods. Increasing temperatures and earlier snowmelt may lead to changing emergence times, away from when birds are hatching (a phenomenon known as phenological mismatch, see the discussion below).

Certain species may have a positive reaction to a changing climate, but have a negative impact on people. Midges, horseflies and ticks can be expected to increase in abundance. Not only do these organisms bite humans (see also Section 4.6.4), but they also bite deer, driving the animals uphill for longer periods where they graze on the more sensitive alpine vegetation (Shaw and Thompson, 2006). Increasing numbers of biting insects such as ticks also increases the risk of Lyme disease transmission to humans and Louping-Ill virus to sheep and other domestic animals, as well as to grouse chicks. Diseases are not only dangerous for the individual infected, but can affect the local economy; a grouse shoot for example can lose significant value if there is a large tick infestation (Shaw and Thompson, 2006). Heather beetles (*Lochmaea suturalis*) and plagues of moth caterpillars have also become an issue in recent years, which might be due to increasing temperatures and the changes in precipitation. These animals devastate heather, leaving bare patches up to an acre in size (Shaw and Thompson, 2006).

**Seasonal shifts and changes in phenology**

Climate change is already altering 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. Evidence for this phenomenon has been reported across Europe, with a notable example being 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 *et al.*, 2006 and Both *et al.*, 2006). Although phenological mismatch could be due to a number, and/or combination of several climate drivers, the overwhelming evidence indicates that changes in temperature are the main driver of phenological change (Sparks *et al.*, 2006).

A consequence of such phenological mismatch may be a disruption of ecosystem functions and knock-on consequences for related ecosystem services. Approximately 75% of phenology series in Scotland already show at least some evidence of advances (Sparks *et al.*, 2006) which may have serious implications for populations of certain species. Examples of these include:

- The decline in capercaillie in Scotland since the 1970s has been hypothesised as being linked to a phenological mismatch between winter moth (*Operophtera brumata*) larval abundance and chick development (Moss *et al.*, 2001), although the primary decline is believed to be as a result of low breeding success, exacerbated by deaths of fully grown birds flying into forest fences (Moss *et al.*, 2001) as well as increasing evidence of predators in capercaillie forests (SNH, 2011a-c).
- Winter moth larvae are also a staple diet for great tits (e.g. Picozzi et al., 1999). However, advance rates for both these species are similar (Sparks et al., 2006).

- First egg-laying dates for birds are estimated to be advancing on average by 0.1 days per year, and mean first capture dates for aphids by 0.5 days per year, (Sparks et al., 2006). The young of several birds rely on aphids, including seed-eaters such as chaffinches (Fringilla coelebs), linnets (Carduelis cannabina) and greenfinches (Carduelis chloris).

- Migrating birds are typically arriving three weeks earlier and leaving a week later than they were 30 years ago. However, these trends are not consistent across Scotland, and an analysis of records in Deeside for example indicated smaller trends (Sparks et al., 2006). Migratory birds typically rely on a range of flying insects, and their availability could become more limited around arrival or on the emergence of young.

Research indicates that terrestrial plants have advanced their phenology most, with animals further up the food chain having responded at slower rates. This highlights the potential for asynchrony or mismatch of phenology (Thackeray et al., 2010). The rate at which a species will change will however also be dependent upon other factors, such as local conditions or biological traits. It is quite possible that through behavioural change (species’ “plasticity”) and natural selection that the phenology between species may through time become synchronous again. 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.

Species migration

Many animals migrate over long distances to seek favourable climate conditions and maintain a suitable food supply during the annual cycle of seasons. A change in climate can lead to these migration patterns changing as the factors that trigger them are modified. Changes in climatic conditions, altering the suitability of different breeding and wintering grounds may increase or decrease the length of the migrations undertaken. Whereas decreases in distance may be a benefit, increases may increase the risk to individual mortality and extinction risk within the species. Different migratory species will react differently to climate change pressures, some species are likely to be more vulnerable than others. As a result, it is not possible to draw a conclusion that ‘fits’ all species, rather each species must be considered individually, within the context of its particular surroundings and life-cycle requirements. It is also important to note that, species that migrate may be affected by changes in climate elsewhere in the world as well as in the UK.

Observational evidence has recorded present-day changes in migration patterns, a trend that may be anticipated to continue. Recent evidence has indicated significant drops of at least a third in a number of migratory Scottish seabirds such as kittiwakes (Rissa tridactyla), fulmars (Fulmarus glacialis) and herring gulls (Larus argentatus) over the last 10 years (JNCC, 2010). Mackey and Mudge (2010) also suggest that waterbirds are becoming less reliant on the security of overwintering in Scotland as milder winters become more common on continental Europe. Although there are opportunities for species such as Arctic terns (Sterna paradisaea) and the guillemot (Uria aalge), there are also indications that these have also failed to escape recent breeding problems. The climate space for a number of new migratory birds such as the stone curlew (Burhinus oedicnemus) and turtle dove (Streptopelia turtur) may extend into, or further into Scotland over the rest of this century (Walmsley et al., 2007) increasing the potential that their migratory paths might include more Scottish locations.
Movements of species are particularly important for regulating other species, either as predators or prey, having implications for community structure, ecosystem functions and services. Changes in migration patterns have potentially serious implications for the designated site network as the qualifying features for which the sites were designated, move to other locations. New species using Scotland as part of their migration pattern in the future may also create opportunities for designation of new sites.

Generalist species favoured over specialist species

As a changing climate can result in changes to species interactions and species communities, it is logical that those species with the most specific niches and habitat preferences will be most greatly affected by the changes. If the species is unable to adapt to these changes in habitat, this may result in its localised extinction. Conversely, those species with very general habitat requirements are more likely to be able to find suitable niches and habitat for their requirements in a changed environment and therefore continue to survive. Consequently the overall diversity of species can be reduced if generalists are favoured over specialist species.

Data at a Scotland only level is relatively limited. At a UK level, butterflies have extensive abundance datasets used to analyse their populations and the species have been split up and identified as generalists and specialists. Analysis of butterfly populations indicates that there are often large year to year fluctuations in populations, particularly of generalist species. This can usually be attributed to the weather of that year, indicating general climate sensitivity. A long-term trend is more difficult to find, as after a significant decline following 1976 (an anomalously warm year), the index shows no significant changes. Further work on the combined effects of habitat loss and climate change indicated that at a local scale, butterfly assemblages were becoming increasingly dominated by generalist species and the specialist species were less able to adapt to the changes occurring in the environment (Menendez et al., 2006).

Analysis of specialist versus generalist species is intrinsically related to the relationship between habitat loss and climate change.

A decline in specialist species would reduce overall biodiversity; believed to be an intrinsic part of giving an ecosystem resilience to change. Reduction in ecosystem resilience can also reduce resistance to invasive non-native species, pests and disease-causing pathogens. Specialist species’ ability to adapt is often compounded by being restricted to semi-natural habitats (such as mature woodland, heathland or wetland) that are small in area and fragmented across the landscape due to historic habitat loss. Adaptation potential may be improved by ensuring the ecological network

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To date, most evidence related to generalist species being favoured over specialist species is in relation to human induce environmental changes, such as changes in land use, rather than as a direct result of a changing climate.
(primarily designated sites) is large enough, connected enough and of a high enough quality.

The limited ability of specialist species to adapt to changes in the environment has led to many declining in population or distribution to such an extent that they have been included on the UK Biodiversity Action Plan list of priority species\(^\text{62}\), including (for example) the capercaillie (discussed above), which has its habitat in Caledonia pine forests. Another group under threat from changing environmental conditions, including but not limited to climate change, is insect pollinators. The value of these pollinators to Scottish agriculture is conservatively, about £43 million per annum; this is about 5% of the value of all crops grown in Scotland or almost 9% of the value of horticulture and crops other than cereals. Most of the wild plants that make up the vegetation of semi-natural grasslands, mountains, moorlands, heathlands, woodlands and coastal margin habitats are also dependent on pollination. Between 62% and 73% of species are pollination limited (Burd, 1994 and Ashman \textit{et al.}, 2004 cited in Scotland NEA, 2011). The value of pollination services to non-agricultural ecosystems is currently unknown, but is thought to be high (Scotland NEA, 2011).

The magnitude of the effects of climate change on a species will also depend on the rate of change. Rapid changes in environmental conditions and habitat will limit the ability of species to adapt to the new conditions. Thus specialist species are likely to be disproportionately affected by more rapid changes in climate that induce large range shifts.

Pests, diseases and invasive non-native species

In this assessment, pests are either native or non-native organisms that cause damage to native species or ecosystems. Diseases are micro-organisms (pathogens such as bacteria, fungi or viruses) that cause harm when transmitted to a particular host. The spread of pests and diseases can cause damage to biodiversity and the natural environment. They have the potential to disrupt key ecosystem functions causing damage to the economy and/or society. As a result much of the information surrounding pests, pathogens and diseases is usually focussed on those that impact agriculture, forestry and human health. Examples include bluetongue virus (see Section 4.3.1), \textit{Phytophthora ramorum}, Lyme disease (or Lyme borreliosis) and the varroa mite that impacts bee populations and pollination services. The severity of the impacts of pests and diseases at different ecosystem levels (species, habitat, ecosystem function or service) depends upon a multitude of different and interacting variables.

Invasive non-native species (INNS) are those non-native (alien) species that substantially modify an ecosystem and that, by displacing key species and modifying functions, can cause substantial damage to the environment, economy or social systems. No terrestrial invasive non-native species were examined for the CCRA (see the freshwater, Section 4.2.2 and marine, Section 4.2.4 natural environment sections for more information).

As each pest, disease or INNS is different (with a diversity of habitat and climate requirements, adaptive ability and consequences for natural environment) they need to be considered on a single species, case-by-case basis. The following terrestrial pests and diseases were discussed in the CCRA to illustrate the potential threat that may result from climate change:

\textit{Phytophthora ramorum}

\textit{P. ramorum} is a fungus-like species that causes the phenomenon more commonly known as Sudden Oak Death. Potential outbreaks have already

\(^{62}\text{www.ukbap.org.uk}\)
occurred across the UK, including in areas of the southwest of Scotland and recent research evidence shows that the pathogen can now infect blaeberry (*Vaccinium myrtillus*) and other heathland plants (*Sansford et al.*, 2009), as well as commercially important Larch species. Studies indicate that under a future climate this pathogen had an east-west divide, with increased risk to the moister west of the UK, with the lowest risk noted for Eastern Scotland.

**Chytridiomycosis**

This is a potentially fatal frog disease now found in the UK. It has been identified as a major cause of amphibian extinctions (e.g. golden toad, *Bufo periglenes*) and catastrophic population declines in many species across North, Central and South America. It seems to be temperature limited (*Garner et al.*, 2005) and climate change has been recognised as a causal factor enhancing the ability of the fungus to spread and/or induce disease (animals can carry the fungus without showing disease symptoms). The climate space for this disease is inferred to be expanding across Europe to include much of the UK and an increased frequency of milder wetter winters is therefore associated with an increased risk of outbreaks (*Bosch et al.*, 2006).

**Red band needle blight**

Red band needle blight (RBNB), caused by the fungus *Dothistroma septosporum*, has resulted in the widespread failure of Corsican pine (*Pinus nigra ssp. Laricio*) across its British distribution, including in Scotland. The reason for the increase in disease incidence is unclear, but it could be caused by increasing rainfall in spring and summer coupled with a trend towards warmer springs, that may act to optimise spore dispersal and infection. RBNB is also becoming more apparent on other pine species including lodgepole pine (*Pinus contorta*) and Scots pine. The CCRA was only able to analysis this pathogen at the Great Britain scale. The area that may be affected by RBNB in Great Britain is projected to increase by 12-25% in the 2020’s, 50-98% in the 2080’s and to 100% in the 2080s (Medium emissions scenario).

**Green spruce aphid**

Green spruce aphid (*Elatobium abietinum*) cause damage to spruce forest in Great Britain, most of which is situated in the Scottish Uplands. There is some evidence to suggest that low mean winter temperatures may be a controlling factor in green spruce aphid populations (*Forest Research, 2010a and 2010b*). The CCRA analysis indicates that area extent of spruce forest in Great Britain that is affected by green spruce aphid is unlikely to change above the baseline as a result of climate change up to the 2020s and 2050s, however, by the 2080s, 15-30% of spruce forests may be affected by green spruce aphid.

The sensitivity of pests and diseases to climate is not fully understood. Organisms may be directly affected by climate, their lifecycles may be regulated by temperature or moisture or they might have threshold values under / over which they are not able to survive. Specificities of pests/diseases also mean that the assessment of one pest/disease does not give a direct response function to another. Individual species studies so far, indicate that milder winters could increase the survival rates and spread of these organisms. Their introduction is nearly always a result of human actions, either deliberate or accidental. Ignorance of the risks of pests and diseases can lead to decisions that can lead to inadvertent consequences. More monitoring and research in particular is required in this area.
In terms of ecosystem services, the greatest impacts from invasive non-native species, pests and disease are likely to be where provisioning ecosystem services, such as food or fibre provision are affected. This does not discount that regulating services (e.g. flow regulation) or cultural services (e.g. amenity value) may also be affected when a large-scale outbreak or infestation occurs. Much less information is available for the wider impacts on biodiversity and ecosystem function.

There is growing awareness of the role of biodiversity in providing an ecosystem service by mediating the spread of pests and diseases, particularly vector-borne diseases (Johnson and Thieltges, 2010). Therefore, damage done to species, habitats and ecosystems that reduces overall biodiversity whether through changes in climate or other means may all act to exacerbate the risks posed by climate change.

Human actions can exacerbate the prevalence of invasive non-native species, pests and diseases by transfer of infected individuals or lack of control of suitable hosts. Non-climate factors such as technological innovation, transport and trade of natural resources, and international regulation, will have a role in which species become a particular threat (Tait et al., 2006).

**Impacts on habitats, ecosystem processes and functioning**

**Soil moisture**

Reductions in summer rainfall and increasing temperatures are projected to cause an increase in the risk of drought. In addition, future extreme droughts are likely to be more severe than droughts experienced to date. A reduction in summer rainfall is also likely to lead to a reduction in groundwater recharge, a potentially significant issue for Scotland which has a significant number of abstractions.

Whilst UKCP09 does not provide guidance on the magnitude of future droughts, a review of relative aridity information for Scotland (Section 3.1.2) suggests that an average year by the 2080s could be similar to the extreme drought of 1921. This means that the baseline (i.e. an ‘average year’) for future droughts could be far more severe than at present. The consequences for the natural environment could be significant.

About 46% of Scotland’s land area is covered by mountains, moors and heathland (Scotland NEA, 2011) which is far more extensive than anywhere else in the UK. Of this, just over 20,000km² is bog habitats (in 2007, Scotland NEA 2011). It has been estimated that blanket bog in particular covers approximately 13% of the land area of Scotland and that Scotland contains the most natural raised bog in the UK (MacGuire and Elster, 1998).

All peatland habitats, including blanket bog, are primarily dependent on the depth of water table, with peat accumulation taking place only when the water table is approximately level with the surface over the long-term (Parish et al., 2008). Bioclimatic envelope modelling for peatland in Great Britain indicates that more than 50% of the peatland area is likely to become vulnerable to change by the 2050s, although western Scotland is identified as the least vulnerable area. The current risk is primarily manifest during dry years but the projected future trend to drier summers would increase the exposure to harmful drought events. Variations in local conditions will determine the actual change in risk based upon factors such as soils and topography. Land management (e.g. drainage systems) will also combine with climate change to exacerbate or alleviate changes in soil moisture levels.

Loss of blanket bog could affect both biodiversity and ecosystem function and services. Increased summer drying would have impacts on invertebrates, such as worms and crane flies, which are a key component of ecosystem food webs. Drier soils would also increase levels of soil erosion. Key services provided by peatland habitats include the
regulation of water quantity and quality, storage of carbon, and landscape amenity, exploited in particular for tourism, recreational activities and human wellbeing.

In the peatland areas, the main sources of non-service sector employment are agriculture, forestry, sporting management (deer stalking and fishing) and tourism. Tourism is a significant seasonal employer providing, in the Highlands & Islands, some 20% of the average GDP and generating 13% of the total number of jobs (Wilkie, 2007). Therefore, peatland restoration projects such as LIFE Peatlands Project (2001-06) (LIFE, 2007) are vitally important not only to the area’s natural assets but also for the people who live and work in the area.

Drought, experienced as an extreme soil moisture deficit, may be observed in spruce and fir trees through a phenomenon called ‘shake’ (stem cracking). This stem cracking makes timber unsuitable for structural use and therefore dramatically reduces its value. Recent drought years have induced visible and well known effects on tree crown colour and defoliation. The assessment of drought risk is complex and needs to consider local differences; the impact is greatest and most noticeable on tree species that are not well matched to local site conditions (Read et al., 2009). Drought also makes trees more susceptible to a number of fungal diseases including the root diseases Armillaria species and Heterobasidion annosum, and to insect attack, especially from bark beetles which themselves can introduce disease (Green et al., 2008). Drought damage leading to dieback has been observed in a range of species in the UK, including oak, ash and beech, and is associated with ‘top dying’ in Norway spruce (Picea abies).

It is important to note that tree growth reductions and yield losses (loss of provisioning ecosystem services) can occur at soil water contents above those associated with drought and visible damage (Pereira et al., 2006). Therefore, in parts of the UK projected to have more frequent summers with larger soil moisture deficit, especially areas in the east of England and Scotland (see e.g. Broadmeadow et al., 2009) there would be significant reductions in growth and yield of some of the major commercial production species (Broadmeadow, 2002), and there may be increased incidence of drought damage (for more information on tree yields and productivity, see Section 4.3.2). CCRA projections show there is approximately a 15% (range 10% to 23%) yield loss from drought in northern Scotland by the 2080s. This compares to a 10% yield loss from drought for baseline conditions (present day).

Soil organic carbon
Soil organic carbon (SOC) for Great Britain was estimated by Dawson and Smith (2007) to be 9800±2400Mt (6900Mt in Scotland and 2800Mt in England and Wales), although recent research suggest this may be an overestimate. Hence, recent reappraisal of SOC in peatlands (blanket bog, lowland raised bogs and fen) has estimated that they contain 2300Mt of carbon, of which the majority, 1620Mt is in Scotland (Bradley et al., 2005; Chapman et al., 2009; Billet et al., 2010).

Soil organic carbon is a surrogate measure for soil organic matter which is a fundamental ecosystem property produced and maintained by the dynamic interactions of soil biodiversity with vegetation, climate and other drivers. Soil organic matter is the primary energy source for soil organisms and therefore changes in the composition or amount of soil organic matter can in turn alter the composition and activity of soil organisms. All components of soil biodiversity are considered to be at risk from climate change. Any threat to soils should be a major source of concern since soils maintain effective functioning in all terrestrial ecosystems and support the delivery of many vital ecosystem services (e.g. crop production, water regulation, carbon sequestration, water purification, etc.). Soils are also an important global reserve for biodiversity, including many BAP species, such as fungi, bees and ants.
The paleoenvironmental record clearly shows that soil organic matter is sensitive to changes in climate (particularly temperature, solar radiation and rainfall). However, relationship between soil carbon and climate are very complex and typically confounded by other factors (Billett et al., 2010), including forest management and drainage activities.

![Deeply dissected blanket bog at the summit of Creag Loisgte (Northwest Highlands)](image)

**Figure 4.3** Deeply dissected blanket bog at the summit of Creag Loisgte (Northwest Highlands)

Source: Richard Webb

Broadly, higher temperatures in the cool temperate climate of the UK would increase soil decomposition rates, resulting in loss of SOC stocks, although this may be offset by increased plant growth and consequent higher inputs. Warmer conditions would extend the growing season length and the period of more active soil decomposition, and the effect may be relatively large in the cooler upland areas of the UK. However, higher temperatures are likely to increase evaporation, resulting in drier soils, and therefore reduced decomposition rates, particularly during summer.

The impacts of precipitation changes are less easy to generalise, as they will depend on existing regimes. In already wet areas, increased rainfall may lead to waterlogging, which may result in reduced decomposition; conversely drier conditions would lower water tables increasing decomposition and consequent CO$_2$ loss (although decreasing methane emissions). In dry areas, reduced rainfall may lead to reductions in decomposition, particularly during summer. Prolonged drought may cause or exacerbate peat cracking in organic soils and thus increased drainage and SOC loss. Increased frequency of high rainfall events may also cause more runoff or particulate organic carbon (POC) and dissolved organic carbon (DOC).

Recent measurements of changes in SOC suggest that climate change has had a rather less significant impact than land use change to date (Kirk and Bellamy, 2010). However, the complexity of interactions involved mean that the risk factors are poorly

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63 www.geograph.org.uk/photo/12954. This figure is the copyright of the owner but has been reproduced in accordance with the copyright as detailed by the Creative Commons licence: http://creativecommons.org/licenses/by/3.0/legalcode.
understood. The larger changes in projected climate suggest that these interactions will be further modified. However it is not currently possible to state with certainty whether this will result in an increased carbon store or sink or, in addition, what the precise implications for ecosystem functions and services (e.g. nutrient cycling and water retention) would be. There are potentially major implications for climate change adaptation and mitigation policy in this area.

For example, in terms of carbon storage as a whole (and other ecosystem goods and services), it is important to consider the interactions between SOC turnover, nutrient cycling and tree growth. Warmer conditions are likely to result in increased decomposition and loss of SOC, but increased inorganic nitrogen availability and increased tree growth (Melillo et al., 2011). Increased rainfall, however, may cause more leaching of nutrients and therefore reduce tree growth and associated services.

**Extreme events**

Extreme weather events that have an impact on the natural environment include drought (discussed earlier in this section), river and coastal flooding (Section 4.2.3), wildfires and extreme winds (wind throw is discussed in Section 4.3.2).

**Wildfire**

The risk of wildfire could increase in hotter, drier conditions. It is estimated that the risk of wildfires in Scotland could increase by of the order of 30 to 40% by the 2080s from a 1980s baseline (see Forestry Sector Report). Some key habitats are sensitive to fire including woodlands, grassland, peatlands (including blanket bog) and heathlands. It should also be noted that peat is a significant carbon sink as noted earlier, and carbon stored within peat could therefore be released back into the atmosphere, severely restricting the ability of this habitat to act as an effective carbon sink. Fires could therefore lead to a significant loss of biodiversity (in important nature conservation areas such as the CNP, highlighted earlier), as well as increasing rates of erosion and detrimental effects on water quality. The effects would be most keenly felt by rural communities who could potentially be at direct risk, or indirectly affected by (for example) closure or blockage of access routes.

**Indirect effects**

**Agriculture**

Projected changes in land use (see Section 4.3.1) are likely to include an increase in agricultural activity. This ultimately would lead to a higher proportion of biomass produced by net primary productivity being removed from the ecosystem with nutrients becoming depleted (unless replaced by artificial fertilisers). This will have negative implications for biodiversity, which together with the application of pesticides and herbicides will result in severe reductions in species abundance and diversity, unless remedial measures are applied. In Scotland, research has shown that the areas of prime agricultural land (as defined using the LCA system) 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) and water for irrigation available. This change in land use may be further encouraged due to concerns regarding food security, with additional food required to be produced in the UK. 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.

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64 The availability and access to food.
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 (‘field capacity’) 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. A decline in headage payments for sheep in recent years has therefore been associated with a reduction in sheep numbers in the more marginal areas, which has been described as a ‘retreat from the hills’ (Scottish Agricultural College, 2008). This has 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.

Recreation and tourism
A further indirect impact of climate change would be changes in outdoor activity and the substantial levels of natural tourism that take place in Scotland65. Increased temperatures, and reduced rainfall levels in Scotland would be anticipated to increase these activities, possibly having a detrimental effect on the terrestrial environment. However, changes in the natural environment would also affect these activities to varying degrees, and it is difficult to assess and quantify what these effects may be.

Climate mitigation
Actions to reduce greenhouse gas emissions, such as via renewable energy schemes, are fundamental to a healthy future planet. However, if these schemes are not properly planned or acknowledge future change in the natural environment, then they could potentially cause significant threats to the natural environment, affecting both wildlife and rural communities. Conversely, appropriately planned schemes could increase opportunities for biodiversity and rural communities. The introduction of windfarms into many upland landscapes is probably the mitigation measure that is of most concern, although other schemes such as tidal schemes, hydroelectricity and bioenergy are also a potential concern. These schemes are likely to continue into the future as Scotland looks to meet its renewable energy requirements (see Section 4.5.3) alongside the upgrading and expansion of national growth, and the growth of offshore windfarms.

Like any development on sites with biodiversity value, renewable energy sites can have a negative effect on priority species and habitats depending on the technology and the location. Wind turbines, for example, are known to cause deaths among some species of birds and bats due to collision with the turbine blades (see case study below). Wave and tidal generators may impact marine and estuarine habitats. Hydroelectricity schemes primarily affect riparian and fluvial habitats. Biomass crops are thought to have both positive and negative impacts on biodiversity depending upon both crop and its management.

Evaluating the risk posed to biodiversity from renewable energy projects at a national scale is difficult due to a scarcity of suitable examples and their relatively recent appearance in the landscape. The only renewable energy source to be developed at anything approaching a national scale is wind energy, and there has been little

65 Nature based tourism is currently estimated at £1.4 billion per year (Bryden et al., 2010)
research on the effects of wind turbines on biodiversity at anything but the local scale, a single breeding cycle or single species or species group (Pearce-Higgins et al., 2009). A significant problem faced by such research is that it is often difficult to ascertain whether any changes observed are due to the impact of the renewable energy scheme itself, or other factors such as changes in climate or natural fluctuations in population size.

**Case Study: Effect of Wind Turbine Blades on Bird Populations**

Due to the higher average wind speeds and relative scarcity of human habitation, the mountainous regions of Scotland that support priority bird species are a prime candidate for wind farms, particularly bearing in mind the renewable energy targets for Scotland outlined in Section 1.3 which are significantly greater than for the rest of the UK. This can have effects on bird populations as well as potential impacts on peat, which has implications for carbon storage and climate change mitigation. There may be social impacts on rural communities as well. The Royal Society for the Protection of Birds published a ‘bird sensitivity map’ in 2006 to assist developers and local planning authorities select wind farm sites in Scotland that were less likely to have an impact on bird populations. Areas of relative sensitivity were identified mainly by buffering known breeding distributions of priority bird species (Bright et al., 2006). This map, shown in Figure 4.4 indicates 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.

**Figure 4.4** Bird Sensitivity Map for Scotland

Sensitivity is based upon the distribution of 16 species of bird of conservation importance and the distribution of Special Protection Areas (SPAs).

Source: Bright et al. 2006
Scotland has a target of 100% of gross annual energy consumption from renewable energy generation by 2020 (including offshore renewable energy, see Section 4.5.3). This means that it is likely there will be a significant increase in wind farm construction in the near future. Currently the total capacity of wind energy projects that are proposed, but not yet operational for Scotland greatly exceeds the capacity of projects that are already operational (see Section 4.5.3).

The majority of proposed projects have to undergo an Environmental Impact Assessment (EIA), and this is done before they are consented, as part of the application process. This allows any EIA mitigation measures or post-consent monitoring requirements to be included as part of the planning conditions should consent eventually be given. Most turbine projects also have a lifespan of 25 years, with the infrastructure removed and the land returned to its “pre wind farm” state at the end of this period. However, the current requirements for approval do not explicitly take into account future requirements for biodiversity and, as previously discussed, changes in climate space and migration patterns could lead species to inhabit other areas. This coupled with the expected increase in renewable energy developments, particularly in Scotland, means that the potential for negatively impacting biodiversity is large. However, with the right strategic approach and consideration for future biodiversity needs, this could present an opportunity too, for biodiversity, sequestration of soil organic carbon and for climate mitigation. Additionally, the impact of renewable energy development may be much less than no action to counter climate change impacts, or an increase in fossil fuel use if renewable energy generation isn’t developed.

The other renewable energy source that has expanded significantly recently is bioenergy (although as yet with a small land footprint at UK level), in particular the use of short rotation coppice (SRC) and forestry by-products. The impacts of bioenergy crops have been reviewed by Booth et al., (2010) who highlighted inter alia the following issues:

- Impacts on biodiversity depends on the use of native or non-native species, and the provision of additional habitat diversity.
- Removal of brash and coarse wood material from existing forestry removes habitat, ground cover and food resources for small invertebrates, mammals (e.g. bats) and fungi leading to changes in community structure and loss of species that utilised this material.
- Microbial biomass and most soil fauna groups increase in abundance and diversity after afforestation, particularly decomposers, compared to arable land.
- Forestry or SRC expansion is likely to be at the detriment of rare birds adapted to open habitats. However SRC in farmland can provide increased cover and food for rare species, notably through increased invertebrate diversity.

Hence, the consequences for biodiversity strongly depend on the land use that bioenergy crops replace and the implications for changes in habitats and species diversity (Haughton et al., 2009). Hence, beneficial effects often accrue from the development of schemes in the lower land areas that enhance farmland diversity, whereas there is a risk of increased disruption in the upper land areas where semi-natural habitats are most common.

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66 Note that established consultation procedures for forestry take into account potential impacts on such species, and well-planned woodland expansion can also benefit rare woodland and woodland-edge species.
Summary of results
The results of the analysis are shown in Table 4.1.

Table 4.1 Climate change impacts on the natural environment (terrestrial)

| Threats | Species unable to track changing climate space | Changes in species migration patterns | Changes in soil organic carbon | Risk of diseases to biodiversity | Generalist species more able to adapt than specialists | Risk of pests to biodiversity | Risks to species and habitats due to drier soils | Loss of service through loss of keystone species | Asynchrony between species breeding cycle and food supply | Wildfires due to warmer and drier conditions | Changed recharge and groundwater levels | Impact of outdoor leisure, sport and tourism | Agricultural intensification | Environmental effects of climate mitigation measures |
|---------|-----------------------------------------------|-------------------------------------|---------------------------------|---------------------------------|------------------------------------------------------|---------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| BD5     | High consequences (positive)                  | Medium consequences (positive)      | Low consequences (positive)     | Low consequences (negative)     | Medium consequences (negative)                        | Low consequences (negative)    | High consequences (negative)                  | Central estimate                              | Timing                                           | 2050s                                          | 2080s                                          |                                                    | 2020s                                          |                                                    |
| BD9     | UK                                            | UK                                 | UK                              | UK                              | UK                                                    | UK                              | UK                                            | UK                                            | UK                                              | UK                                            | UK                                             | UK                                              | UK                                             |
| BD8     | S                                              | S                                  | S                               | S                               | S                                                     | S                               | S                                             | S                                             | S                                               | S                                             | S                                              | S                                               |
| BD4     | IJ                                             | IJ                                 | IJ                              | IJ                              | IJ                                                    | IJ                              | IJ                                            | IJ                                            | IJ                                              | IJ                                            | IJ                                             | IJ                                              |
| BD1     | BD1                                           | BD1                                | BD1                             | BD1                             | BD1                                                    | BD1                             | BD1                                            | BD1                                            | BD1                                             | BD1                                            | BD1                                             | BD1                                             |
| BD46    | BD6                                           | BD6                                | BD6                             | BD6                             | BD6                                                    | BD6                             | BD6                                            | BD6                                            | BD6                                             | BD6                                            | BD6                                             | BD6                                             |
| BD23    | BD23                                          | BD23                               | BD23                            | BD23                            | BD23                                                   | BD23                            | BD23                                          | BD23                                          | BD23                                           | BD23                                          | BD23                                           | BD23                                           |
| BD12    | BD12                                          | BD12                               | BD12                            | BD12                            | BD12                                                   | BD12                            | BD12                                          | BD12                                          | BD12                                           | BD12                                          | BD12                                           | BD12                                           |
| GNr5    | IJ                                             | IJ                                 | IJ                              | IJ                              | IJ                                                     | IJ                              | IJ                                            | IJ                                            | IJ                                              | IJ                                            | IJ                                             | IJ                                              |
| BD6     | BD6                                           | BD6                                | BD6                             | BD6                             | BD6                                                    | BD6                             | BD6                                            | BD6                                            | BD6                                             | BD6                                            | BD6                                             | BD6                                             |
| BD1     | BD1                                           | BD1                                | BD1                             | BD1                             | BD1                                                    | BD1                             | BD1                                            | BD1                                            | BD1                                             | BD1                                            | BD1                                             | BD1                                             |
| BD46    | BD6                                           | BD6                                | BD6                             | BD6                             | BD6                                                    | BD6                             | BD6                                            | BD6                                            | BD6                                             | BD6                                            | BD6                                             | BD6                                             |
| BD23    | BD23                                          | BD23                               | BD23                            | BD23                            | BD23                                                   | BD23                            | BD23                                          | BD23                                          | BD23                                           | BD23                                          | BD23                                           | BD23                                           |
| BD12    | BD12                                          | BD12                               | BD12                            | BD12                            | BD12                                                   | BD12                            | BD12                                          | BD12                                          | BD12                                           | BD12                                          | BD12                                           | BD12                                           |
| GNr5    | IJ                                             | IJ                                 | IJ                              | IJ                              | IJ                                                     | IJ                              | IJ                                            | IJ                                            | IJ                                              | IJ                                            | IJ                                             | IJ                                              |

Summary of the main impacts of climate change on the terrestrial natural environment
- Some species may not be able to track their changing climate space
- Changes in phenology may lead to declines in some species and may affect food webs.
- Changes in species migration patterns may affect species populations and the designated site network
- Environmental change, such as changes in climate, may disproportionately favour generalist species, which may result in a reduction in overall biodiversity and ecosystem resilience.
- Pests and diseases may find a changed climate more favourable and affect provisioning ecosystem services and biodiversity.
- Changes to soil moisture may lead to changes in carbon stored in soils and damage to priority habitats and provisioning ecosystem services.
- An increased risk of wildfire, by the order of 30% to 40% by the 2080s from
4.2.2 Freshwater

Climate change could lead to changes in freshwater biodiversity and ecosystem functions, which would not only affect the natural environment, but would also have knock-on impacts for society and the economy.

**Impacts on species, community structure and habitat change**

**Changes in phenology**

As discussed in relation to the terrestrial natural environment, changes in climate may alter the seasonal timing of events, possibly leading to a mismatch (or asynchrony) between species. This phenomenon may also be an issue in the freshwater environment. Phenological mismatch in these cases may similarly lead to reduced population sizes and have implications for ecosystem services.

In lowland Scottish lochs, increased water temperatures have shown a significant correlation with increased spring densities of aquatic invertebrate grazers (*e.g.* water flea *Daphnia* spp.) (Carvalho and Kirika, 2003). Projections based upon the analysis of Durance and Ormerod (2007) suggest that macro-invertebrate abundance in spring might decline by 21% for every 1°C rise. Although many core species could persist if temperature gains reached 3°C, mostly scarce taxa (5–12% of the species pool) would risk local extinction. This type of impact may have potentially serious implications for food webs in these lochs.

**Water temperature and stratification**

Increasing air temperatures could lead to stratification of water bodies including rivers and lakes, with adverse impacts on aquatic habitats, particularly those with a lack of riparian vegetation (Malcolm *et al*., 2008). Studies have shown that changes in stratification can result in changes to the distribution of dissolved oxygen, nutrients and any toxins within the water column (Nickus, 2007) which could then have impacts on water quality and the ecological status of the water body. Oxygen stores in the bottom layers in the lower levels are in particular most likely to be depleted (Moss, 1998), which has implications for species at these levels. Aquatic ecosystems feature intricate food webs. Therefore changes in individual species can modify the structure and functioning of the whole system. Aquatic and wetland ecosystems provide a key service to humans by regulating water quality and flow levels.

For rivers, there is evidence that small upland streams are more sensitive to changes in air temperature than lowland rivers, and as such, some of the upper branches of the river network may become unsuitable for cold water species (Hrachowitz *et al*., 2010). This was also indicated by Webb and Walsh (2004) for example, based on projections from UKCIP98 (Hulme and Jenkins, 1998). They predicted that future higher river temperatures in winter over the current century would be detrimental to salmon (*Salmo spp.*) spawning and incubation, especially under the highest scenario considered. They also predict that for the same scenario, rivers that currently support brown trout
(Salmo trutta spp.) in Northern Scotland would no longer provide a suitable habitat by the end of the current century. However, some rivers will develop physiologically acceptable temperature regimes for a greater number of coarse fish species (Webb and Walsh, 2004). In addition, a climate change vulnerability index for lochs in Scotland (based upon latitude, altitude and mean depth) by Winfield et al. (2010), indicates that southern lochs at low altitude and with shallow waters have a high vulnerability and are more likely to get warmer than deep, mountainous lochs in the north. This assessment corresponds closely with sites that show the largest decline in Arctic charr (Salvelinus alpinus) populations since 1990, providing preliminary data that rising water temperatures might be an important influence on species decline.

Future temperature increases (along with other climate change effects such as increased frequency of summer drought and winter flood) are likely to have significant effects on the growth rate of freshwater fish, such as trout, salmon and grayling (Thymallus thymallus) (Webb and Walsh, 2004; Davidson and Hazlewood, 2005). It has also been suggested that along with impacts to in-stream habitats, warmer waters may influence some physiological characteristics of native fish. Although most fish in Scotland currently live well within their thermal limits, two cold water lake fish species, the whitefish (Coregonus lavaretus) and Arctic charr, are likely to be particularly vulnerable (Arnell, 1998).

Water temperature changes also have implications for loch phytoplankton due to likely increases in primary productivity. Modelling work by Elliott et al. (2006) suggests a potential for cyanobacteria to dominate the phytoplankton community and that this dominance was at its greatest when high water temperatures were combined with high nutrient loads. Similarly, changes in stratification and mixing may have impacts on plankton abundance and composition, with the occurrence of massive blooms of buoyant cyanobacteria, lower oxygen concentrations and lower light levels considered more probable in a warmer future climate (Mitchell et al., 2007).

Species with low temperature tolerance limits will be most affected. Different species will have different thermal tolerances, therefore the differential impacts between species implies an enhanced prospect of changes to community structure and ecosystem function. Aquatic ecosystems are important for the range of ecosystem services that they provide including natural filtering, water purification, and the regulation of oxygen supply and other nutrients. A range of provisioning and cultural services are associated with these systems, particularly associated with fish, which provide important social and economic benefits for some areas, see the case study below.

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**Case Study : Salmonid fisheries**

Salmon is the focus for economically-important sport and commercial fisheries.

Factors known to affect freshwater growth of Atlantic salmon include temperature, food availability, and density (Elliott and Hurley 1997; Grant et al., 1998). A relationship between mean age at smolt stage and the combination of temperature and day length has been demonstrated across the range of Atlantic salmon by Metcalfe and Thorpe (1990). Climate change is therefore associated with a shorter time for salmon to reach smolt stage. Experimental evidence has led to qualitative suggestions that waters with current average temperatures below 16-18°C will show increased populations as a result of increasing temperatures (e.g., Langan et al., 2001), whereas waters with higher current temperatures will show population decreases (e.g. Langan et al., 2001; Swansburg et al., 2002). However, this will also be dependent on other factors, such as the continued availability of food.

In the UK and elsewhere, the number of fish returning annually to spawn (comprising

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67 A young salmon at the stage of migrating to the sea for the first time.
the great majority of the female breeding stock) has shown a dramatic downward trend over the past 40 years which is associated with increased marine mortality (Friedland et al., 1993). The life cycle of the salmon, which involves both freshwater and marine components, is therefore vulnerable to climate change at various stages.

In Scotland in 2006, more than 130,000 tonnes of Atlantic salmon was produced by 44 companies farming at 252 sites (Scotland NEA, 2011). In addition to their economic value, salmon have an important cultural role on many UK rivers. This includes the association between their migratory behaviour and the pattern of seasons (sometimes celebrated in a yearly ceremony), and the tradition or folklore based upon sport fishing.

A decline stream stocks, possibly linked to changes in ocean temperature (Friedland et al., 1993) or increased stream temperatures (Friedland, 1998) could have significant implications for sport and commercial fisheries in Scotland.

**Changing water quantity**

Whilst annual precipitation in Scotland is not projected to change significantly, there is projected to be a marked difference between precipitation in the summer and the winter (see Section 2.3.2). The reduction in summer rainfall would cause reductions in river flows and soil moisture. The increase in winter rainfall would tend to result in increases in flooding and waterlogging.

Low flows in watercourses may lead to a decline in ecological status as water availability for biodiversity reduces. This pressure is likely to be increased by a projected increase in societal water demand, which analysis in the CCRA for England and Wales indicated may rise by 4% (range 2-5%) by the 2050s and 5% (range 3-8%) by the 2080s (from a 1997/98 baseline). Although it was not possible to estimate increases for Scotland, it is likely that similar increases will be experienced.

Drought conditions increase nitrogen mineralisation and sulphur oxidation, leading to the release of nitrate and sulphate into surface waters which can further impact on water quality (Whitehead et al., 2009). Storms that terminate droughts act to flush nutrients or generate acid pulses in acidified upland catchments. Upland systems are particularly vulnerable to these events because of their normal low-nutrient status.

The impact of low flows on biotic communities will be different for different species. Some species such as algae may benefit while others, including some invertebrate communities may suffer. If the period of low flow is infrequent, systems are more likely to be able to recover but a sustained drought can mean recovery times are much longer.

Changes in flow and water levels will interact with impacts on water quality and thermal regime to modify the functioning of aquatic ecosystems. 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. This includes water purification and supply plus impacts on fish stocks and other aquatic species. Therefore the potential drying-up of watercourses could have significant implications for wider landscape amenity and cultural value, including recreational and navigational access.

**Indirect impacts**

**Water pollution risk and eutrophication**

Low flows due to changes in both air temperature and rainfall can affect surface water quality in a number of ways. First, there can be a reduction in the dilution and dispersion of contaminants. For example, downstream of point sources there could be higher concentrations of contaminants during periods of low flow. Varying flow patterns
may also have indirect consequences due to changing river velocities, in-stream processes and sedimentation and erosion (Whitehead, et al., 2009; Hammond and Pryce, 2007). Low flows can also increase water temperatures, potentially influencing the rate of bacteriological processes and chemical reactions that occur within them. Higher temperatures together with higher nutrient loads could further increase the risk of algal blooms. A change in nutrient status, dissolved oxygen concentration (DOC) or toxins in water bodies can all have detrimental impacts. For example, growth measurements of fish can be related to environmental conditions indicating that poor water quality, environmental stress and limited food sources will result in low growth (Elliott and Hurley, 1997). Reduced dilution effects and increased organic pollutant concentrations during low flows can combine with the higher biological oxygen demand (BOD) during such episodes to exacerbate stresses on aquatic ecosystems due to lower DOC levels.

A changing physical, biological and chemical environment may have implications for aquatic ecosystems, with any changes in water quality due to climate change potentially leading to a lack of compliance with Water Framework Directive (WFD) requirements. This could in turn limit certain abstractions and affect industrial processes such as those involved in energy production which discharge cooling water to the environment. The WFD requires that Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015. Figure 4.5 provides more detail on the 2009 WFD classification results for ecological status and ecological potential for surface water bodies in Scotland. Ecological status concerns the structure and functioning of surface water ecosystems and is assessed by various biological, chemical and physicochemical and hydromorphological quality elements.

**Figure 4.5 2009 WFD classification results for water bodies in Scotland**

Adapted from SEPA, 2011a

The figure shows that while a number of water bodies were classified as high or good status, many were also classified as having less than good status (46% for Rivers, 37% for Lochs, 16% for Estuaries, 5% for coastal waters and 21% for groundwater in 2009). There are a number of environmental problems which affect waters in Scotland, mainly
around the agricultural areas along the east coast, and larger urban areas including Edinburgh and Glasgow (SEPA, 2011a). Pressures affecting water bodies include pollution and alterations to water flows and levels.

Data showing a possible change in water bodies complying with WFD objectives due to variations in flow are currently unavailable for Scotland. However, it is possible to look at the latest classification maps for Scotland for surface water status and link these with the changes in low flows (Q95). This indicates where a decrease in flows could potentially lead to a reduction in the number of water bodies complying with WFD objectives. Figure 4.6a shows the overall status of surface waters in the Scotland River Basin District (RBD) in 2008, while Figure 4.6b shows the overall status of surface waters in the Solway Tweed RBD in 2008. Overall surface water status is the lower of ecological status and chemical status. Chemical status is classified according to environmental quality standards for a number of priority substances or other dangerous substances.

![Status of surface waters in the Scotland RBD in 2008](image)

**Figure 4.6a** Status of surface waters in the Scotland RBD in 2008

Source: Scottish Government, 2009e
Figure 4.6a shows that the majority of water bodies in the Scotland RBD classified as either ‘Bad’ or ‘Poor’ are located in the central and southern parts of the country. Looking at the corresponding UKCP09 river basin regions, the impact of climate change on Q95 is projected to be highest for the Clyde, followed by the Forth (see Section 3.1.1 for full details for changes in Q95). Both basins are in the south of the country. In Northeast Scotland there are also a number of water bodies classified as either ‘Bad’ or ‘Poor’, however projected decreases for this river basin region are not as great as those for the Clyde and Forth. River basin regions such as West Highland and North Highland, where water body status is generally better, are also projected to have slightly smaller decreases in Q95 than these southern basins.

![Map showing water body status](image)

**Figure 4.6b** Overall status of surface waters in the Solway Tweed RBD in 2008


Figure 4.6b shows that surface water bodies with a status of ‘Poor’ or ‘Bad’ are located throughout the Solway Tweed RBD, as are those that are currently classified as ‘Moderate’. Projections for the Solway river basin region indicates that Q95 will decrease although slightly less than for the Clyde. Decreases in Q95 for the Tweed river basin region are projected to be greater than those for all the other river basin regions in Scotland.
Water quality may also be affected by stratification and water temperature increases. Poor water quality is detrimental to the effective functioning of aquatic ecosystems including supporting services such as nutrient cycling and oxygenation. A surplus of nutrients during eutrophication mean that these nutrients are not cycled through the system and the dynamic balance of the ecosystem is destabilised, particularly when toxic algal blooms occur. This has implications for the purification and supply of clean water. Impacts are also apparent for fish stocks which provide an important economic, social and cultural service in key locations, and for other important species that provide ecosystem benefits. 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.

Increased winter precipitation is projected to lead to an increase in flooding as well as more frequent and extended periods of waterlogging, which will provide both opportunities and threats to biodiversity. Increased winter precipitation will also lead to increases in diffuse pollution and could lead to greater soil erosion and runoff of nutrients and faecal matter.

Case Study: Water Pollution Risk and Eutrophication in Freshwater Bodies
(SEPA has a responsibility to review the eutrophication status of Scottish coastal, estuarine and inland waters as required by the Urban Waste Water Treatment Directive, every four years.

Eutrophication is the process by which nutrients added to the water cause algae and plant-life to grow excessively resulting in a disturbance to water borne organisms. These so-called algal-blooms reduce light and oxygen levels within the water reducing the water quality. This process is predominantly caused by phosphorous and nitrogen as well as increased organic matter.

Environmental guidance indicates that the maximum level of nitrate concentrations is 50mg/l with levels above this considered to be eutrophic (EU, 2010).

Occurrences of polluted water bodies in Scotland are low. For inland waters only 17 of Scotland’s freshwater lochs show negative impacts of nutrient additions. For estuarine and coastal environments the only area affected is the Ythan estuary in Aberdeenshire (SEPA, 2005).

Freshwater Environment - Strathclyde Country Park Loch
Strathclyde Park Loch is located between the M74 and Motherwell. It is an artificial water body created in the 1970s. Popular with locals and tourists the loch is used for a wide range of activities including water sports, recreation and sporting events. In 1997 the loch was designated as being eutrophic (SEPA, 2005).

SEPA suggested that a combination of point sewage discharge, diffuse agricultural waste and other pressures received along the length of the River Clyde all contributed to the pollution detected within the loch.

Monitored phosphate and chlorophyll concentrations indicated levels within the eutrophic range with peak chlorophyll levels being within the hypertrophic range.

Eutrophication within Strathclyde Park Loch has resulted in its closure to the public. Closures may have a significant impact on the local community, detrimentally affecting the local tourist trade. In 2008 a Triathlon championship event was postponed and the 2010 Great Scottish Swim was cancelled, reducing the number of global visitors and competitors to the area.

The Clyde Valley is a substantial farming region in Scotland. With a change in climate 68 http://www.scotland.gov.uk/News/Releases/1999/10/c936234a-ba14-4098-90d9-0d7d825fab04
likely to cause an increase in the number of growing days, and with the length of growing season and the area of land designated as high grade likely to increase (see Sections 3.1.8 and 4.3.1), crop production in the Clyde Valley may increase. Furthermore, it is possible that an increase in arable land is seen in the South and East of Scotland, as world food demand and food security increases. This could have an increasingly detrimental effect on nutrient levels and water quality downstream in the loch.

A consequence of the potential reduction in summer rainfall within Scotland (as discussed above) may cause “drought” like conditions to be experienced more often. This coupled with the increased land use could lead to compaction of the soil by livestock and farm machinery. It has been shown that the infiltration capacity of such land can be reduced by up to 80% which significantly increases runoff (Defra, 2008a). This may lead to an increased concentration of pollutants and minerals entering the system having a negative impact downstream.

Climate change is implicitly included within the water framework directive in which strategies to reduce other stressors such as land-use change and pollution can be developed in order to allow water bodies to successfully adapt to changing climatic conditions (Wilby et al., 2006). A key challenge for water quality is to reduce the risk from diffuse pollution through measures either at their source (e.g. timing of fertiliser application; precision farming) or before they enter water bodies (e.g. buffer strips). The effectiveness of these alternative adaptation measures in varying environmental and

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socio-economic contexts requires further assessment including, for example, in different land use systems and catchment contexts.

**Flood defence structures**

For a river in its natural state during high flow conditions a critical level is reached when some water leaves the normal watercourse and spreads out over a larger area which represents its floodplain. The variety of sediment left during floods and the ephemeral state of the floodplain produce a diverse range of habitats that support many important species. Man-made engineering structures are designed to protect people, properties, and land on the floodplain from the adverse effects of flood inundation by maintaining the river within a predictable course. However, these structures act to separate the river from its floodplain to the detriment of the associated riparian and wetland habitats.

An increased risk of flooding from climate change will require measures to reduce that risk to a level judged acceptable by society. If floodplains continue to be populated and cultivated, then it is very plausible that an adaptive response will be to increase the extent of flood defence structures. This will be particularly likely if society becomes more ‘risk averse’ in future and continues the current inclination to favour structural approaches to flood defence influenced by a reaction to provide visible responses to risk (Harries and Penning Rowsell, 2011). This acts against schemes that integrate natural flood management incorporating the river floodplain and wetland habitats to buffer against flood risk. If this happens the future of riparian habitats and the dynamic evolution of floodplain wetland habitats will be negatively impacted. In addition to supporting coastal realignment, the second National Planning Framework for Scotland also notes the Scottish Government’s approach to the integrated management of water. It notes that flood risk can be reduced by slowing water flow to rivers and burns by increasing the capacity of natural features such as wetlands, meanders and floodplain woodlands as well as engineered structures (Scottish Government, 2009a).

**Societal water demand**

The frequency, magnitude and duration of low flows are known to have impacts for aquatic communities. Many UK rivers have regulated rather than natural flows and a key challenge presented by climate change is to modify regulatory regimes to maintain healthy ecosystems. Indirect consequences that may occur from an increased human demand for water may cause additional stress on the natural environment.

Datasets of water demand collated by water companies in England, show per capita consumption is sensitive to mean monthly temperature and that it rises during heatwave periods. A warming climate may therefore lead to increased societal water demand if trends are similar in Scotland. If levels of water demand and abstraction rates increase in many catchments this would act in combination with any direct impact on changes in water supply from climate change to modify flow regimes. Recovery of the ecosystem may therefore be further jeopardised, particularly during extended drought periods.

Changes in flow and water levels will interact with impacts on water quality and temperature changes to modify the functioning of aquatic ecosystems. Supporting services such as nutrient cycling and oxygenation may be affected, which would have implications for a range of regulating, provisioning and cultural services that these systems provide including: water purification, supply and recreational uses. Increased competition for water is likely in the future. Policy tools are available to plan for and regulate abstractions. Ministers set their expectations of Scottish Water through objectives. The current investment programme for 2010-15 has been issued by Ministers and includes objectives to inform climate change adaptation.
Summary of Results

The results of the analysis are shown in Table 4.2.

### Table 4.2 Climate change impacts on the freshwater environment

<table>
<thead>
<tr>
<th>Threats</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD15</td>
<td></td>
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<td>BD10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NW5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Central estimate**

- **Threats:**
  - Increased societal water demand
  - Lower summer river flows (Q95)
  - Ecosystem risks due to low flows and increased water demand
  - Biodiversity risks due to warmer rivers and lakes
  - Raw water quality
  - Warmer and drier conditions
  - Water quality and pollution risks
  - Asynchrony between species breeding cycle and food supply
  - Impact of outdoor leisure, sport and tourism

- **Confidence:**
  - High confidence
  - Medium confidence
  - Low confidence
  - Too uncertain

- **Coverage:**
  - S: Scotland
  - UK: United Kingdom
  - Q: Quantitative

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### Summary of the main impacts of climate change on the freshwater natural environment

- Changes in phenology may occur, affecting food webs in lochs.
- A reduction in raw water quality possibly leading to a reduction in the number of water bodies complying with WFD objectives.
- Temperature changes and stratification may affect species growth and have negative impacts on ecosystem goods and services such as fish.
- Increased eutrophication of saltwater and freshwater bodies, increasing the number of coastal dead zones.
- Changing water quantity and quality, affecting provisioning and cultural ecosystem services; affecting water supplies and landscape amenity.
- Flood defence structures, if increased in response to climate change, would have further negative impacts on the natural environment.
- Societal water demand, if increased due to warmer climate, may act to jeopardise ecosystem recovery rates, particularly following extended drought periods.
4.2.3 Coastal

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Biodiversity and Ecosystem Services Sector Report and the Floods and Coastal Erosion Sector Report.

Scotland has a long and varied coastline, with the mountainous western coastline characterised by a highly indented landscape with exposed islands, high sea cliffs and rocky skerries\(^70\). The north coast tends to be abrupt and exposed and adjacent to deep water, with the east characterised by three major estuaries and a broad fertile strip. 70% of Scotland’s coast is classified as hard coast (rocks and cliffs), 29% soft coast (unconsolidated gravels, sand and silts) and less than 1% are artificial (harbours and sea walls). Scotland also has approximately 70% of Britain’s dunes by area, 60% of sea cliff by length, 15% of saltmarsh by area and less than 5% of shingle by length (Angus et al., 2010). Three quarters of the coast is broadly stable, 8% is accretional and 12% is erosional (Mackey and Mudge, 2010). This terrain combined with the indented coastline means that settlements and transport links are often, by necessity, located within a relatively narrow coastal zone.

In addition to the mainland, Scotland also has over 790 separate islands (although only about 100 of these are inhabited), including the Northern Isles and the Hebrides. Including the main islands, the length of the Scottish coastline is approximately double that of England (based on Ordnance Survey measurements along the mean high water mark) despite having just over half the area of England.

The coastal environment is an important natural heritage resource. In addition to important habitat types such as sand dune systems and shingle beaches there are other rare habitats such as Machair, an ecosystem unique to Scotland and Ireland.

Habitat change

Coastal erosion

Similar to the rest of the UK, much of the Scottish coastline are threatened with climate change due to rising sea levels, with current projections for the scenarios considered in the CCRA (CCRA, 2012) indicating an absolute rise of about 0.30m (range 0.09m to 0.61m) by the 2080s relative to the 1990 baseline, although the relative rates are generally greater on many of the Islands, see Section 2.3.3. Coastal erosion is currently occurring on about 12% of the Scottish coastline. This compares with about 30% of the English coastline, and about 23% and 30% of the Welsh and Northern Irish coastlines respectively (Eurosion, 2004). Approximately 70% of Scotland’s coastline is classified as hard. In general Scotland is considered to have the lowest levels of coastal erosion in Europe. This compares with high levels for much of the east coast and southeast coast of England and moderate rates for the rest of the UK (Eurosion, 2004).

Despite the relatively lower risk of coastal erosion in Scotland, many of Scotland’s inner and developed Firths are composed of soft coastlines. The projected rise in eustatic sea levels is therefore likely to expose these areas to increased levels of erosion and flooding (see case study on Dornoch Firth below).

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\(^70\) A measurement of the Western Scottish coastline undertaken for the BBC2 television programme Coast indicated that it was the second most contoured, or rugged coastline in the world after Norway.
Case Study: Habitat changes at the Dornoch Firth

Morrich More in the Dornoch Firth is a transgressive dune plain resembling a staircase of sand dune ridges (Figure 4.8) that extends from the Holocene 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 which support the hypothesis that changes in sea level leads to geomorphological and ecological responses within the coastal zone. Erosion and frontal recession has replaced long-term accretion along the northeast facing frontal edge of the dune system (Figure 4.9). This appears to be the most extensive erosion in the last 7,000 years, and is now reworking the eroded sediment towards the dune interior via the low-lying saltmarsh troughs. Ecological adjustments have also been identified and numerous examples can be seen of pioneer saltmarsh species invading lower edges of mature sand dune habitats (Figure 4.10). Terrain analysis is being undertaken to establish the areas of sand dune which 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 we might expect to our dynamic coastal habitats over the coming decades.
Figure 4.9  Frontal erosion has replaced longstanding accretion on the northeast facing frontal edge of the sand dune system (cliff face approximately 3m high)
Source: Alistair Rennie

Figure 4.10  Saltmarsh species are invading the lower edges of mature sand dunes within the dune interior
Source: Alistair Rennie
Saline intrusion

Saline intrusion is the movement of saline water into freshwaters areas and aquifers. As a result of rises in sea levels, the movement of brackish / saltwater further inland will increase, with the potential to flood coastal BAP habitats inland of the natural and defended coastline.

In the Outer Hebrides, lagoons within rock basins will be expected to become increasingly saline, and eventually fully saline, with replacements formed as rising seas flood fresh-water lochs. In the Northern Isles, the same process is likely to operate on existing lagoons, possibly with an additional role played by storms whereby shingle barriers will be dismantled and rolled landward (Angus et al., 2010). Again, numerous coastal shingle-bound freshwater lochs are likely to become saline, as has already been observed as a result of rapid relative sea level rise in Nova Scotia (Carter et al., 1989). This is a potentially serious issue as 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. However, there could also be the opportunity for gain in some habitat spaces.

It is likely that expansion of one habitat may be at the expense of another, particularly where intervention is made through managed coastal realignment. Although the original habitat may be damaged, it is likely to change to another habitat type, i.e. there will be losses and gains, or changes and transitions. What is important (within the context of understanding this risk) is the impact of losses, or shifts in habitat types, on the ecological function of the coastal ecosystem as a whole.

The majority of the habitats that would be affected by coastal flooding landward of the natural and defended coastline have variable but generally limited ability to tolerate saline inundation. Inundation of these habitats with brackish / saline waters has the potential to result in damage or loss through mechanisms such as changes in species composition (loss of salt-intolerant species), impacts on growth through alteration of soil-water potential, changes in soil structure (either the flocculation of clay minerals or dispersion of particles) and changes in fauna. This could include (for example) loss of invertebrate populations important in their own right or that may be an important food source for other animals and bird populations, and loss of amphibians and fish that may be important for carnivorous birds such as bittern.

The magnitude of the effect on habitats depends on a range of parameters including:

- salinity level of the water flooding a habitat;
- pre-existing salinity level of the habitat being affected e.g. saline ditches or freshwater ditches;
- frequency of flooding;
- duration of flood events;
- season the event occurs in; and
- presence and degree of freshwater flushing that a particular habitat is exposed to.

It should also be noted that the effects of inundation are not the same for each habitat as different species and communities will react differently to different levels of salinity.

This impact was not assessed as part of the CCRA for Scotland as no known published results exist. However, Defra project CR0422 – Developing Tools to Evaluate the Consequences for Biodiversity of Options for Coastal Zone Adaptation to Climate
Climate Change (Defra, 2011), considers the risk of certain habitat loss71 in England under a range of epochs. Following from this work, not more than about 4% of the total resource of habitats in the coastal floodplain of Scotland would be projected to be lost under the most extreme scenarios.

The risk matrix developed for the Defra project analysed the impact of saline intrusion on a range of habitats. Included was an indication of damage done to the habitat and the duration of time needed to return the habitat back to normal, if this was possible at all. Analysis shows that reedbeds (accounting for faunal species) and lowland raised bogs are most susceptible to permanent damage and change from saline intrusion, as even in the presence of long durations between inundation, the habitat will not recover. Unsurprisingly the high saline lagoon habitats were least affected by salt-water intrusion, with no effect or quick recovery times expected (Defra, 2011).

### Case Study: Machair

Machair is a low lying fertile plain that forms when sand with very high shell content is blown landwards by prevailing westerly winds, creating a fertile, calcareous, low-lying plain behind dunes (Figure 4.11). Generational fertilizing of these plains by farmers with seaweed, combined with wind blown sand has helped to create a rich habitat for waterfowl such as white-fronted geese (*Anser albifrons*) and whooper swans (*Cygnus cygnus*), invertebrates and water plants (including the very rare slender naiad, *Najas flexilis*).

The way in which Machair is formed, through natural and traditional human-led activities makes this very rare habitat extremely important for cultural heritage, biodiversity and tourism.

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71 The project looked at grazing marsh, saline lagoons, eutrophic standing waters (lakes and ponds), lowland fens, reedbeds, deciduous woodland, lowland raised bog, and purple moor grass and rush pastures
Machair is one of the rarest habitats in Europe and is only found in the north and west of Britain and Ireland. The total global extent is only 19,000 ha and 70% of this is in western Scotland, mostly on the Western Isles, with the remainder being in Western Ireland (see also Section 5.2.3). The majority of it is now internationally recognised as being of unique conservation importance, and is within the suite of Natura 2000 sites, including Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC) and Special Protection Areas (SPA) site designations. In Scotland, nearly half of the Machair occurs in the Outer Hebrides, with the best and most extensive in the Uists and Barra, and Tiree.

Importance of Machair

Orkney Machair is home to the rare limestone bedstraw (*Galium sterneri*) and the Hebrides are the last British stronghold for the cornrake (*Crex crex*). Other birds that are associated with Machair are corn buntings (*Miliaria calandra*), the rare little tern (*Sterna albifrons*), golden plover and lapwing (*Vanellus vanellus*). The oystercatcher and ringed plover (*Charadrius hiaticula*) are particularly reliant on the crofting practices carried out by farmers due to their preferences for breeding on newly ploughed and bare ground.

Orchids are particular Machair highlights. The rare pyramidal (*Anacamptis pyramidalis*) and fragrant (*Gymnadenia conopsea*) orchids both occur in the Outer Hebrides which is also home to a particular Hebridean type of spotted orchid (*Dactylorhiza fuchsii*). A small stretch of North Uist has its own variety of marsh orchid, *Dactylorhiza majalis scotica*, found nowhere else.

The distinctive mix of culture, landscape and wildlife found in Machair areas generates tourism that is essential to the economy of the islands it is found on.

![Figure 4.12 Pictures of Corncrake (left) and Lapwing (right) taken on the Hebrides](image)

Source: Steve Round (Corncrake)

Impacts of climate change on Machair

The principle threat that climate change poses to Machair is through rising sea level and enhanced coastal erosion that can impact the distribution of sediment. This can lead to coastal flooding, salt deposition and osmotic stress on vulnerable species. The impact is likely to be larger on areas that are less accustomed to such flooding and can
Projected increases in precipitation could also increase levels of flooding and periods of standing water. This would inhibit ploughing and disrupt arable practices, impacting upon the care of the livestock and reducing the biodiversity value of the area. Any future change in the nature of storm conditions could also have an effect with increased levels of erosion and flooding of the protecting dunes, with associated salinity changes on the Machair behind the dunes.

**Extreme events**

Scotland places a high importance on shallow marine and coastal habitats as they are vital for the countries economy. Many of Scotland’s industries, including tourism and aquaculture rely on a varied coastal habitat, and the biodiversity found is a result of different tidal habitats, many which support unique ecosystems.

Lagoons in west Scotland form the most extensive saline lagoon system in the UK. This system exhibits saline, transitional and freshwater environments and supports an exceptionally wide range of habitat types, organisms and communities. Important rare species, such as the sea cucumber (*Labidoplax media*) are found in abundance.

As coastal conditions continue to change, mainly related to likely increases in the magnitude of extreme sea levels, incidences of coastal flooding are likely to increase. This could alter the composition and range of shallow marine habitats currently found within Scotland. This may lead to more frequent inundation of isolated lagoons, increasing the salinity and altering the established habitats. Although many shallow marine habitats are mobile features, it is possible that increased flooding and inundation will cause modification to occur at a greater rate than the lagoon can adapt to.

Increased incidences and levels of coastal flooding are also likely to increase the salinity of freshwater and transitional lagoons which can have a devastating effect on the established ecosystems through an increase in salt-stress. The modification or loss of marine habitats could have a severe impact on coastal businesses and tourism. An increase in flood events may also increase the risk of saltwater inundation on terrestrial environments, and affect environments within freshwater river systems. This could impact on important bird breeding sites and priority habitats (including lagoons and dunes) as well as economically important coastal resources and recreation. Additionally, habitats may be affected through a reduction of light penetration. A greater turbidity or simply deeper water may decrease the light available for submerged vegetation. This can reduce the photosynthesis potential altering the nutrient dynamics and increasing the risk of eutrophication. A reduction in light penetration can also reduce visibility for feeding predators. Deeper waters nearshore is also likely to increase turbidity and wave action, making the environment more unsuitable for established habitats.

Flooding is likely to cause the erosion of habitats currently at equilibrium within sheltered areas. Erosion can affect habitats by actively eroding the habitat itself, or through deposition of eroded material, burying plants and organisms, thus starving them of oxygen and light. Erosion of coastal environments results in a more dynamic marine environment, unsuitable for most biota. Through increasing frequency of flood events, it is possible that shallow water habitats such as

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73 http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0017070
75 http://www.ecologyandsociety.org/vol14/iss1/art8/
76 http://www.foe.co.uk/resource/briefings/uk_coastal_habitats.html
77 http://www.rspb.org.uk/reserves/guide/k/kirkconnellmerse/
78 http://www.ecologyandsociety.org/vol14/iss1/art8/

lagoon and saltmarshes may be eroded away before they can become established elsewhere within the coastal system. For those relying on the coastal environments for their livelihood, this could have a serious detrimental affect.

**Indirect impacts**

**Water Pollution Risk and Eutrophication**

As discussed for freshwater, climate change may impact water quality directly or indirectly by exacerbating current land uses that pollute water. Saltwater bodies can also be affected as highlighted in the Ythan Estuary case study below.

### Case Study: Water Pollution Risk and Eutrophication in Saltwater Bodies: Saltwater Environment – Ythan Estuary

The Ythan Estuary in North East Scotland is the only saltwater environment in Scotland to be designated as eutrophic. Environmental monitoring and evidence of excessive growth of opportunistic algae suggests that this is caused by sewage pollution, possibly as a result of agricultural discharge. Due to this, the estuary has been designated as a Nitrate Vulnerable Zone (NVZ).

Blooms located in marine environments are of a greater concern than those of freshwater as there is a higher diversity of toxic species, this having a significant impact upon marine life (Smith et al., 1998). Local fish stocks could be affected as plant life reduces oxygen content and reduces the food source. Aberdeenshire relies heavily on the fishing business, and eutrophication of local waters may have a significant impact. Local estuaries can provide recreation and leisure opportunities for the local population and visitors, and with polluted water, there could be a health risk to those visiting. The local government may need to fund cleaning operations at a cost.

With the Ythan Estuary being an important wildlife reserve (SEPA 2011b) there is a need to combat the spread of algae. Previously the rapid growth of algae has formed algal mats which can smother and kill benthic organisms. This has a knock-on effect on feeding birds and lowers the biodiversity of the area (SEPA, 2011b). Additionally with the Scottish tourist industry relying heavily on scenery and wildlife79 (see Section 4.4), visitors may be deterred.

SEPA has estimated that 13% of fertilizer applied to farmland enters the estuary each year (SEPA, 2011b, p.4). With the projected lengthening of the growing season and increase in suitable land available (Sections 3.1.8 and 4.3.1), an increase in the farming and therefore fertilizer use within the Ythan catchment could be expected. Under current conditions nitrate use is reducing, therefore the problem could decrease depending on the agricultural and climatic changes.

Lower projected precipitation during summer, may lead to an increase in pollutant concentration. Similar to the Clyde Valley, increased farming may lead to greater runoff through an expanding agricultural area and subsequently the volume of pollutants entering the watercourse.

A recent publication on agricultural practise in Aberdeenshire has identified the need for land improvements. Analysing these improvements indicates that they may have a negative effect on the water quality within the Ythan Estuary. This includes an increase in land drainage, which could potentially hasten the transport of pollutants and reduce infiltration, increasing the soil nutrient level of the soil (Aberdeenshire Council, 2008a).

Additionally there is the suggested drive to farm marginal land and reinvigorate beef and sheep sectors (Aberdeenshire Council, 2008b). The drive within the farming sector to expand and develop a greater productivity may increase pollutants and organic matter entering the estuary, increasing the risk of eutrophication in the future.

79 http://wildlife.visitscotland.com/
Coastal Squeeze

In a natural environment, sea level rise typically causes coastal landforms to migrate landwards; a process often referred to as ‘rollover’. Where this is constrained by coastal defence structures a phenomenon known as ‘coastal squeeze’ may occur. This can give rise to a reduction in space for intertidal habitats, particularly where fixed coastal defence structures are in place. In some locations this is leading to a management choice between loss of saltmarsh\(^{80}\) (often designated as SAC) or loss of coastal grazing marsh (often designated as SPA), depending on whether the status quo (‘hold the line’) is maintained or there is a shift towards managed realignment (see Dornoch Firth case study above). Soft coastal habitats are particularly vulnerable as their mobility means they typically occupy a particular position in the tidal energy frame. Changes induced by rises in mean sea levels, or a potential change in wave regime (associated with storm conditions and prevailing storm tracks) could therefore lead to shifts in areas/patterns of erosion/accretion potentially leading to major reorganisation of landforms and habitats.

![Figure 4.13 Nigg Bay coastal re-alignment](source: RSPB\(^{81}\))

Species migration patterns are likely to change as a result of climate enforced change, thus large areas of saltmarsh and mudflats may be left without their usual influx of migratory species. In addition, the changes in climate space of all species has potentially serious implications for the designated site network as these are fixed locations, unable to be moved as the climate changes. Therefore, areas currently designated for their importance for bird populations e.g. SPAs, may lose the species for which they are designated.

There is already concern that there has been a reduction in migratory birds within coastal estuaries as outlined in Section 4.2.1 as a direct result of climate change.

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\(^{80}\) Most of the saltmarsh in Scotland is Atlantic saltmarsh. This tends to form a very dense mat with a strong root system (Angus et al., 2010), and is consequently more resistant to erosion than most other types of saltmarsh.

\(^{81}\) http://www.scotland.gov.uk/Publications/2004/08/19805/41607
However, there may also be opportunities for new species using Scotland as part of their migration pattern in the future. Furthermore, some coastal habitats, notably saltmarsh and dunes, have an important role in coastal defence and therefore can provide protection to humans from rising sea levels and extreme water levels. They also have an important part to play in carbon sequestration; Shepherd et al., (2007) have reported carbon sequestration rates of 0.44-1.7t/ha/yr from the Blackwater estuary. An assessment for the UK BAP has estimated saltmarsh losses at 100ha/yr and mudflat losses at 100-150ha/yr (Mieszkowska, 2010). It was not possible to calculate the potential loss of coastal habitats for Scotland in the CCRA owing to a lack of suitable data.

There could be increased pressure on the coastal environment from increased tourism as a result of warmer and drier summers. This could lead to greater disturbance and damage to coastal areas, and a greater need for conservation and protection.

**Summary of results**

The results of the analysis are shown in Table 4.3.

<table>
<thead>
<tr>
<th>Threats</th>
<th>Risks to species and habitats due to coastal evolution</th>
<th>Changes in species migration patterns</th>
<th>Major coastal flood/reconfiguration (includes coastal erosion)</th>
<th>Water quality and pollution risks</th>
<th>Physical effects of extreme events (flooding) on shallow marine habitats</th>
<th>Priority habitats lost due to coastal erosion</th>
<th>Saline intrusion</th>
<th>Impacts of geomorphological changes</th>
<th>An expansion of tourist destinations in Scotland (marine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD2</td>
<td>High consequences (positive)</td>
<td>Medium consequences (positive)</td>
<td>Low consequences (positive)</td>
<td>Low consequences (negative)</td>
<td>Medium consequences (negative)</td>
<td>High consequences (negative)</td>
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<td>BD9</td>
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**Table 4.3 Climate change impacts on the natural environment (coastal)**

<table>
<thead>
<tr>
<th>Threats</th>
<th>Risks to species and habitats due to coastal evolution</th>
<th>Changes in species migration patterns</th>
<th>Major coastal flood/reconfiguration (includes coastal erosion)</th>
<th>Water quality and pollution risks</th>
<th>Physical effects of extreme events (flooding) on shallow marine habitats</th>
<th>Priority habitats lost due to coastal erosion</th>
<th>Saline intrusion</th>
<th>Impacts of geomorphological changes</th>
<th>An expansion of tourist destinations in Scotland (marine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD2</td>
<td>High consequences (positive)</td>
<td>Medium consequences (positive)</td>
<td>Low consequences (positive)</td>
<td>Low consequences (negative)</td>
<td>Medium consequences (negative)</td>
<td>High consequences (negative)</td>
<td>BD2</td>
<td>BD9</td>
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<td>FL17</td>
<td>BU8</td>
<td>BU8</td>
</tr>
</tbody>
</table>

**Timing**

- **2020s**
- **2050s**
- **2080s**

**Confidence**

- **High confidence**
- **Medium confidence**
- **Low confidence**
- **Too uncertain**

**Coverage**

- **UK**
- **S**
- **I**

**Method**

- **Q** Quantitative
- **IJ** Informed judgement

**Coverage of analysis**

- **S** Analysis undertaken for Scotland only
- **UK** Analysis undertaken for the UK
Summary of the main impacts of climate change on the coastal environment

- Changes in erosion and accretion may lead to losses of important habitats particularly where landward migration is constrained by coastal defence structures.
- Coastal erosion is a particular problem for Scotland’s inner and developed Firths that are composed of soft coastlines and rare habitats such as Machair.
- The composition and range of shallow marine habitats may change as sea levels increase.
- Saline intrusion may increase leading to changes in ecological communities along the coast, affecting priority habitats and economically important coastal resources and recreational services.
- Water pollution and eutrophication of saltwater bodies may increase.
- The composition and range of shallow marine habitats may change as sea levels increase.

4.2.4 Marine

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Biodiversity and Ecosystem Services Sector Report and the Marine and Fisheries Sector Report.

Almost all (99%) of existing UK marine based finfish aquaculture activity is located in Scotland. Scotland is the third largest salmon farming nation in the world, currently producing some 10% of global farmed Atlantic salmon (Ernst and Young, 2005). The remainder of the marine finfish farming in Scotland consists of cod and halibut accounting for more than 1,000 tonnes in 2007 (Fisheries Research Services, 2008, Scotland NEA, 2011). The fish farming sector now accounts for around 60% of all Scottish food exports.

Given the current projections, climate change could therefore have a significant effect on UK mariculture over the next decade and in the future (MCCIP, 2008), as well as impacts on human health, outdoor leisure, sport, tourism and the natural environment. Scotland is projected to experience rises in annual and seasonal mean water temperature of up to 2.5°C by 2080. Rising average water temperatures could result in faster growth rates for some species which are more tolerant of higher temperatures (e.g. Atlantic salmon) but prolonged periods of warmer summer temperatures may adversely affect some cold water species (e.g. cod, Gadus morhua and Atlantic halibut, Hippoglossus hippoglossus) and intertidal shellfish (such as some oysters) as the thermal optima for the animals physiology may be exceeded for long periods of time. Such changes could make sheltered, warmer sites unsuitable for those species during the summer months.

83 Such an increase in temperature would mean that the water temperature would be at the limit of Atlantic salmon tolerances, exceeding it in some areas.
Invasive non-native species (INNS)

The coastal marine environment could be seriously affected by alien and invasive non-native species. These could potentially affect the whole coastline of the UK during the 21st century as sea temperatures increase. To assess the potential spread of non-native species in the CCRA, the potential northerly latitude of nine non-native species by the 2080s was considered under the Medium emissions scenario. This indicated that eight of these species, that currently encompass the southern half of the Scottish coastline namely Chinese Mitten Crab (*Eriocheir sinensis*), Ctenophore (*Mnemiopsis leidyi*), Slipper Limpet (*Crepidula fornicata*), Japanese Wireweed (*Sargassum muticum*), Carpet Sea Squirt (*Didemnum vexillum*), Pacific Oyster (*Crassostrea gigas*), Common cord-grass (*Spartina alterniflora*) and American/Atlantic jack knife clam (*Ensis americanus/Ensis directus*), could potentially encompass the whole of the Scottish coastline by the 2080s. The ninth, Wakame (*Undaria pinnatifida*), which currently encompasses southern England and the South Welsh coastline, may encompass all but the most northerly parts of the Scottish coastline by the 2080s. These could have significant economic and environmental implications, particularly where they occupy the same niche as native or commercial species.
More than half the total number of introduced species in UK waters is attributed to shipping, whilst half of the non-native marine algae are attributed to deliberate introductions for mariculture. Invasive non-native marine plants have often spread quite rapidly, while invasive non-native invertebrates have tended to spread more slowly (Eno et al., 1997).

Species shifting and migration

Shifting of marine species is projected to occur as a result of changes in sea temperature. The Marine Climate Change Impacts Programme (MCCIP) notes an abrupt ecosystem shift in the late 1990s which was most pronounced in parts of the North East Atlantic near the 9-10°C sea surface temperature isotherm. This isotherm represents a critical boundary between ‘warm’ and ‘cold’ water ecosystems and has moved northwards at an approximate rate of 22km/yr since the 1960s.

The best data on change in marine species comes from commercially important fish species where long data sets (90 years) have been used to highlight that some species at least appear to be shifting their distribution due to climate change (either northwards or into deeper water), although pressures from overfishing are often dominant. Potentially, commonly fished species might move about 20 to 150 km from present fishing grounds by the 2080s. By 2050, climate change modelling indicates that pelagic species (such as herring and anchovy) move northward by an average of 600km and demersal species (such as cod and haddock, Melanogrammus aeglefinus) by 220km. Other cold-water species such as maerl are also likely to be affected (in combination with ocean acidification impacts) with negative implications for the wider ecological community given their importance as ‘ecosystem engineers’. Loss of mollusc, Limaria hians would have a significant effect on marine communities, see case study below. Species such as salmon and eel which have life cycles in both fresh and marine waters have been shown to be particularly vulnerable to climate change with impacts on both the freshwater and marine phases. Warming will also impact on
the pattern of marine currents, which redistribute warm and cold water, with consequences for the dispersal of fish eggs and larvae. It seems likely that winter and early spring spawners (such as cod and plaice) will experience poor larval survival, whereas warmer-water species (such as sprat) may benefit. In addition, some species of toothed whales and dolphins are showing shifts in distribution, which may be linked to increasing sea temperatures.

Keystone Species

A keystone species is a species that has a disproportionately large impact upon the community in which it lives, compared to its biomass. Therefore, a keystone species may not be particularly abundant in a habitat, but will have a large affect on the other species living within that habitat.

Considering the marine environment, Flameshell reefs are created by the mollusc *L. hians*. The west coast of Scotland is home to the majority of this habitat in the UK. These spectacular reefs can support over 250 species of plants and animals including sponges, worms, molluscs and crustaceans. In this case, the impact that *L. hians* has on the marine environment is disproportionately large compared to its own biomass. Hiscock *et al.* (2001) projected that *L. hians* could reduce in abundance and extent or disappear all together from Scotland by 2100.

A northward shift in the distribution of many plankton species has also been recorded, typically by more than 10º latitude over the past 50 years. In the North Sea, the population of the previously dominant cold-water zooplankton species *Calanus finmarchicus* has declined in biomass by 70% since the 1960s. These significant

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84 [http://www.buglife.org.uk/conservation/Scotland/Special+Species](http://www.buglife.org.uk/conservation/Scotland/Special+Species) [Accessed 22/02/2011]
changes in plankton abundance have had impacts through the food chain, contributing to the reduction in quality and abundance of species such as sandeels (*Ammodytes marinus*) which provide food for many seabirds and potentially some baleen whale species. Phytoplankton and zooplankton also have a key role within marine ecosystems and therefore, changes in their distribution may modify services such as oxygen production, carbon sequestration and nutrient cycling.

Changes in fish distribution would have knock-on impacts for fishermen, extending fishing trips for current species, but also providing opportunities for new catch species and affecting the 'catchability' of some species as migration or spawning locations move. 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 sea bass, red mullet, John Dory, anchovy and squid.

### Algal, phytoplankton and jellyfish blooms

Coastal and marine waters are impacted by nutrient enrichment (eutrophication) as a result of runoff of agricultural fertilisers and human or animal waste. This encourages an increase in algal biomass rise that can become harmful when dominated by a single species or species group. The effects of such harmful blooms include overgrowth and shading of sea grasses, oxygen depletion of the water as a result of algal and bacterial respiration, suffocation of fish from stimulation of gill mucus production, direct toxic effects on fish and shellfish, and mechanical interference with filter feeding by fish and bivalve molluscs (Landsberg, 2002). There are potential implications for fish and shellfish stocks, bathing water quality and tourism. A strong regional distribution is observed in the UK with the impacts being more regularly detected along the coasts of Scotland and the south and western coasts of Ireland.

Changes in temperature, precipitation, CO$_2$ levels, levels of sunlight, circulation patterns and stratification may all impact algae and phytoplankton populations, altering communities and ecological processes and potentially increasing the frequency of bloom occurrences.

Increases in the frequency of harmful algal and jellyfish blooms (associated with an increase in warmer waters with calmer, drier summer months) has already been observed in Scottish waters over the last two decades with large blooms of the dinoflagellate, *Karenia mikimotoi*, which has previously been confined to the English Channel. It is also likely that warm water species such as *Prorocentrum micans* may increase their prevalence over the rest of this century. However, the projected reduction in summer precipitation may benefit 'classification status' of shellfish growing areas (MCCIP, 2008).

There is also some evidence of a recent trend to earlier stratification and onset of the spring plankton bloom in Scottish seas, largely in response to warming air temperatures. This is having consequences for other parts of the ecosystem (notably commercial fish), with wider implications for maritime industries including fisheries and coastal aquaculture.

### Disease hosts and pathogens

Disease of marine (and mariculture) species through bacterial, viral, parasitic and fungal infection may be affected by a changing thermal regime (plus other factors such as acidification and pollution), but in a largely unpredictable manner.

A warming climate is therefore liable to increase the risk of disease outbreaks by modifying the range of host species, by changing their susceptibility to disease, and by
altering species interactions which may transmit disease to new hosts. For example phocine distemper virus (PDV) had previously been recognised in other species but has caused mass mortality in recent decades in harbour seals and grey seals. Warmer conditions may allow the establishment of exotic diseases and pathogens such as vibrios that have consequences for human health via contaminated shellfish and bathing waters. Rising temperatures may also extend the season and infective pressure of sea lice on salmonid species. Increase prevalence and virulence of diseases, coupled with the potential to infect new hosts may ultimately lead to modification of the ecosystem if the species at risk are key components of that ecological community. Few epidemiological studies of marine organisms have been carried out, and these are often limited to taxa such as corals and oysters, therefore the wider consequences for biodiversity are very uncertain.

Impacts on habitats, ecosystem processes and functioning

Ocean acidification

The relationship between atmospheric concentrations of carbon dioxide (CO₂), uptake in the ocean and consequences for ocean pH are relatively well understood and can be accurately modelled. Both modelling and observational studies suggest that the absorption of CO₂ by the ocean has already decreased pH levels by 0.1 since 1750 (Orr et al., 2005), which is about 100 times the rate of change that has been detected in the geological record. The analysis conducted for the CCRA anticipates a pH change of 0.2 to 0.5 pH units compared to pre-industrial values in the North Sea by 2100. This gives an indication of the direction and level of change; however, projecting the precise future changes is extremely difficult due to the influence of many factors including changing rate of uptake through biological processes.

Ocean acidification could have dramatic consequences for organisms that lay down hard calcareous shells, including commercial shellfish species. Other functions other than calcification (such as metabolism, behaviour and immune responses) can also be affected by ocean acidification. This will lead to implications for marine food webs including higher species such as fish, and have associated socio-economic impacts (e.g. tourism reduction and damage to fisheries). However, the impacts of acidification on marine species and ecosystems are not fully understood. It may also have an impact upon the propagation of sound through the oceans and the rate of conversion between different nitrogen compounds and affect the availability of trace metals which could in turn impact upon phytoplankton growth, nutrient cycling and water toxicity levels. Changes in plankton may lead to wider changes in ecosystem composition, structure and functioning with potential deleterious impacts on ecosystem goods and services.

Acidification could lead to economic losses in the UK to shellfish and mollusc fisheries of the order of £2.3-£8.8 million annually per annum by the 2020s, rising to £13-£115 million annually by the 2080s. This is potentially significant for Scotland which currently accounts for about 20% of the shellfish aquaculture in the UK each year. Whilst the effect on cultured aquatic species has not formally been assessed in the CCRA, it is probable that there will be an adverse impact based on the UK estimate.

Indirect impacts

Impacts on marine tourism

Increasing coastal marine tourism as a result of warmer and drier summers could increase pressure on the marine environment. Potential impacts include increases in waste water (and therefore a decline in water quality), increasing demand for seafood and greater disturbance of coastal waters. Algal and jellyfish blooms may also have negative impacts on marine and coastal tourism.
Marine wildlife tourism, which includes viewing a range of marine species such as whales, dolphins, basking sharks (*Cetorhinus maximus*), seals and seabirds could also be at risk due to species shifting. These species are all highly mobile and environmental factors caused by climate change can result in distribution shifts. A shift in the distribution of the common dolphin (*Delphinus delphis*) and white-beaked dolphin (*Lagenorhynchus albirostris*) has already been recorded around Northern Scotland which is thought to be related to climate change (MacLeod et al., 2005). A quarter of a million tourists are involved with whale-tourism activities annually in west Scotland, with the total income generated by whale-tourism being estimated at £7.8 million in 1994 (Pugh and Skinner, 2002).

**Summary of results**

The results of the analysis are shown in Table 4.4.

### Table 4.4 Climate change impacts on the natural environment (marine)

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Confidence</th>
<th>Coverage</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in fish catch latitude/centre of gravity (plaice, sole)</td>
<td>Medium consequences (positive)</td>
<td>UK</td>
<td>S</td>
</tr>
<tr>
<td>Species migration (fishing industry)</td>
<td>Medium consequences (negative)</td>
<td>UK</td>
<td>S</td>
</tr>
<tr>
<td>Distribution of marine alien/invasive species</td>
<td>Low consequences (positive)</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>Low consequences (negative)</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>Changes in fish catch latitude/centre of gravity (cod, haddock)</td>
<td>Too uncertain</td>
<td>UK</td>
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<tr>
<td>Increased ocean acidification</td>
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<td>UK</td>
<td>S</td>
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<tr>
<td>Damage to cultured aquatic species</td>
<td>Too uncertain</td>
<td>UK</td>
<td>S</td>
</tr>
<tr>
<td>Loss of service through loss of key species</td>
<td>Too uncertain</td>
<td>UK</td>
<td>S</td>
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<tr>
<td>Risk of Harmful Algal Blooms due to changes in ocean stratification</td>
<td>Too uncertain</td>
<td>UK</td>
<td>S</td>
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<tr>
<td>Plankton blooms</td>
<td>Too uncertain</td>
<td>UK</td>
<td>S</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>Too uncertain</td>
<td>UK</td>
<td>S</td>
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<tr>
<td>High consequences (positive)</td>
<td>High confidence</td>
<td>UK</td>
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<tr>
<td>High consequences (negative)</td>
<td>Too uncertain</td>
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<td>S</td>
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</tbody>
</table>

*Coverage of analysis*   | *Method of analysis* |
---|---|
S | Analysis undertaken for Scotland only | IJ | Informed judgement |
UK | Analysis undertaken for the UK | Q | Quantitative |
Summary of the main impacts of climate change on the marine environment

There is a high degree of uncertainty regarding the impacts of climate change on the marine environment owing to the complexity of processes and the difficulty of predicting future change.

- Invasive non-native species may become more prevalent in Scottish waters.
- Species range shifts and changes in migration may have consequences for ecosystem function and provisioning ecosystem services, including salmon fishing.
- Algal, phytoplankton and jellyfish blooms may affect wild species as well as provisioning, regulating and cultural services.
- Disease outbreaks may increase, with potential consequences for ecological communities and human health.
- Ocean acidification has already occurred and may negatively affect ecosystem structure, function and goods, in particular commercial shellfish species, in the future.
- Warming seas are likely to lead to shifts in the distribution of commonly fished species. This would affect the fishing industry, with some species moving north out of Scottish waters, although replaced by new species moving in from the south.
- Impacts on marine tourism may place the natural marine environment under further pressure.

4.3 Agriculture and Forestry

The land in Scotland is dominated by agriculture which covers approximately 6.2 million hectares, 80% of the land area of Scotland\(^{85}\). However, the terrain and climate of much of this land limits its use. Most agricultural land is rough grazing, with 85% classified as Less Favoured Area (LFA). With most agricultural land given over to livestock, which is of particular significance to Scottish agriculture, the area of land used for crops, fallow and set-aside represents only about 10% of the total agricultural area\(^{86}\).

Woodland in Scotland covers approximately 1.4 million hectares which represents just over 17% of the land area\(^{87}\). A total of approximately 0.4 million hectares of these forests are native, whilst most of the mature woodland is made up of exotic coniferous species, such as Douglas fir, larch and Sitka spruce (\textit{Picea sitchensis}). Forests occur throughout Scotland with particularly heavy concentrations in the uplands of Dumfries and Galloway and Argyll.

Agriculture and forestry are very closely related to the climate. Any changes in climate are likely to lead to changes in agriculture and forestry, both positive and negative. Opportunities include increases in plant yield, new plants and carbon storage. Threats include the potential for new pests and disease to establish and for existing ones to become more damaging.

\(^{85}\) http://www.scotland.gov.uk/Publications/2010/11/19093904/1
\(^{86}\) http://www.scotland.gov.uk/Publications/2010/05/05134234/3
\(^{87}\) The Scottish Forestry Strategy, Scottish Executive (2006), has set a target of achieving a 25% woodland cover by 2050.
Over the rest of this century, there is anticipated to be a demand across many land use sectors, a consequence amongst other factors a continued growth in population and incomes, the impact of climate change, new technologies, and changing public attitudes and values (Foresight, 2010). With agriculture and forestry representing the vast majority of land use in Scotland, these changes will create significant challenges in how to manage the associated significant increases in the demand for, and on land in the face of an uncertain climate. These factors are not considered in this report; however, they are discussed in detail in the Agriculture and Forestry Sector Reports.

The CCRA analysis was carried out under the headings of arable, horticulture, livestock and forestry. Livestock is heavily dependent on the availability of pasture and feed crops, and both arable and horticulture are concerned with crops. The impacts of climate change are therefore discussed below under the headings of agriculture and forestry.

4.3.1 Agriculture

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Agriculture Sector Report.

The beef industry is the single largest sector of Scottish agriculture with approximately 500,000 breeding beef cows, with production worth in excess of £500 million. Sheep in addition to cows are often farmed in the LFAs and the combination of beef and sheep farming, sometimes mixed with a small area of cropped land brings various benefits in terms of biological and landscape value. Dairy cows are also a significant sector of Scottish agriculture, with a production value in the region of £300 million. In addition, pigs, deer and chickens are farmed in Scotland but to a much lesser extent.

![Figure 4.17 Black Angus cattle](image)

By tonnage, Scotland is responsible for approximately 12% of the UK’s cereal production, of which approximately 60% is barley, with most of the remainder wheat. Cereal farms are mainly concentrated in the east of the country where the majority of the Agricultural prime land is found (see Figure 4.19). Potatoes and oilseed rape

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(Brassica napus) are also farmed over a large area in Scotland, with about 75% of the seed potatoes for the UK grown here\textsuperscript{89}.

Figure 4.18 Barley (left) and Wheat (right)

Fruit and vegetable production is geographically limited (approximately 2,000 hectares of land in Scotland is given over to fruit production\textsuperscript{90}) and is mainly restricted to the most fertile areas such as Tayside and Angus.

**Crop yields**

Crop yields are sensitive to a range of climate variables (solar radiation, temperature, rainfall and relative humidity) as well as non-climate factors, such as fertiliser application rates, choice of crop variety, land management practices, soil type and introduction of new technology. Crop yields also vary regionally and across farms (often not climate related), and the effects of climate variables on crop yields may not be consistent between sites.

A thorough investigation of crop yields would need to consider the wide range on influencing factors; however, based on the CCRA method (Defra, 2010a), only a single climate variable has been used for projections. Projections given in this report must therefore be treated with care.

To assess the effect of climate on crop yields, the CCRA considered 3 reference crops, wheat and sugar beet from the arable sub-sector and rain-fed potatoes from the field vegetable sub-sector, and investigated crop yields against a range of climate variables (rainfall, temperature and global radiation) as well as time period (e.g. season). However, as sugar beet is not grown in Scotland, winter and spring barley yields were instead investigated specifically for East Scotland (see Appendix C). From the analyses carried out, the strongest relationships to yield for wheat and spring barley were found for average growing season temperature. For winter barley and potatoes, the strongest relationships were found for winter and summer rainfall respectively.

For wheat, yields may increase significantly over the coming century, with projections indicating that these could more than double by the 2050s (range 60% to 230%)

\textsuperscript{89} http://www.scotland.gov.uk/Publications/2009/06/19141120/3
\textsuperscript{90} http://www.scotland.gov.uk/Publications/2011/06/15143401/62
increase for Scotland). For barley, the message is mixed with winter yields projected to decrease typically by 20% (range 14% to 32% decrease), yet spring barley projected to increase by about 12% (range 9% decrease to 50% increase) by the 2080s (Appendix C6). The overall effect on production indicates a slight decrease in barley production up to the 2050s, although this is projected to change to a slight increase by the 2080s. For rainfed potatoes, little trend is observed in yields, although it is projected that there will be a slight decrease by the end of the current century across Scotland (range 10% decrease to 2% increase)\(^{91}\).

Assuming crop husbandry factors for rain-fed potatoes remained unchanged, farm yields showed only marginal increases due to climate change owing to limitations in nitrogen availability. In contrast, future potential yields, without restrictions in water or fertiliser availability, were reported to increase principally due to increased radiation and temperature levels and elevated CO\(_2\) concentration effects (Daccache \textit{et al.}, 2011).

These figures represent analysis undertaken using a single climatic variable. In reality as already noted, crop production depends on a combination of climate parameters as well nutrient and water availability and soil type. This should be borne in mind whilst analysing these results.

The recent changes in the climate, Section 2.2, has resulted in an increase in the number of growing degree days, the length of the growing season, a reduction in frost, and an increase in the frost free season, trends which are likely to continue over the coming century. These would generally be anticipated to have a positive affect on the development of crops and on food production and increase future food security. However, an increase in temperatures could reduce vernalisation for some crops\(^{92}\) and pests and diseases could be more likely to survive winters, and/or potentially thrive more in warmer summers (see below). Soil moisture is also anticipated to reduce (see below), although not to a significant enough level within Scotland to be a problem.

**Grassland productivity**

Experimental evidence shows that grass production can increase in response to higher temperatures or CO\(_2\) concentrations or especially in combination, as long as other factors affecting grass growth are not limiting (see for example Harmens \textit{et al.}, undated). Projected increases in temperature and elevated levels of CO\(_2\), as well as a longer growing season are likely to lead to increased grass growth, but only under conditions where water and nutrient supply, particularly nitrogen availability, are non-limiting.

The principle risk metric for grassland-based livestock production is herbage dry matter yield.\(^{93}\) Based on this, grass yields in Scotland have been projected to increase by 19% (range 10% to 29%) for the 2020s, 32% (range 16% to 52%) for the 2050s and 44% (range 22% to 54%) for the 2080s\(^{94}\). Changes in Scotland grassland yield may be greater than those of England as water stress is likely to be less of a limiting factor, or be less due to differences in soil type. Fitzgerald \textit{et al.}, (2008) analysed grass yield in Ireland and found grassland productivity had greater potential for increases in the North East of Ireland, with a climate and soil type similar to parts of Scotland. However, this

\(^{91}\) These figures relate to crops not constrained by limited water or/and nutrients.

\(^{92}\) Effects in Scotland have already been noted for blackcurrant crops, where a lack of winter chill has resulted in asynchronous development, http://www.knowledgescotland.org/briefings.php?id=36 accessed 14/02/2011.

\(^{93}\) 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.

\(^{94}\) The 2080s figures have been extrapolated from the 2050s, as no modelled outputs existed for the 2080s from UKCIP98
study found the maximum increase in grassland was 34% by the 2080s, which is lower than those projected by the CCRA. Therefore, this is a potential opportunity for livestock agriculture in Scotland, although other factors (such as dietary changes and the suitability of ground conditions for grazing or cutting) need to be taken into consideration.

It must be borne in mind that the analysis for grassland productivity focussed on temperature increases alone. However, it is possible that including the effects of CO2 fertilisation may also increase the productivity as shown by Fitzgerald et al., (2008) for grasslands in Ireland, although in reality the increase in drought events and water limitations would determine the productivity of grass, as would nutrient availability.

An opportunity also exists in the lengthened grazing season for a reduction in the requirements for conserved silage. However, the impact of climate change on grassland quality and digestibility is an important factor as a decline may limit liveweight gain and outweigh the benefits of increased yields.

**Summer water availability**

Projected changes in rainfall could lead to an increase in water stress in the summer and increased waterlogging and leaching in the winter, both of which are likely to impact on agricultural production.

The Potential Soil Moisture Deficit in Scotland is projected to increase by approximately 150 mm (range 6mm to 355mm) and 220 mm (range 20mm to 596mm) by the 2050s and 2080s respectively (Table 4.5) with a corresponding significant reduction in moisture available for crops. Supplementary irrigation may therefore be required, particularly for the high value crops able to be grown in Scotland.

### Table 4.5 Change in potential soil moisture deficit from present (mm)

<table>
<thead>
<tr>
<th>Emissions Scenario</th>
<th>Western Scotland</th>
<th>Northern Scotland</th>
<th>Eastern Scotland</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>2050</td>
<td>2080</td>
<td>2020</td>
</tr>
<tr>
<td>p10</td>
<td>p50</td>
<td>p80</td>
<td>p10</td>
</tr>
<tr>
<td>Western Scotland</td>
<td>39 144 270</td>
<td>61 181 330 Low</td>
<td>121 269 452 Low</td>
</tr>
<tr>
<td>Northern Scotland</td>
<td>6 95 202</td>
<td>20 119 241 Medium</td>
<td></td>
</tr>
<tr>
<td>Eastern Scotland</td>
<td>9 120 254</td>
<td>24 146 296 High</td>
<td></td>
</tr>
</tbody>
</table>

| Western Scotland   | 10 83 193        | 121 269 452 Low |
| Northern Scotland  | 20 114 227       | 54 166 305 Medium|
| Eastern Scotland   | 31 151 297       | 69 209 382 High |

| Western Scotland   | 84 208 355       | 189 367 596 Low |
| Northern Scotland  | 32 131 247       | 94 222 388 Medium|
| Eastern Scotland   | 42 164 308       | 116 273 477 High |

Whilst crop water use in Scotland is currently modest compared to water availability, noticeable increases are anticipated in the future. Although data for Scotland was not available for the CCRA, average agricultural water demand increases in the region of 15%, 25% and 50% were projected for the 2020s, 2050s and 2080s respectively for England and Wales based on the p50 Medium emissions scenario. The cooler temperatures of the north would indicate a smaller increase for Scotland, although this cannot be quantified.

Currently water abstraction for utilisation by livestock agriculture is small and is predominantly related to watering and washing of livestock and their production systems (e.g. housing). This is anticipated to increase as a result of climate change in the future, however the difficulty in proportioning water use to livestock directly meant

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95 Leaching of nutrients and pesticides in the summer due to a change in the frequency and/or intensity of high intensity rainfall events could also be an issue.
that it was not possible to indicate how this was likely to change in the future on a UK wide or regional basis.

Relative to the rest of the UK, Scotland has a plentiful supply of water. Although this is anticipated to reduce in the future, there is still anticipated to be a surplus in most Scottish river basins to the 2080s. The potential deficit in the Tay river basin by the 2080s (see Table 4.14, Section 4.5.2) could put pressure on water resources on the high value water intensive crops in this region, however as noted above, this is a relatively small part of Scottish agriculture.

The risk of summer droughts is also projected to increase and future droughts could be more severe that those experienced to date. These events could cause very severe damage to agricultural production, particularly for the east coast crop growing areas, and the frequency and severity is likely to increase. In addition, warmer drier summers could lead to drying of soils and an increase in soil erosion. Although this risk is potentially high for many parts of the UK, generally higher rainfall levels and storage, combined with lower temperatures that are likely in Scotland relative to the rest of the UK means that this is assessed as a lower risk for Scotland (Agriculture Sector Report).

**Flooding and waterlogging**

Flooding is projected to increase as a result of increased precipitation and sea-level rise. Land that is flooded regularly (particularly from the sea) may become untenable for normal agricultural use. There is therefore a risk of loss or downgrading of some agricultural land as a result of increased flooding, with effects particularly being felt on rural communities96, as well as the potential for loss of land due to coastal erosion. Increases in the intensity and duration of winter rainfall is likely to lead to poaching, as well as more frequent and extended periods of waterlogging (see Section 3.1.5), as well as an increase in the number of unworkable days on land in the winter, although there will be an overall decrease over the full year. There will also be an increase in the unbroken period of workability of land between spring and autumn (see Appendix C2). However, warmer drier summers would be expected to reduce periods of waterlogging, and on an annual basis, the number of unworkable days per year due to waterlogging is projected to decrease slightly. The CCRA assessment for a typical site growing barley in East Scotland shows a decrease of approximately 1 day per decade over the rest of this century (see Appendix C2).

Currently no flood risk assessment has been carried out for Scotland. Under the Flood Risk Management (Scotland) Act 2009, SEPA are to undertake a flood risk assessment for each flood risk management district which was due for completion by 22nd December 2011. This will not include agricultural land at risk of flooding, or erosion. However, based on the assessment carried out for England and Wales, the area of agricultural land at risk of flooding relative to a 1961-1990 baseline could be expected to increase by up to 100% by the 2050s and 170% by the 2080s, with land that floods frequently (i.e. on average once every 3 years or more) increasing approximately four fold by the 2080s. In addition, some agricultural land could be lost to coastal erosion, although this is not anticipated to be more than about 0.1-0.2% by the 2080s.

**Diffuse pollution**

Diffuse sources of pollution include run-off from roads, houses and commercial areas, forestry, transport, run-off from farmland, and seepage into groundwater from developed landscapes of all kinds (Table 4.6). Diffuse sources are often individually

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96 The loss of agricultural land could also result in opportunities for coastal realignment, therefore increasing coastal habitats and reducing coastal squeeze and flood waters elsewhere as discussed in Section 4.2.3.
minor, but collectively significant with such contamination driven by the nature of the land use and the impact of rainfall events.

There is a high importance of diffuse pollution affecting water bodies. For rivers, diffuse sources associated with agriculture were the largest identified. For lochs at risk of failing to meet good status, agriculture is again the largest contributor by impact and forestry is also a serious cause. Agriculture was also an important contributor in transitional and coastal waters.

Table 4.6 Sector impact on diffuse pollutants affecting water bodies in Scotland

<table>
<thead>
<tr>
<th>Pressure type</th>
<th>Key Contributor</th>
<th>Rivers</th>
<th>Lochs</th>
<th>Transitional</th>
<th>Coastal</th>
<th>Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuse source pollution</td>
<td>Agriculture</td>
<td>4,025km</td>
<td>143km²</td>
<td>177km²</td>
<td>97km²</td>
<td>16,946km²</td>
</tr>
<tr>
<td></td>
<td>Forestry</td>
<td>652km</td>
<td>170km²</td>
<td>-</td>
<td>10km²</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Urban development</td>
<td>1044km</td>
<td>1km²</td>
<td>77km²</td>
<td>98km²</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>5,721km</td>
<td>314km²</td>
<td>254km²</td>
<td>205km²</td>
<td>16,946km²</td>
</tr>
</tbody>
</table>


Fertiliser and pesticide use varies from farm to farm. Variations in their use occur due to soil type, crop choice, land use, livestock choice, storage facilities and farm management. These factors can greatly affect the level of diffuse pollution entering the watercourse, and climate change may act to exacerbate diffuse pollution problems.

Climate change may increase the potential for diffuse pollution especially when soils are bare and unprotected. Higher intensity rainfall can lead to more erosion and suspended solid generation and washing off from fields. Conversely projected lower flows during the summer could reduce the ability of water bodies to dilute higher concentrations of soluble inputs from diffuse pollutants. There is also the potential for impacts through more indirect effects of climate change such as changes in land use, including the potential growth in biofuel production, which will have an, as yet undetermined impact on diffuse water pollution.

CCRA projections show an improvement in the land classification for many parts of Scotland. This may bring more viable land into farming, or improve the conditions of land already used for agriculture. If this leads to an expansion in the area of land farmed across Scotland, there could also be an associated increase in fertiliser and pesticide use.

An increase in flooding may also increase the risk of diffuse pollutants entering water courses. Recommended practise is to leave a 10m buffer strip near watercourses to limit direct runoff; however, if flows levels are higher due to an increase in winter rainfall and extreme events, this boundary could be become narrower increasing the risk of pollution entering the network.

The quality of the water environment in Scotland must be maintained and, where necessary, improved, to meet the objectives of the Water Framework Directive (WFD). As diffuse pollution has a significant impact on water quality, changes to land management practices may be required in response to the potential impacts of climate change to ensure compliance (as deterioration in ecological status is not permitted by the WFD).

Pests, diseases and heat stress

Crops

97 http://www.scotland.gov.uk/Publications/2008/06/27092800/4
An increase in winter temperatures may increase the risk of over-wintering of pests and diseases, and increased potential for pest species to complete more generations in a season, leading to larger populations. Combined with an annual increase in temperatures (also leading to reduced vernalisation), this could increase or change the range of native/non-native pests and diseases, resulting in damage to some crops (including due to more extreme temperatures). In addition, there may be an increased risk of new pests and diseases invading previously safe areas, affecting livestock as well as crops.

Crop production would need to adapt to more prolonged and frequent droughts, changes in rainfall distribution, more storms and other extreme weather events, increasing and changing pest loads and changes in soil water balances. Plant breeding for increased drought tolerance and pest resistance may also be required, especially for new pests and diseases. However, a change in farming practices may also occur to adapt to new pests and diseases (as they have in the past), particularly if there is a future decrease in the number of available active substances to control these.

Projected lower summer rainfall levels (Section 2.3.2), and the increased risk of drought conditions (Section 3.1.2) may reduce soil moisture content and increase the prevalence of common potato scab on Scotland’s important seed potato crop. Potato scabs form during the early growth stage when the ground becomes too dry. Light scab damage may not affect the crop itself, but may affect the cosmetic appearance of the crop and therefore the market value. More aggressive outbreaks affect the structure of the crop and can cause rotting.

Although no simple robust climate risk metrics could be identified to assess the impacts on crops, recent research has shown that many pests and pathogens exhibit considerable capacity for generating, recombining, and selecting fit combinations of variants in key pathogenicity, fitness, and aggressiveness traits. There is therefore little doubt that any opportunities resulting from climate change will be exploited by them (Gregory et al., 2009), although the effects are too uncertain to assess.

Livestock

Pests and diseases are one of the factors that affect livestock welfare and product quality and, are therefore considered important in Scotland due to the significant level of livestock farming. Foot and mouth outbreaks affecting Scotland in 2001 and the impact of the Surrey outbreak in 2007 showed how serious the consequences of livestock disease can be. The outbreak in 2007 was estimated to have cost the livestock sector £32 million and another £4.5 million of costs to attached businesses (auctions, abattoirs, haulage etc., Pareto Consulting, 2008), due to a ban on exports and restrictions to animal transportation.

With potentially warmer and wetter weather, livestock could also face new diseases such as West Nile virus, as well as an increase in outbreaks of (for example) bluetongue, for which research suggest a possible link to climate factors (see for example Purse et al., 2005). This could potentially cause significant economic damage, with an increased threat to UK food production, as well as the agriculture sector and individual farms.

There are also potential knock-on consequences for the tourism and leisure sector when access to land is restricted to control the spread of diseases.

Case Study: Spread of bluetongue by virus.

Bluetongue is a vector-borne disease that affects livestock. It is transmitted by Culicoides biting midges and in 1998 it was reported in Europe for the first time in 20 years. The disease was first ever recorded in Europe 75 years ago, and only in areas that also had the old world vector, Culicoides imicola. The range of C. imicola has extended northwards considerably in that time. Other Culicoides species, that inhabit more northerly ranges now overlap in range with the old world vector and are thought to also now be carriers of the disease. This means that the disease may be able to spread naturally to more northern countries; a spread that may be facilitated by humans moving infected animals. Between 1998 and 2005, bluetongue was responsible for the death of over 1.5 million sheep in Europe (Bayliss and Githeko 2006). Further outbreaks occurred in Europe in 2006, 2007 and 2008.

Scotland’s first case of bluetongue virus was found in a cow amongst a herd of cattle imported from Germany in 200799. The cow was culled. Bluetongue is considered one of the most deadly of animal diseases and that the consequences of an outbreak could be as severe as the foot-and-mouth outbreaks in 2001 that saw so many animals killed and livelihoods disrupted. Following the case of bluetongue virus found in 2007, the first compulsory bluetongue vaccination programme was introduced to Scotland in 2008. Vaccination was compulsory for cattle and sheep, with recommendations for vaccination for other susceptible animals such as deer.

All animals have a range of ambient environmental temperatures that are conducive to health and performance. The critical upper limit of this range is the point at which heat stress effects begin to affect the animal, and environmental factors that contribute to heat stress include high levels of humidity and radiant energy (sunlight). This can have a significant effect on their productivity. Cows for example normally reduce their milk production under heat stress, decreases that can range between 10-25%. Heat stress can also affect reproductive performance, which can affect animals several months after the heat stress exposure.

Overall, the current Scottish climate does not result in losses from the dairy system or pose a major risk to dairy production and this is likely to continue for the rest of the century. For example, for the 2080s High emissions scenario central estimate (p50), the percentage loss of annual milk production simply due to heat stress is projected to be 8 million kg/per annum, which is only about 0.02% of UK milk production. There will be costs related to declines in herd fertility; however, these will be minor for Scotland. For the High emissions scenario in the 2080s considering the upper estimate (p90), these are projected to be less than £1 million (Agriculture Sector Report). Increased livestock stock deaths due to heat stress will be near zero for the rest of the century under all emission scenarios.

Agricultural land classification and crop suitability

Land Capability for Agriculture (LCA) identifies the potential to use an area of land for different agricultural systems or management practices. It provides a standard classification system that has gained wide acceptance across a range of users, including planners, land managers and valuation agents. The LCA classification is based upon intrinsic physical limitations of the land (climate, soils and topography) that cannot be removed or ameliorated by reasonable management. These underlying factors therefore constrain how the land is used for agricultural purposes. Higher-grade

99 http://news.bbc.co.uk/1/hi/scotland/south_of_scotland/7163612.stm
land has more options for use, and therefore greater flexibility, as it also has the potential to be used as specified for any of the lower classes.

LCA was not assessed as part of the UK CCRA. However, Brown et al. (2008) considered the implications of climate change in Scotland from the Land Capability for agriculture classification, and the conclusions outlined here have mainly been drawn from this separate study. It should be noted that this assessment was based on UKCIP02, not UKCP09.

Since the original land classification in the 1970s, there have been some subtle, yet important changes in the climate of Scotland (Figure 3.6). Regions classified as ‘cold-wet’ have decreased, whilst ‘mild-wet’ regions have increased, with some even becoming ‘mild-very wet’ in the west. By contrast, in the east, a new ‘warm-dry’ region has considerably expanded, including the Borders, Angus and Moray areas. The changes for the 2050s future scenario are much more pronounced. The west continues to comprise mainly ‘mild-wet’ regions, with most of the ‘cold-wet’ regions lost from the uplands.

Based on the projections for the Medium-High emissions scenario, Figure 4.19 shows the projected changes for the 2050s. This highlights the potential for large areas of land to move to a higher class, particularly in eastern and southern regions. Table 4.7 outlines these projected changes in more detail. Currently approximately 6% of the land area of Scotland is considered prime land. For the scenario considered in the 2050s, this is projected to increase to over 20%, with a consequent positive benefit to potential food production, and hence food security. This would be anticipated to increase landscape value, with a particular benefit for those in more rural communities. Hill farming for example could quickly respond to warmer temperatures and increased grass growth by increasing stocking rates (Agriculture Sector Report).

Projected climate changes indicate that current marginal land may be available for agricultural improvement, especially land currently classified as 32, 41, 42 and 5 due to their future potential. Improvement can only be considered where soils and topography are suitable. A potential increase in the viability of marginal land, could lead to increases in the area of land available to agriculture and changes to farming practices in some areas. For example, in upland areas there is the potential for grassland productivity to increase in some areas (discussed above), and other areas may become more suited for arable crops (although this could also impact on drinking water quality in some catchments due to an increased use of pesticides). This could lead to changes in the landscape, with for example an increase in livestock numbers due to a potential increase in forage growth, and the loss of internal dry stone walls. Land use could also influence or be influenced by Scottish trading patterns (discussed below) with a consequent permanent change in land use. It is important to consider that even with a change in land availability improvements may differ from those indicated. Local markets and customer demands may lead to more crops being grown for biofuel and energy, rather than traditional crop and farming choices.

However, any change in agriculture would need to be sensitive to ecosystems and the diversity of benefits that agriculture provides, and not just food production. However if sheep farming becomes impractical or uneconomic due to higher rainfall, there are few alternative farming options available, although diversification to forestry or short-rotation coppice (SRC) may be a possibility. An increase in the area of land used for intensive agriculture could negatively impact on areas of a high biodiversity. The impact of agricultural intensification is set to be most pronounced on marginal agricultural areas. However, if climate change results in continued increased precipitation during crucial times, this practice may have to be curtailed. An increase in heavy rainfall events may lead to wetter soils for longer periods, affecting the soil structure and access to land. This could have a large impact upon species whose niche requirements rely on a small amount of disturbance.
Marginal land pressures are highlighted by the Scottish Parliament Rural Affairs and Environment Committee report into the future of Scotland’s agriculture\textsuperscript{100}. Objectives include the drive to make marginal land more economically efficient in a sustainable manner (Cook et al., 2008), possibly threatening biodiversity targets for economic gain. Marginal areas are rich in biodiversity and a change in agricultural practices or in the timing, could lead to a change or reduction in the species seen. Under certain conditions biodiversity may benefit. The presence of low-intensity agriculture and land abandonment could promote species diversity, although associated changes in rainfall and temperature may negate this and reduce the biodiversity seen (Biodiversity and Ecosystem Services Sector Report). However, these issues are large and complicated, and essentially driven by changes in the CAP, being the chief driver of agricultural practices, and Government policy rather than climate.

Conversely marginal land has potential to deliver public environmental goods (including biodiversity and ecosystem services), so some areas may attract agricultural subsidies in the future to support this, thereby reducing the drive for improvement. The Pack report (2010) identifies the importance of stabilising livestock numbers to achieve a balance between delivering public goods and avoiding land abandonment. An approach based on meeting multiple needs (public goods, sustainable livestock systems) through appropriate levels of grazing would need to be flexible in the context of future changing climate, and avoid the problems of ever-increasing numbers of livestock simply to collect the headage payments.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4_19.png}
\caption{Comparison of the original LCA with the 2050s Medium-High emissions scenario projection}
\label{fig:4.19}
\end{figure}

\begin{flushright}
Source: Brown et al., 2008
\end{flushright}

\textsuperscript{100} http://archive.scottish.parliament.uk/s3-committees-rae-reports-11/rur11-04.htm
<table>
<thead>
<tr>
<th>Class</th>
<th>Category</th>
<th>Climate Limitations</th>
<th>Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prime</td>
<td>None or very minor</td>
<td>Very wide range of crops with consistently high yields</td>
</tr>
<tr>
<td>2</td>
<td>Prime</td>
<td>Minor</td>
<td>Wide range of crops, except those harvested in winter</td>
</tr>
<tr>
<td>3</td>
<td>Prime</td>
<td>Moderate</td>
<td>Moderate range of crops, with good yields for some (cereals and grass) and moderate yields for others (potatoes, field beans, other vegetables)</td>
</tr>
<tr>
<td>4</td>
<td>Non prime</td>
<td>Moderate</td>
<td>Moderate range of crops, with average production, but potentially high yields of barley, oats and grass</td>
</tr>
<tr>
<td>5</td>
<td>Non prime</td>
<td>Severe</td>
<td>Improved grassland, with mechanical intervention possible to allow seeding, rotavation or ploughing</td>
</tr>
<tr>
<td>6</td>
<td>Non prime</td>
<td>Very severe</td>
<td>Rough grazing pasture only</td>
</tr>
<tr>
<td>7</td>
<td>Non prime</td>
<td>Extremely severe</td>
<td>Very limited agricultural value</td>
</tr>
</tbody>
</table>

Changes in international trading patterns as a result of climate change

The availability and prices of overseas commodities could change in the future, affecting future land use directions in Scotland. A review commissioned by the Foresight Global Food and Farming Futures project for example has suggested that, by 2050, there will be, on average, 18% less water available worldwide for agriculture, due to pressures from environmental flow requirements, as well as municipal and industrial water demands collectively (Strzepek and Boehlert, 2010). In addition, the effects of extremes of heat and water availability, as well as sea level rise and any changes in the intensity and frequency of rainfall patterns could have serious consequences for agricultural productivity overseas. In the short term, climate change could affect the security of supply and price of some agricultural commodities more than others, impacting food security. Resultant sharp food price volatility is likely to be exacerbated by the protectionist responses of some countries’ responses focused on more immediate national concerns (such as the Russian ban on exporting wheat from August to December 2010 following a severe drought and wildfires\(^\text{101}\)) which inhibit usual market adjustments. These effects would not just affect food crops, but are also likely to include increases in heat stress in livestock, particularly during transportation (although offset in some countries where very low temperatures are experienced). Water availability and coastal grazing areas may also have a negative impact on livestock production.

The potential impacts of climate change should be viewed in the context of other overseas changes. Technological adaptation could result in the development and selection of crops and livestock more suitable to changed climatic conditions, for instance by improving water-use efficiency of crops and resilience to abiotic stress.

Additionally the adaptation of agricultural practices and the more widespread adoption of engineering solutions e.g. for efficient water management will have an important role to play in agricultural adaptation. Further, scientific innovations may also combat the threat in these countries as a result of pests and diseases. The geographical distribution of the production of agricultural commodities could also change to ones more suitable to the changed climate, with consequential effects on agricultural land use in Scotland.

Up to the mid-century, it is unlikely that there will be dramatic consequences for imported agricultural commodities due to climate impacts (Foresight, 2011). For implications beyond this, global agriculture may change, and Scottish agricultural practices and land use may have to change in response to the global markets and price structures. However, how any future changes will affect security of supply and price of agricultural commodities is unclear due to the complexity of change and length of timescales involved (Foresight, 2011).

**Increase in Greenhouse Gas emissions**

A changing climate is likely to have a wide range of impacts on farming in Scotland. Changes in yields, feed quality, thermal stress, disease spread and control and management of waste may all influence GHG emissions (Biodiversity and Ecosystem Services Sector Report). At present, agriculture and related land use accounts for approximately 21% of all GHG emissions in Scotland\(^{102}\), of which 25% is estimated to be as a result of land use change. Most N\(_2\)O is produced as a consequence of agricultural activities (Scottish Agricultural College, 2011).

Potential increases in the area of land brought into production in Scotland (discussed earlier) combined with intensification of agriculture as global food demands increase, is likely to impact negatively on emissions from farming (based on current technology and management practices). However, emissions from agriculture and related land use fell by 27\% between 1990 and 2009\(^{103}\), with methane by 16\%\(^{103}\), mainly due to a decline in cattle and sheep numbers - a trend which is likely to continue\(^{104}\). Direct N\(_2\)O emissions from agriculture are attributed to direct fertiliser applications; however, there is also evidence to suggest that warmer and wetter seasons may increase N\(_2\)O flux between agricultural land and the atmosphere (Wie *et al.*., 2010). On a global scale, livestock numbers are currently estimated to account for approximately 9\% of total anthropogenic GHG emissions (Smith *et al.*, 2007b). Taking into account all associated activities, this rises to 18\% of all anthropogenic emissions and almost 80\% of all agricultural emissions. Although there is some debate on these estimates (Herrero *et al.*, 2008), this does indicate the significant contribution of agriculture, and livestock in particular to anthropogenic emissions.

A likely increase in machinery use could also lead to increased soil erosion, returning stored carbon to the atmosphere and thus impacting on GHG emissions. The projected reductions in soil moisture content for Scotland (see Table 4.5) could further exacerbate this problem. In peatlands, drier soils may lead to a reduction in Sphagnum mosses; peat-forming vegetation. This could be a particular problem for the south-east of Scotland, where drier conditions combined with land more suitable for crops could combine and return greater amounts of stored carbon to the atmosphere. The areas most vulnerable as a result of climate change are those where the peat has been degraded through loss of vegetation and structure. Of the 6.9 billion tonnes of soil organic carbon in Scotland\(^{103}\), 4.5 billion tonnes are held in peatlands, blanket bog, lowland raised bogs and fen (Smith *et al.*, 2007a,b). In reviewing current evidence and model predictions, Smith *et al.*, (2007a) suggest that land use change and

\(^{102}\) http://www.scotland.gov.uk/Publications/2011/12/14103854/1

\(^{103}\) http://www.scotland.gov.uk/Topics/Statistics/Browse/Environment/seso/sesoSubSearch/Q/SID/226

\(^{104}\) Recent research indicates that this may be an over-estimate. This is discussed in more detail in Section 4.2.1.
management have been the more significant historical drivers of change in soil organic matter, while climate change will likely become more significant over time. It has been projected that up to 50% of the suitable climate space for peat-forming vegetation could become vulnerable by the 2050s (Biodiversity and Ecosystem Services Sector Report), although western Scotland is the least vulnerable. If this corresponds to an actual loss in peat-forming vegetation, then peatlands which are vital for regulating services such as water flow, quality and carbon storage, will be severely degraded or lost. This loss may result in the release of GHGs such as carbon dioxide and methane. However, the processes that surround the flow of carbon between soils and the atmosphere are not well quantified.

Summary of results
The results of the analysis are shown in Table 4.8.

Table 4.8 Climate change impacts on Agriculture

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Confidence</th>
<th>Coverage</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG1b/d: Changes in wheat and spring barley yield (due to warmer springs)</td>
<td>High</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>AG25/51/52: Agricultural land classification and crop suitability</td>
<td>Medium</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG10: Changes in grassland productivity</td>
<td>Low</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG21: Waterlogging effects (annual)</td>
<td>Low</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG1c: Changes in potato yield (due to combined climate effects and CO₂)</td>
<td>Too uncertain</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>GNr4: Changes in global trading patterns</td>
<td>Too uncertain</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>AG66: Human food supply from domestic agriculture</td>
<td>Too uncertain</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>AG2/FL4: Flood risk to high quality agricultural land</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>WA5: Public water supply-demand deficits</td>
<td>Too uncertain</td>
<td>UK</td>
<td>IJ</td>
</tr>
<tr>
<td>AG1e: Changes in winter barley yield (due to wetter winters)</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>FL14a: Agricultural land lost due to coastal erosion</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG4: Drier soils (due to warmer and drier summer conditions)</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>AG44: Livestock pests and diseases</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG21: Waterlogging effects (winter)</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>AG7a: Reduction in milk production due to heat stress</td>
<td>Too uncertain</td>
<td>UK</td>
<td>IJ</td>
</tr>
<tr>
<td>AG8/15: Livestock heat stress factors</td>
<td>Too uncertain</td>
<td>UK</td>
<td>IJ</td>
</tr>
<tr>
<td>AG65: Loss of particular landscapes and associated rural communities</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG26/27: Biodiversity/wildlife changes</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG3: Risk of crop pests and diseases</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG17/59: Increase in greenhouse gas emissions</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG30/57/58: Breeding habits/reproductive nature of species</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>AG19: Soil erosion and leaching</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>GNr4: Changes in global trading patterns</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
</tbody>
</table>

*Coverage of analysis
S: Analysis undertaken for Scotland only
UK: Analysis undertaken for the UK

**Method of analysis
I: Informed judgement
Q: Quantitative
Summary of the main impacts of climate change on agriculture

- Wheat yields are projected to increase (potentially in excess of over 100% over the coming century).
- Winter barley yields are projected to decrease by up to a third by the 2080s. Spring barley yields are projected to increase by up to half, although they could potentially decrease slightly by the 2080s. Overall, there is expected to be little change in barley yields over the coming century.
- Little change is projected for rainfed potatoes, with projections indicating either a small increase or decrease by the 2080s.
- Grassland productivity may increase significantly over the coming century, possibly by as much as a half by the 2050s.
- Flooding and coastal erosion of agricultural land is anticipated to increase, potentially reducing the land class of some land. The agriculture land at risk of flooding relative to a 1961-1990 baseline could be expected to increase by up to 100% by the 2050s and 170% by the 2080s.
- The numbers of pests and diseases is expected to increase, and there is expected to be an increased risk from new pests and diseases. This would be expected to increase damage to some crops and affect livestock welfare and product quality.
- Land classifications are generally anticipated to change, leading to a greater potential range of land use and greater level of productivity. This would allow new areas of land to be farmed with a positive impact on productivity, although with potential negative impacts on biodiversity and marginal land.

4.3.2 Forestry

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Forestry Sector Report.

Woodland in Scotland constitutes approximately 1.4 million hectares (45% of the UK total) with the forestry sector providing goods to the value of approximately £700 million to the Scottish economy in 2008. Forestry directly employs in the region of 14,000 people full-time, with an additional 26,000 jobs supported in the primary wood processing industry (e.g. sawmills, paper, panels). Scotland’s timber harvest was 6.4 million m³ in 2009, contributing 5.1% of the UK’s wood sales. New forest planting was 5,100 hectares in 2010-2011 with an aim that an increase in this rate will increase Scotland’s woodland cover from the current 17% to around 25% by the second half of the current century (Scotland Executive, 2006). Within Scotland, regional differences may have a large impact on the extent that climate change affects the sector, additionally, local and global markets, transport and customer demand may have a greater impact than changes in Scottish climate.

In addition to timber production, forestry also provides a range of additional services. Ecosystem services are provided through recreation, education and biodiversity with

105 http://www.forestry.gov.uk/website/forstats2011.nsf/0/061E41873F94CC788025735D0034F33B
106 http://www.forestry.gov.uk/website/forstats2011.nsf/0/D881D5834408C7C08025734E00312F0A
8.7 million visits to forests in 2007 contributing £209 million to the Scottish economy (Forestry Commission Scotland, 2011a).

**Pests and Diseases**

Pests and diseases appear to be posing increasing risks to trees, woodlands and forests, mainly due to external factors such as international trade. Pest/pathogen life cycles are often linked to climatic conditions, and it has therefore been suggested that climate change may exacerbate the frequency and severity of attack to trees, both in rural and urban locations. Projected effects demonstrate very significant potential threats to traditional silviculture in Britain, with some tree species under real threat of decline or failure, with potential economic and environmental consequences. Environmental risks are mainly associated with the management of strategies to reduce risk, including use of pesticides, and in the course of managing forests when pests and pathogens are present. Pesticide use in modern forestry is almost exclusively in the nursery production phase. Loss of, or damage to, woodlands from pests and pathogens may occasionally reduce or restrict public access to forest areas and have impacts on societal enjoyment of these environments.

**Case Study : Deer populations**

Red deer (*Cervus elaphus*) populations in Scotland have increased in recent decades despite more intensive culling. Milder winters and warmer, wetter springs may have resulted in earlier birth dates, and increased juvenile growth and survival linked to milder weather and increased food availability due to extended growing seasons (Irvine *et al.*, 2007). These climate trends are projected to continue (Section 3.1.8), although projected warmer and drier summers may lead to reduced food availability with a consequent negative effect on populations. However, due to the importance of deer for sport and meat produce to Scotland and its local communities, the role of the private landowner and the shooting agenda will have the most significant influence on Scotland’s deer population.

Deer can have both negative and positive impacts on the plant community. Increased deer populations are likely to lead to increased damage to young trees, although future land management is likely to play a larger role in determining deer populations. Evidence from upland heath communities also indicates that deer density is related to heather production (Irvine *et al.*, 2007).

In woodlands, deer density is negatively related to tree seedling abundance so that deer increases associated with earlier plant phenology (see Section 4.2.1) and longer growing seasons may have deleterious effects on woodland establishment.

An expansion of the deer population may lead to a greater exposure to ticks and tick borne diseases including Lyme disease. A larger deer population may allow tick numbers to grow and their geographical range to spread. Combined with an increase in outdoor activities, this may increase Scotland’s exposure to tick bites and the risk of Lyme disease (see Section 4.6.4).

Within the CCRA, the climate change affect of pests and diseases was assessed semi-quantitatively based on expert judgement for forest extent affected by red band needle blight\(^{107}\) and forest extent affected by green spruce aphid.

The optimum temperature conditions for establishment of red band needle blight are given as 12-18°C (Brown and Webber, 2008) and 16-20°C (Gadgil, 1968), with a critical time of infection of spring and early summer. The disease appears to have increased

\(^{107}\) Also known as Dothistroma needle blight
in extent and severity over the last five years possibly due to changes in the number of warmer, moist days but also possibly due to a change in the pathogen itself (there are two mating types and 99 genotypes identified to date in the Scottish population). This disease has already had a profound impact on Scottish forestry practise, as it severely affects Lodgepole Pine. This species is now avoided as a tree crop.\textsuperscript{108} The incidence and impact of red band needle on Scots pine, a species previously thought to be more resistant to this pathogen than other pine species, appears to be increasing. With projected increases in spring and summer temperatures (see Section 2.3.1), the incidence and impact of red band needle blight on pine species would be expected to increase over the coming century, with most pine forest affected by the 2050s, and almost all the pine forest affected by the 2080s.

![Sitka Spruce, Scotland](http://www.geograph.org.uk/photo/117237)

Figure 4.20  Sitka Spruce, Scotland
Source: Chris Court\textsuperscript{109}

For green spruce aphid, there is no published evidence that provides a direct relationship between spread of the pest and climate. Ray \textit{et al.}, (2008) however indicates that outbreaks of this pest every five to eight years correlates with average winter temperature of 6°C reached every five to eight years, which was therefore taken as the threshold in the CCRA analysis for optimum spread of the pest. Most of the UK’s spruce forest is in Scotland (about 75%), mainly in the Scottish uplands. With a current mean winter temperature for Scotland of around 2°C, a 4°C increase in mean winter temperature would see the conditions for optimum spread of this pest being reached. However, the converse would be true for drier summers, and even under the upper estimate of the High emissions scenario, mean winter temperatures are not projected to increase to this level.

\textsuperscript{108} http://www.forestry.gov.uk/forestry/INFD-7L6E57#6.4
\textsuperscript{109} http://www.geograph.org.uk/photo/117237. This figure is the copyright of the owner but has been reproduced in accordance with the copyright as detailed by the Creative Commons licence: http://creativecommons.org/licenses/by/3.0/legalcode.
The Scots pine has a current range in the UK confined to the Highlands of Scotland; its area spans 17,000 hectares – only 1% of the original ‘Caledonian’ forest extent, however its natural range extend to southern Europe and across northern Asia. The Caledonian forest is characterised by Scots pine, Birch (*Betula pendula* and *Betula pubescens*) and important plants including Twinflower (*Linnaea borealis*) and One-flowered Wintergreen (*Moneses uniflora*).110

Such is the importance of Scots pine forest in supporting rare species, it has been classified as a priority habitat under the EU’s Habitats Directive111, creating habitats for the Scottish crossbill (which is found exclusively in Scots pine forest) and capercaillie, as well as helping support pine marten (*Martes martes*) and red squirrel populations.

![Pine marten (left) and red squirrel (right)](source: Helen Udale-Clarke)

The timber industry is an important part of the Scottish economy. Woodfuel also makes an important contribution to Scotland’s renewable heat targets, and also provides biomass electricity. Additionally, 18-24% of people in Scotland regularly access these forest areas for fruit, fungi, etc. with this having an estimated value of £9.2 million in 2005 (Moffat and Vangelova, 2009). Revenue created by tourism and day visits is also vital to the local economy (Forestry Commission, undated). Forest visits also play an important role in education with evidence that such learning may improve interpersonal skills and teamwork (Lovell *et al.*, 2010).

Scots pine trees generally develop on infertile soils with these estimated to store 36Mton of CO₂ (to a depth of 80cm) (Moffat and Vangelova, 2009). In thin soils the tree exhibits a shallow network of roots112 helping to bind the soil together reducing erosion. With their high canopies, they also reduce the impact of rainfall on the surrounding soils. This reduces soil compaction by rainfall (Lull, 1959 p.13), and regulates the water flows and therefore reduces river flows and flood risk (Scottish Wildlife Trust, 2008).

Scots pine as a dominant species offers a range of supporting services to the

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111 http://www.treesforlife.org.uk/tfl.scpine.html  
112 http://www.forestry.gov.uk/forestry/INFD-5NFLAP
ecosystem. Nitrogen from the air is fixed through lichens and is available to other forest plants when the tree dies. Scots pine produces 3000–6250 kg/ha/year of needle litter (Moffat and Vanguelova, 2009) vital for the ground ecosystem and wood ant populations. Pine cones provide an invaluable food source for the Scottish crossbill, red squirrel, mice and voles. Cone foragers are a food source for the pine marten and other mammals.

Ecological Site Classification (ESC) modelling (see below) suggests that Scots pine will increase in productivity in Scotland (Forestry Sector Report) and possibly will require a range (climate space) shift. Adaptive action may be required to support migration across the landscape. To date, severe water deficits in pine have not been catastrophic in the UK (Irvine et al., 1998) and even in Mediterranean climates extended drought episodes have resulted in reductions in annual growth increment, not death. The projected changes in climate in Scotland, and specifically in the native pinewood ranges, are such that the species is most likely to survive under future climatic conditions in Scotland, with perhaps a reduced growth in occasional severe prolonged drought episodes (Giuggiola et al., 2010).

**Drought and wildfire risk**

Drought already affects tree physiology and woodland ecology in dry summers, but climate change predictions demonstrate that considerable areas of the UK are likely to be progressively affected in the following decades depending on soil type and site conditions. This is likely to be most acute in southern and south-eastern Scotland (Ray et al., 2008). Economically, drought will affect timber productivity and returns on market investment. Environmentally, the largest effects will be on woodland habitat for particular fauna and flora; in addition, drought may increase the susceptibility of some tree species to attack by pests and pathogens as well as an increase in the risk of wildfire. Direct effects on society are likely to be subtle, with most impacts through the changing visual appearance of woodlands and possible adaptive management to reduce wildfire risk, such as erecting exclusion zones in summer months.

The analysis presented in the Forestry Sector Report indicates that the baseline loss of yield due to drought is 10% in Northern Scotland. By the 2020s, this is estimated to increase by approximately 2% (range 2% gain to 6% loss). By the 2050s and 2080s this will increase to 14% (range 10% to 18%) and 15% (range 10% to 23%). Soils prone to prolonged periods of dryness are also expected to become more unfavourable for Sitka spruce than for other drought resistant species (Forestry Commission, 2008).

The risk of wildfires is also likely to increase in warmer drier summers, with adverse consequences for timber production and biodiversity. This has been estimated as a 30-40% increase by the 2080s from a 1980s baseline (Section 4.2.1).

**Change in tree productivity**

Climate change is expected to have substantial impacts on tree biology, and hence on survival and growth. In turn, these will determine forest productivity, as measured by the rate of timber volume production. 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). This 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, which is a measure of

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113 http://www.treesforlife.org.uk/tfl.scpine.html
114 http://www.treesforlife.org.uk/tfl.scpine.html
maximum stem growth rate (maximum mean annual increment). ESC does not account for the physiological impacts of rising CO₂ levels or increased nitrogen deposition in its assessment of tree productivity changes.

Figure 4.22 shows the present potential productivity on the National Forest Estate¹¹⁵, as modelled using the ESC climatic response function and its predicted change for 2050 and 2080 climate projections, for several key broadleaved and conifer species. Potential productivity for each species was estimated as modelled yield class multiplied by existing forest area managed by the Forestry Commission for that species. Thus baseline potential productivity estimates differ between species due to the areas planted, suitability and productivity. The projections for 2050 and 2080 show significant differences between some of the species analysed. In general, projected climate change is likely to increase productivity, markedly in the case of Sitka spruce, Scots pine and lodgepole pine. For broadleaved species, positive and negative changes are observed for all species across parts of Scotland, although the viability of these species economically may still be site and market driven.

The broad grouping of results into different regions hides some important regional differences due to climate. This is particular the case for differences in projected productivity between the east and the west for species more suited to wetter than drier conditions such as the Sitka spruce (see Figure 4.23), Scotland’s forestry’s principle commercial species. Additionally, infrastructure and markets may have a larger influence on the changes in the Scottish forestry sector, with the lack of access roads, transporting infrastructure and processing in the North and West of Scotland, potentially limiting the extend to which these areas may be used as viable plantations. These areas are also more exposed to heavy wind and rain than more marginal locations elsewhere increasing the risk of waterlogging and windthrow.

Climate projections for the south and east indicate a climate more suitable to Scots Pine and Larch growth, however, these species have recently been more prone to pathogens (Brown and Webber, 2008) reducing their popularity as a plantation species. Of the viable broadleaves, Birch may suit the projected changes in climate for the southern and eastern locations. However, currently this species is principally grown for the woodfuel market which is small scale.

¹¹⁵ The tool was applied to the National Forest Estate only because there is reasonable information on soil type for public sector forests. More information is given on this in the Forestry Sector report.
Figure 4.22 Potential yield under baseline climate conditions and its change in 2050 and 2080 for selected tree species, (with current national forest estate areas)
Figure 4.23 Change in potential productivity yield in 2050 and 2080 for selected tree species compared to baseline (current potential yield, (assuming current national forest estate areas))
The results obtained from using the ESC potential yield response function, based on the key climatic and environmental input variables, show that future climatic change projections are likely to support mainly increased productivity, although this is highly dependant on location and tree species. However, the model does not take into account the potential effect from damaging pests and pathogens, nor unpredictable or extreme events, in particular wind throw which is an important factor for forestry (discussed below). Neither does it account for the likely change in choice of tree species upon restocking in the future in order to plant species more resilient in future climate conditions. Therefore the modelled potential productivity values cannot be used in commercial production forecasting, but they are nevertheless valuable in helping to inform the sector where species adaptation is most important and most urgent.

**Forest biodiversity**

Changes in climate, and likely adaptive forest management as a response to this, would change the nature of forest biodiversity, though it is far from clear whether it will be universally impoverished. The CCRA analysis indicated that some species would benefit from climate change, but others, some of which may be regarded as important, may suffer. More importantly, woodland floral and faunal biological relationships are likely to change, with consequent effects on tree physiology and biogeochemistry. Hence, changing some elements of forest biodiversity may impact on timber productivity, though there is no convincing evidence for this to date. Climate mitigation measures designed to increase carbon storage could also mean that many parts of Scotland would see an expansion of productive and native semi-natural woodland which could either change or reinforce existing biodiversity and landscape character (Land Use Consultants, 2010).

Concerns over the integrity and future character of forest biodiversity in the face of climate change were raised consistently during the consultation stage of the CCRA. These concerns were generated in part as a result of the need or desire to conserve important woodland wildlife habitats as they are currently classified and managed (i.e. to preserve priority and/or important woodland habitat where it currently occurs). Other interests sitting within the broad concept of biodiversity include the conservation of particular species of woodland fauna and flora, notably those considered rare or endangered. With the decline in native woodlands since the expansion of forestry during the 20th century, there has been a fragmentation of both wooded and non-wooded habitats, with a significant threat to forest biodiversity. A reduction in habitat area combined with greater isolation between habitat patches increases the likelihood of local extinction, and climate change will pose further threats to isolated populations as the limited genetic base of small populations gives them less capacity to adapt to new conditions (Forestry Commission Scotland, 2011a).

Another point of view focussed on the preservation of diversity itself. Because biodiversity is such a complex and, in many respects, a personal and political concept (Escobar, 1998), and because individual species respond to climate in individual ways, it was not possible to develop a single response function by which to explore the possible changes due to climate change. Nevertheless, there has been much work to explore likely effects on woodland biodiversity, and UK evidence of climate change impact on habitat and species is considerable. A number of comprehensive reviews have been produced summarising effects across different taxonomic groups, biological systems, regions and type of response (e.g. Parmesan and Yohe, 2003; Root et al., 2003; Hickling et al., 2006; Thomas et al., 2006; Berry et al., 2011).

Changes in climate can affect a species’ autoecology including phenology, growth, reproduction, germination, establishment, competition and response to herbivory (Fitter and Fitter, 2002; Sparks et al., 2002). These impacts not only affect species and their
Climate Change Risk Assessment For Scotland

populations, but can have major implications for community structures and ultimately even ecosystem function (McCarty, 2001).

There is a risk of major canopy trees losing bioclimate space from 2050 in Scotland. Additionally, Scottish species composition could be expected to change. Many species that are dominant in the south today may be more successful competitors in the north in the future including Lowland Beech and Yew woodland (Berry et al., 2011). This could impact upon native species, or affect current ecosystems. Some mobile species gain bioclimate space, including important species such as the red squirrel (although invasive non-native species such as grey squirrels would also be expected to benefit). However, a number of species with strongholds in Scotland due to present cooler conditions are likely to suffer including the Scottish crossbill, Scottish wood ant and capercaillie.

The willow species found in wet woodlands may suffer bioclimate space losses. Lowland mixed deciduous woodland should remain relatively stable. A number of important tree species could experience small losses which may affect the competitive balance in some woodlands (e.g., between ash and oak in ash woodlands) although there are some striking gains including three rare species (large-leaf lime and both service trees). Management of land adjacent to existing Caledonian forest would assist in the expansion and movement of this biotype.

As discussed earlier, pests and diseases of Scots pine are likely to increase with warmer temperatures, but incidents of wildfire may increase, which often aid the regeneration of Scots pine and silver birch. Woodland structure, therefore, may change, with sessile oak stands possibly increasing, while Scots pine decreases. Subsequently, as also discussed earlier, the species associated with Scots pine could also decrease, including Scottish crossbills and wood ants.

**Waterlogging, landslips, windthrow and productivity**

Increased waterlogging may occur during wetter winters, weakening tree roots, leaving trees more vulnerable to wind throw. Given the known relationship between mean wind speed and extreme events, it is possible that a small change in wind speeds could lead to an increase in endemic wind damage, and more frequent catastrophic wind damage in forests (Forestry Commission Scotland, 2008). Overall, windthrow is likely to be a threat for Scotland due to the increased vulnerability to waterlogging, although with a high level of uncertainty. Extreme weather conditions, such as those most likely to cause windthrow or land slippage, for example, are met by contingency planning based on past experience (Forestry Commission, 2008).

Landslips may increase in Scottish forests as a result of a reduction in slope stability caused by wetter winters, which may affect local transport routes that are in close proximity to forest areas.

Despite the western and northern parts of Northern Scotland being on average, the windiest in the UK (Section 2.1), current projections from UKCP09 indicate a negligible change in summer or winter wind speeds. There is therefore expected to be a negligible change in tree windthrow aside from any impact as a result of waterlogging outlined above. This is consistent with recent data over the 20th century, with Read et al., (2009) indicating no trend in wind damage over this period. However, wind is an important factor for forest management with exposed areas with wind exposure influencing tree type and management practises. Currently to avoid planting on wind exposed site, and to aim for the 25% woodland cover target, sheltered sites often in lowland areas are favoured, which could result in greater land-use pressure on more favourable agricultural land (Ray et al., 2008). In Scotland the last large impact storm was January 2005 and resulted in 405,000 m³ of wind thrown timber volume. Much of this material is recoverable, though it may be compromised in terms of its structural
integrity so may be utilised in low-grade timber or fibre markets. The main impact is in an in-year increase in material affecting market prices and the productivity forgone by early harvest.

Tree and timber production is reduced when drought occurs during the period of woody growth, although yearly variation in rainfall or drought is usually invisible and integrated into the overall estimate of site productivity. Nevertheless, droughts can have more serious effects, notably when they occur in succession (such as in 1984 and 1985). Timber productivity is also significantly affected by single event storms. The 1987 storm in southern England for example resulted in a loss of 3.9 million m³ trees, a volume equivalent to a little less than half of annual timber production for the UK as a whole (Quine and Gardiner, 2002). However, the warmer weather and greater levels of CO₂ is likely to be the overriding influence on tree productivity, and although not assessed as part of the CCRA, there would be anticipated to be small increase in productivity over the next century. This was indicated for example by the Forestry Commission (2008) who, based on UKCIP02, indicated that Sitka spruce productivity may increase by 2-4 m³ per hectare per year if water and nutrients are not a limiting factor by the end of the current century (also see earlier).

Snow and frost damage

Understanding is weak of the effect of rising temperatures on damage to trees. Although rising temperatures would be anticipated to reduce frost damage, evidence indicates a significant potential from frost damage as a result of earlier budburst (Read et al., 2009). In addition, there is the potential for less natural seed emergence as some trees need severe frosts to induce dormancy. However, this is more relevant for semi-natural woodland where natural regeneration of seed is the principal means of woodland regeneration. A further factor to consider is a likely greater range of tree types from more southerly locations in Scotland in the future which could lead to an increase in frost damage.

Heavy snowfalls can damage trees, by breaking branches, and this damage is typically confined to predominately conifer species, as deciduous species are usually leafless when snowfalls occur. However, this is considered to be less of a problem based on previous work by Read et al. (2009).

Although this impact was not assessed as part of the CCRA, the likelihood is that an increase in mean average temperatures would lead to a general reduction in frost and snow damage, although there is the potential for less natural seed emergence for trees that need severe frosts to induce dormancy.

Diffuse pollution

The potential risks to water associated with forestry are due to indirect phosphate input to highly sensitive upland lochs, sediment delivery due to soil disturbance associated with road laying, planting and clear felling made worse during heavy rainfall events and potential pollution incidents associated with spillages of fuel or chemicals (SEPA, 2007). An increase in forestry plantation may increase this risk of pollution input from this sector.

Summary of results

The results of the analysis are shown in Table 4.9.
Summary of the main impacts of climate change on forestry

Opportunities for forestry can be broadly captured by identifying the benefits of warmer weather and increasing levels of CO₂, which are the main drivers in timber productivity. Overall these are likely to result in an increase in timber productivity over the rest of the current century, particularly for Sitka spruce.

The most serious risk to forestry as a result of climate change is likely to be warmer and drier summers leading to a probable increase in drought, especially in the eastern side of Scotland, which will most probably affect Sitka spruce most adversely of the main conifer species. Currently, yield loss due to drought is 10%, and this is projected to increase to 14% (range 10% to 18%) by the 2050s. An increased risk of wildfires (projected to increase by 30% to 40% by the 2080s from the 1980s), with adverse effects for both timber production and biodiversity may also occur. Pests and diseases are also a concern as large proportions of different woodland types could be adversely affected as temperatures rise, with increased likelihood of optimum conditions for pathogen establishment being reached.
4.4 Business and Services

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Business, Industry and Services Sector Report and the Floods and Coastal Erosion Sector Report.

There are approximately 290,000 enterprises in Scotland (Office of National Statistics, 2010). These range from large industrial and commercial undertakings that employ a large number of people to the many small businesses such as privately owned individual shops. Excluding North Sea oil, Scotland has the third largest GDP per capita of any region in the UK after the southeast of England and London, although this is still lower than the average for the UK as a whole. Despite Scotland’s diverse range of industries in manufacturing, a legacy from the Industrial Revolution, in common with most advanced industrialised economies these have declined. However, their decline has coincided with a significant growth in the service sector, which is now the largest sector of the economy in Scotland. An overview of some of the main businesses and services for Scotland is given below.

- **Service sector**
  - The service centre in Scotland is primarily centred on the cities of Edinburgh and Glasgow. It accounts for about 74% of output\(^{116}\), and around 80% of jobs\(^{117}\).

- **Agriculture and forestry**
  - Agricultural land in Scotland covers approximately 80% of the total land area of Scotland. Forests in Scotland cover approximately 17% of the land area. Combined, they employ about 5% of the workforce; mainly in rural areas (see Section 4.3).

- **Fishing**
  - Fishing is an economic mainstay in many parts of Scotland, with important fish markets in Peterhead, Aberdeen and Troon. Approximately 60% of the total UK catch is landed in Scotland (Scottish Government, 2011d), and shifts in the location of fish stocks could lead to significant consequences for the Scottish commercial fishing industry (see also Section 4.2.4).

- **Oil and Gas**
  - North Sea oil has transformed the Scottish economy since the 1970s, and employs approximately 6% of the working population of Scotland\(^{118}\).

- **Tourism**

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\(^{117}\) Office for National Statistics (ONS) (2010) – GVA in Scotland (excluding North Sea Oil and Gas) amounted to £103 billion in 2009 (8% of UK total).
\(^{118}\) GVA per head is in line with the UK average (at around £18,000 per person).

\(^{117}\) There are a number of sources of employment figures in Scotland/UK. We have used the latest estimates from the Business Register Employment Survey which provides figures for 2009. Available (download from B10) from: http://www.scotland.gov.uk/Topics/Statistics/Browse/Labour-Market/DatasetsEmployment

\(^{118}\) http://www.scotland.gov.uk/News/Releases/2011/06/10082532
- Scotland is a well developed tourism destination, with the industry sustaining in the region of 200,000 jobs, with approximately £4bn spent each year by tourists.

- **Energy**
  - Scotland has abundant potential for renewable energy resources such as wave, tidal and wind. This includes approximately 25% of the total European wind energy resource.

- **Whisky**
  - Whisky is probably Scotland’s best known manufactured export, with shipments worth approximately £4 billion per year, and supporting over of 10,000 jobs.

Climate change impacts on business and services include direct damage caused by extreme events, impacts from gradual changes (such as temperature increases), losses due to business disruption and adverse impacts on financial investments. The greatest single climate change concern for business is probably flooding.

There is a particular concern that many of the smaller businesses are vulnerable to extreme events, either because of inadequate insurances or inadequate resources to recover quickly. These businesses are of particular importance to the Scottish economy. For example, the number of Small and Medium Enterprises (SMEs) account for over 99% of enterprises, and approximately 53% of employment and 37% of employment in Scotland (Office of National Statistics, 2010).

The emergency services are likely to be particularly affected by climate change as they are required to respond to emergencies including floods and wildfires, both of which are expected to increase.

Warming seas are projected to lead to a shift in the location of commercial fish stocks, and the potential opening of new sea routes in the summer as a result of melting of Arctic sea ice (with a major boost for Scottish ports). These could have a significant effect on these Scottish businesses, and are discussed in Sections 4.2.4 (Natural Environment – Marine) and 4.5.1 (Infrastructure and Buildings – Transport) respectively.

### Impacts of increased flooding

Flooding of coastal areas in Scotland is a potential serious issue, affecting people, property, land and infrastructure. According to the Scottish Government (2002), currently about 30% of the Scottish population live in coastal areas (compared to 60% in England and Wales). Currently 130,000 properties (about 5%) have a 0.5% chance of flooding in any one year (a return period of 200 years) of which about 13,000 are non-residential properties. This equates to approximately 5,000 in the 1 in 75 year floodplain (i.e. at significant likelihood of flooding). Although no flood risk assessment for Scotland currently considers climate change, results based on the England and Wales analysis indicates that the number of non-residential properties at significant likelihood of flooding could increase by at least 40% by the 2050s and 60%.

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122 Direct and indirect impacts on buildings, and therefore business buildings are discussed in more detail in Section 4.5.5.

123 This is based on an assessment of the data sets prepared for the flood risk assessment in the Floods Sector report. See also Appendix C1 and Section 4.5.5.
by the 2080s, although the risk could be significantly greater (possibly 2-3 times greater by the 2080s).

Flooding has the potential to disrupt UK businesses' supply chains by causing distribution delays. Flooding is also a factor in the market demand for goods. If extreme flood events affect key suppliers, and no alternate supply is available, then supply chains are severely interrupted. Each of these risks is likely to 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.

### The National Flood Risk Assessment

The National Flood Risk Assessment (nFRA) is currently being carried out by SEPA. It requires a consideration of all sources of flooding for a range of return periods. The nFRA concentrates on flooding from rivers, the coast and heavy rainfall with a further consideration of the influence of groundwater. Separate assessments have been carried out for each source of flooding in order to identify where areas are impacted by multiple flood sources. As the 1 in 200 year return period (see Appendix C) has been utilised for the fluvial, coastal and pluvial extents, the annual exceedance probability factor of 0.5 was applied (SEPA, 2011c).

The planned mapping will cover (SEPA, 2011c):

<table>
<thead>
<tr>
<th>Human health:</th>
<th>- Flood risk in terms of human health has been assessed as</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(i) people and the social vulnerability of the area using a Social Flood Vulnerability Index (SFVI), (Tapsell et al., 2002)</td>
</tr>
<tr>
<td></td>
<td>(ii) community (important facilities that could cause community disruption if affected e.g. schools)</td>
</tr>
<tr>
<td>Economic activity</td>
<td>- Community, based on the number of schools and hospitals</td>
</tr>
<tr>
<td></td>
<td>- Transport (roads, railways and airports)</td>
</tr>
<tr>
<td></td>
<td>- Businesses (number of business properties and the estimated weighted annual average damage of property, WAAD)</td>
</tr>
<tr>
<td></td>
<td>- Agricultural (agricultural land and forestry areas)</td>
</tr>
<tr>
<td>Environment</td>
<td>- Areas designated for natural heritage purposes and their vulnerability to flooding</td>
</tr>
<tr>
<td>Cultural heritage</td>
<td>- World Heritage Sites</td>
</tr>
<tr>
<td></td>
<td>- Listed buildings</td>
</tr>
<tr>
<td></td>
<td>- Scheduled monuments</td>
</tr>
</tbody>
</table>

Climate change projections are also being produced, however, this work was not complete at the time of writing this report.

As the probability of flooding increases, insurance for properties that flood relatively frequently may be increasingly difficult to obtain, particularly bearing in mind the
Statement of Principles on the Provision of Flood Insurance (SPPFI) which is due to expire in 2013\textsuperscript{124}. The Association of British Insurers has identified a preferred threshold for property insurance of a 1 in 75 annual probability of flooding, and under the SPPFI will continue to make flood insurance available until at least 1\textsuperscript{st} July 2013 for properties built before 2009 and protected to this level.

Whilst properties that flood more frequently are still typically able to obtain insurance, this situation may change as the insurance industry adjusts available policy cover to control payouts under increasing climate-related impacts. Insurance contracts are normally only valid for 12 months, and if insurance companies declined to renew cover at the end of this period, it would leave both lender and borrower exposed to an increased risk of loss, particularly if the SPPFI is not extended or a similar agreement put in place after 1\textsuperscript{st} July 2013.

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. Properties that could not get insurance would be significantly devalued, once again exposing a mortgage lender to significant equity risk. Although the mortgage fund at risk due to insurance becoming unaffordable or unavailable was not assessed for Scotland as part of the CCRA, projections for England and Wales indicate that this may be of the order of £100 million to £800 million by the 2050s, and £200 million to £900 million by the 2080s for Scotland, assuming that this does not spur cost-effective adaption activity. This could have significant knock on effects to individuals, leading to financial difficulties, as well as potential business failure. Subsequent effects could also include mental health issues. The socially vulnerable are particularly at risk as they are more likely to live in flood prone areas, and are also less likely to be insured (these issues are discussed in Section 4.6). A future uneven distribution of wealth would further exacerbate this issue, as fewer people would be able to implement risk management measures, which not only includes suitable insurance, but also possibly flood proofing of properties.

\textit{Climate change impacts on infrastructure}

Business relies on a range of infrastructure and associated services including water supplies, waste disposal, energy supplies, supply chain and Information and Communications Technology (ICT). Disruption to any of these services has a direct impact on business.

Water availability for all uses is projected to reduce during warmer drier summers in the future. For example, the number of river sites with sustainable abstraction in the UK is projected to reduce by the order of 45% by the 2020s and 70% by the 2080s.

However, 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 in Scotland. 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 (including power stations). Not only would this require greater water abstraction, but waste water could cause additional environmental impacts on biodiversity. Water abstraction could also be a problem with lower projected flows in

\textsuperscript{124} Since 2000, the Association of British Insurance and the UK Government have had an agreement in place known as the Statement of Principles on the Provision of Flood Insurance. The Statement of Principles commits insurers to make flood insurance as widely available as possible until 1\textsuperscript{st} July 2013, in return for UK and Scottish Government committing to ensure that flood risk is appropriately managed and that long-term flood risk management commitments are made during this period. This statement has been revised over time, with the last agreed version with Scottish Government made in December 2008 (ABI/SG, 2008).
the summer (see Section 3.1.1) when demand is at its greatest. There are also concerns regarding the disposal of solid and liquid wastes due to lower river flows, and the potential effects of infrastructure disruptions including gas and electricity outages.

It is estimated that about 80% of businesses are 'heavily dependent' on ICT, and therefore any disruption would have immediate effects. The risk of major ICT disruption due to climate change is considered to be relatively low for large businesses. However, smaller companies (including SMEs) and remote workers are more vulnerable to ICT disruption and the risks are greater. This is because they are often dependent on a single link which, if it fails, causes a complete loss of service. Failure of ICT links or failure of transport links affecting key workers could be a potential serious issue for business. However, opportunities could also present themselves. Cooler temperatures relative to the rest of the UK for example could lead to data centres relocating to Scotland.\textsuperscript{125}

Possibly the greatest risks to ICT are the currently unknown potential future impacts of climate change. For example, increased flooding risk or intense storms could cause unforeseen damage to ICT infrastructure and equipment.

<table>
<thead>
<tr>
<th>Case Study: Key workers unable to get to work due to extreme events or infrastructure failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A range of different weather events can cause disruption in Scotland, and there have been a number of extreme weather events that have caused significant disruption over the last 20 years. These include:</td>
</tr>
<tr>
<td>• Two large flood events on the River Tay in 1990 and 1993, both of which flooded many rural and urban areas, and dislocated many transport links. Although the flood of 1990 was believed to be the largest flood event on this river since 1951, the 1993 event was significantly larger, and is believed to be the largest event on this river since 1814.</td>
</tr>
<tr>
<td>• On 30\textsuperscript{th} December 1995, extreme cold temperatures were recorded in Scotland, with an equal record low of -27.2°C recorded at Altnaharra in Northern Scotland. This caused significant disruption throughout Scotland, with many vehicles stranded for several days as fuels froze and transport links became impassable. Extreme cold weather has also been recorded in Scotland for the last two winters (see Section 2.2).</td>
</tr>
<tr>
<td>• Severe snowfall in Scotland in December 2010 caused significant disruption to transport and services throughout Scotland. This included closure of a 20 mile section of Scotland’s busiest road the M8 for 2 days as well as a number of other major transport routes throughout Scotland.</td>
</tr>
<tr>
<td>• Gale force winds sweeping in from the Atlantic in two separate events in early December 2011\textsuperscript{126} and early January 2012\textsuperscript{127} caused widespread disruption in Scotland with tens of thousands of people left without electricity across the country. For the event of early December 2011, hundreds of schools were closed on the advice of Scottish Government\textsuperscript{126}.</td>
</tr>
</tbody>
</table>

Apart from the disruption that these events cause, the financial implications of these

\textsuperscript{125} This is already happening with one of the largest data centres in the world due to be built near Lockerbie, with one of the stated reasons being as a result of Scotland’s cooler climate (www.sdi.co.uk/resources/case-studies/ict-and-electronic-technologies/lockerbie-data-centre.aspx). \textsuperscript{126} http://www.bbc.co.uk/news/uk-scotland-16079849. \textsuperscript{127} http://www.bbc.co.uk/news/uk-16409203
events can also be severe. The December snowfalls of 2010 for example was suggested by one study to have cost the Scottish economy up to £2 billion in damage, as well as reduced Christmas spending, and lost days at work. Key workers also struggled to get to work, with many NHS staff for example facing long walks to work or having to sleep on the wards either because they couldn’t get home, or to ensure they could continue to work.

To assess the impact of severe weather on work practices, Alan Speedie Associates (2011) investigated severe weather effects on Scottish Natural Heritage (SNH) workers over the period 2005 to 2010. This indicated that over the period 2005 to 2010, SNH lost in the region of £450,000 as a result of severe weather (approximately 0.5-1% of its budget), and that staff attendance and IT services were badly affected. Alan Speedie Associates (2011) also indicated that an over reliance on IT equipment had a significant effect on the business and that there was a need for planning, training and upgrading of IT equipment to improve resilience.

The challenges facing key workers as a result of climate change are likely to change. Increased levels of flooding would result in greater levels of transport disruption, and on a more regular basis. However, projected lower levels of snowfall (see Section 3.1.3) and increased winter temperatures (Section 2.3.1) would be likely to reduce transport disruption. Overall the effects are uncertain, however, extreme weather events such as those experienced over the 2009/10 and 2010/11 winter periods would be more likely to catch key workers unaware, as they would be less likely to be used to these types of events.

However, learning lessons from the work carried out by SNH, monitoring of severe weather events with provisions to inform staff, combined with weather proofing of buildings and staff training would be vital in reducing levels of disruption to key

128 http://news.scotsman.com/scotland/2000000000-price-of-Scotland39s-ice.6663501.jp
130 http://www.life.com/image/97099405
workers. This is particularly the case for Scotland’s remote locations where there is a
need to be self sufficient during extreme weather.

For the emergency services, most extreme weather related events would likely
impact the very workers who are charged with tackling that event. This would further
increase the pressures on the emergency services at a time when they least need it.
This could include:

- Increases in floods and to a lesser extent extreme high temperatures
could increase strains on NHS resources. Key workers unable, or late
getting to work could put a severe strain on NHS resources at a time
when hospital admissions would likely be increased.

- The Fire and Rescue Service (FRS) in Scotland may have to deal with
increased floods and other water related incidents, which currently run at
almost 200 per annum in Scotland (Tomkins, 2009). A likely increase in
wildfire occurrences would further increase pressures on the FRS’s.

- All extreme weather events would require the police to provide public
safety, and to ensure that operations to control the event are carried out
as smoothly and quickly as possible

Audit Scotland (2009) identifies areas of progress needed in contingency planning,
highlighting that improvements in communication to the public are required. Recent
adverts for SEPA’s Floodline have increased public awareness on flood alerts. Such
schemes are likely to improve public resilience and readiness, and this is likely to
reduce the scale of impacts with a consequence reduction in periods of time spent off
work.

**Climate change impacts on Tourism**

Scotland is a well developed tourist destination, with the industry sustaining in the
region of 200,000 jobs with approximately £4bn spent each year by tourists.

The main attractions for tourism in Scotland are the scenery\(^{131}\), as well as the great
number of historic sites\(^{132}\) and major urban centres such as Edinburgh as well as more
recreational activities such as golf, fishing and the food and drink industry (see case
study on Whisky below). The protected landscapes of the Cairngorms and Loch
Lomond and the Trossachs National Parks, National Scenic Areas and National Nature
Reserves provide further illustration of the value of Scotland’s landscape for tourism
and recreation. Coastal areas also offer an important tourism and recreation resource,
(wild or remote areas also offer an important recreation resource) with a large number
of high quality beaches on both the west and east coasts and on many of the islands,
several close to concentrations of population. These are under threat from sea level
rise, with the risk of beach loss from CCRA projections given as 45 to 225 hectares by
the 2020s, rising to 193 to 964 hectares by the 2080s (approximately 3% to 12% of the
total beach area of Scotland\(^{133}\)). At a more local scale the network of regional parks,
country parks, Local Nature Reserves and urban greenspace provide important
everyday recreation resources for local communities.

Based on modelling studies, future climate change would be expected to make
countries at higher latitudes and altitudes more attractive as a tourist destination, and
would require careful planning and adaptation. Consequently, future climate change

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\(^{131}\) A third of the £4bn spent each year by tourists is based on outdoor recreation.
\(^{132}\) Tourism expenditure in Scotland attributed to the historic environment is estimated to generate £1.3
billion in GVA (ECOTEC, 2008)
\(^{133}\) This is based on certain assumptions on beach slope, width and the proportion of beaches affected
which is outlined in the Business, Industry and Services Sector report.
represents an opportunity for that part of the UK tourism industry whose operations and assets are largely based in the UK. Experiments with climate change projections suggest that the Mediterranean will become too hot in summer, with northern Europe having a more attractive climate (Amelung and Viner, 2006).

Modelling studies predict that the impact for the UK would be to reduce outbound tourism (i.e. an increase in domestic holidays in the UK) and reduce inbound tourism slightly (the balance being broadly positive for the tourism industry as a whole) (Hamilton et al., 2005). The same study, also suggests that later in the century the relative increase declines, as the UK becomes too hot (Hamilton and Tol, 2007).

In addition to the change in the number of domestic tourists in the UK, there may be a shift in the regional distribution of tourists (from both the UK and internationally) under future climate change projections (Hamilton and Tol, 2007). By the 2080s Scotland may have an increased market share (Hamilton and Tol, 2007). For the High emissions scenario, for the majority of regions the change is not greater than 0.5%; however, the exceptions are the regions of Highlands and Islands and eastern Scotland (amongst others) with market share increases of 0.54 and 0.66%, respectively (Hamilton and Tol, 2007).

With so many tourist attractions on the coast, one of the most serious threats to tourism in Scotland is coastal erosion. Based on a series of reports, the organisation Scottish Coastal Archaeology and the Problem of Erosion (SCAPE) indicate that more than 10,000 ancient and historical sites around the Scottish coastline are at risk of erosion. These include the Neolithic settlement of Skara Brae on Orkney and the prehistoric ruins on Shetland. Other climate effects could affect the landscape and certain species with a potential reduction in tourism value (see Section 4.2.1).

With many of the historic golf courses of Scotland on the coast (known as links courses), there is a severe and well publicised effect of the increasing threat of sea-level rise and coastal erosion on a number of famous courses. The best known is probably Royal Montrose, the fifth oldest course in the world, where over recent years several of the tees have become unplayable, or are at an increasing threat. Of the five courses currently on the Open Championship rota, the world’s most famous golf championship, all are links courses, and at least three have taken recent measures to protect their courses against coastal erosion. This includes the “home of golf” St Andrews.

![Coastal erosion at Royal Montrose Golf Club](image1) ![No snow at The Lecht ski resort, Cairngorms](image2)

Figure 4.25 Tourist industry under threat in Scotland?

Source: SNH (coastal erosion)\(^{134}\); www.myslopes.com (Lecht)\(^{136}\)

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\(^{135}\) http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/2.shtml

Scotland also supports a number of freshwater fisheries such as Game angling for Atlantic salmon. Course fishing, although traditionally less important in Scotland than other parts of the UK is becoming increasing popular. Combined, they contribute over £100 million to the Scottish economy each year. An increase in temperatures could affect the climate space or growth or survival of some species. The salmon sector for example has already suffered the effects of climate change (in the migratory feeding grounds, see Section 4.2.2) and this has led to a decline in catch numbers from their peak in the late 1960s. Rivers that currently support brown trout in Northern Scotland may also not be able to sustain a suitable habitat by the end of the current century. Additionally, the stability of salmon spawning beds could also be affected as a result of an increase in winter flow rates (as noted for salmon in Section 4.2.4) and flash floods. However, Scottish rivers will also develop physiologically acceptable temperature regimes for a greater number of coarse fish species (see Section 4.2.2).

Increased coastal flooding and coastal erosion is therefore likely to cause losses to the tourist industry although the magnitude of losses would depend on how the tourist industry changes in the future. There are also opportunities for increased tourism as a result of warmer and drier summers and a longer summer tourist season. This could have a number of effects, including further development of formal and informal recreation infrastructure, particularly in the more accessible parts of Scotland, and in areas around the principal settlements. Increased levels of summer tourism and recreation and the development of new facilities could provide new opportunities for people to experience the landscape and engage in active outdoor recreation, and the potential opening up of new markets based on changing holiday trends. This could have implications for wildland qualities which are important in many remoter parts of Scotland.

However, one area of tourism that will almost certainly decline as a result of rising temperatures is the Scottish ski industry. Although some resorts have diversified in recent years to provide alternative sources of income (such as mountain sports137), a reduction of snow in the region of 65-80% by the end of the current century indicates that the ski industry in Scotland will be difficult to maintain (see Harrison et al., 2001).

137 http://news.scotsman.com/climatechange/Theres-no-snow-on-ski.3277507.jp
Case Study: The Scotch Whisky Industry

**Location**
There are over 100 working malt distilleries and 7 grain distilleries in Scotland. They are owned by a range of companies, from large international plcs to family companies owning a single malt distillery (Scottish Parliament, 2009). The greatest concentration of these distilleries is in the Speyside area of Northeast Scotland, with the next largest being on Islay. Strathclyde accounts for over half of all Scotch Whisky employment in Scotland with Central Scotland and Fife, Grampian and Lothian also having significant shares of employment (Verso Economics, 2010).

**Size of industry**
Scotch Whisky is among the most productive industries in Scotland, second only to oil and gas. Scotch Whisky contributes £2.7 billion in Gross Value Added (GVA) to Scotland’s economy. Overseas exports were over £3 billion in 2008, which is more than four times the value of either business service exports (£0.7 billion) or financial services (£0.6 billion).

The industry employs over 10,000 workers with a total gross income of £464 million. Just over one in five Scotch Whisky jobs are in rural communities. The wider economic footprint supports around 35,000 jobs and nearly £3.9 billion GVA (direct, indirect and induced impact). Scotch Whisky’s impact on the economy is similar in scale to tourism (Verso Economics, 2010). Four-fifths of operating costs are sourced from within Scotland, helping to create £1.1 billion of demand for Scottish suppliers. This proportion is nearly double the average for manufacturing and markedly ahead of the rest of the Scottish economy.

Some 50 distilleries have visitor centres and/or guided tours and host over 1.2 million visitors per year. Each of the distilleries host buyer, supplier and trade/corporate customers throughout the year and, in doing so, use local facilities and services.

Figure 4.26 Distillery stills for Glenfiddich
Source: Colin Smith

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138 http://www.geograph.org.uk/photo/97211. This figure is the copyright of the owner but has been reproduced in accordance with the copyright as detailed by the Creative Commons licence: http://creativecommons.org/licenses/by/3.0/legalcode.
Impacts of Climate Change

Long-term planning and risk assessment is characteristic of the Scotch Whisky industry, reflecting the significant maturation requirements.

The Scotch Whisky industry is a sector taking climate change seriously with the industry commissioning early private research to help individual companies assess the potential impact of change. An industry-wide environmental sustainability strategy was launched in 2009 and climate change adaptation initiatives continue to demonstrate a proactive industry response.

The private research undertaken on behalf of the Scotch Whisky Association (Losenno et al., 2009) confirmed, that, as expected, the key climate change risks for the Scotch Whisky industry relate to cereals, water resources and production processes. These include:

**Water**
- Process water: slowed or stopped production due to low flows for abstraction and poor water quality.
- Cooling water: slowed or stopped production due to low flows and high water temperature making cooling processes less efficient.
- Effluent water: unable to discharge effluent due to low flows and high temperatures in receiving waters.

**Other processes**
- Maturation: increased evaporation loss due to higher temperatures within and around casks affecting spirit quality.
- Maturation: increased likelihood of damage to casks in storage from extreme events such as flooding.
- Distribution: product quality and lost stock due to damage during storage or transit.

**Impacts on cereals**
The supply of all cereals, including barley, could be significantly impacted by future changes in precipitation, flooding, drought and plant diseases. Current estimates indicate that overall there is likely to be a small reduction in barley production by the 2050s, although a probable increase by the 2080s (see Section 4.3.1). In combination with other factors, the future climate is likely to result in farmers changing crops and farming practices.

As well as spending over £200m per year on Scottish cereals (most of which is barley), distillers supply the agricultural industry with various forms of animal feed derived from distillation co-products and supply pot-ale (a distillery co-product) for beneficial use on agricultural land.

**Impacts on water resources and associated processes**
In 2008, the Scotch Whisky industry used over 61 million m$^3$ of water. Across the industry as a whole, 75% of this was used for cooling and returned to the environment. In malt distilling this figure rises to 85%. The industry’s net water use in 2008 was 15.5 million m$^3$, of which 89% is in distilling. The majority (79% in 2008) of water is sourced from private sources, with the remaining 21% coming from the public water supply (Scotch Whisky Association, 2010).

In June 2008, some areas of Scotland, including Islay experienced drought conditions and the ten distilleries on Islay experienced low-flows. To minimise the impact on the...
local waterbodies, the distilleries brought forward their planned summer shutdowns and in some cases extended the normal silent season. The response to this event has been to build additional water storage and identify alternative water sources.

Climate change is likely to impact on both the quality and the quantity of water resources and like all process industries, changes to water supplies might impact on production:

- Droughts, especially in the east, could result in low flows in watercourses, impairing water quality (especially in combination with higher water temperatures). As a result, abstraction for process and cooling water and discharge of effluent might occasionally become prohibited as the dilution factors within the received waters will be reduced.
- Higher water temperatures (due to low flows and higher air temperatures) could result in process cooling becoming less efficient.
- The timing of heavy rainfall and any changes in spring snow-melt could affect the quality and quantity of burn and reservoir water.
- Increased flooding could lead to damage to crops, warehouses, distilleries, the road network and suppliers’ premises.

**Impacts on other production processes**

The traditional processes of malting, distilling and maturing whisky are temperature sensitive and, therefore, could be impacted by climate change.

Some effects of climate change would translate directly into lower or higher energy costs for heating and cooling respectively.

Changes to evaporation rates during maturation could potentially affect the spirit quality. Casks are especially vulnerable due to the long duration of the maturation process (by law, to be called ‘Scotch Whisky’ spirit has to be matured for a minimum of 3 years). Over 19 million casks lay in Scotch Whisky warehouses in 2008 (Scotch Whisky Association, 2010).

Other less obvious impacts on the sustainability of Scotch Whisky include temperature and humidity affects on bottled whisky and packaging during storage and distribution.

**Customer demands (opportunities)**

A changing climate is likely to affect business operations both as a direct result of climate change, as well as policies brought in to address it. Although most sectors of business are likely to be affected, certain sectors such as energy, insurance and agriculture for example are more likely to be affected than others. As a direct result of a changing climate, new companies will thrive, although a number of older businesses will struggle. In addition, a number of business opportunities will present themselves as a result of adaptation to climate change, as well as a result of legislation to combat climate change; for example, greater investments in existing or new or emerging technologies.

Some of the main business opportunities could involve the following:

- The Scottish Government has an aim to generate 100% of Scotland’s equivalent electricity demand from renewable sources by 2020 (Section 4.5.3). This will present a significant opportunity for a number of businesses that supply plants and equipment in the energy sector.
- Although the insurance industry is likely to be at greater risk due to more regular and larger insurance claims, greater risk may lead to greater levels
of insurance taken out at greater profit margins as well as new insurance markets opening up.

- New products or modifications to existing products will emerge to respond to a changing market. Weather events that become more extreme will provide new opportunities for repair and maintenance etc.

- Although climate change will adversely affect certain companies inadequately prepared for climate change, this will present opportunities for better prepared companies.

- Climate change impacts on agriculture in other countries could result in market opportunities for Scottish food production.

- A longer growing season and a greater range of crops grown in a warmer climate will provide opportunities for agriculture.

- Tourism and leisure will change, opening up new markets (as discussed above).

- Climate change could result in UK business operations changing with opportunities presented for Scotland. For example, as noted earlier in this section, cooler temperatures could result in data centres moving to Scotland.

- Projected warmer temperatures will provide opportunities for those in built environment industries for new and innovative climate designed building issues.

- Rapid changes will bring opportunities for companies with a strong emphasis on innovation and Research and Development.

- Demand is likely to increase for certain products under a changing climate such as water management products and clothing for changed weather conditions.

- Projections of future ice cover suggest that the Northern (Arctic) sea routes may become open in the near future and remain open for longer periods during the Arctic summer, with a particular benefit linked to shorter journeys for the most northern UK ports. This is discussed in more detail in Section 4.5.1.

**Climate change impacts on financial services**

Financial services represent an important part of the Scottish economy, contributing about 8% of GDP. Edinburgh is a thriving financial centre, the 11th largest in Europe with influential financial players such as the Royal Bank of Scotland and the Bank of Scotland (now part of Lloyds Banking Group) having a presence in the city. Overall, Scotland’s financial services industry employs about 95,000 people directly (about half in the banking industry) and a further 70,000 people indirectly, generating around £7 billion annually for the Scottish economy. Climate change could have a major impact on investment performance with severe potential consequences for the financial sector. This would be exacerbated if management processes are inadequate to manage the risk or climate change risks are underestimated.

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139 http://www.scotland.gov.uk/Publications/2010/07/GDP2010Q1
140 http://www.sdi.co.uk/sectors/financial-services.aspx
Whilst it has not been possible in the CCRA to estimate the magnitude of these impacts, it is clear that they could be very important with knock-on effects across business and society.

Climate change may also generate opportunities for the financial services. The discussion above highlights potential opportunities within Scotland.

**Climate change impacts on transport**

Transport infrastructure impacts directly on Scottish businesses. A recent Scottish Enterprise report (undated) found the most common impacts on businesses due to transport disruption are a loss of man hours, a loss of business and increased operating costs. Problems with the trunk road network and local roads also appear to be contributing to delays in the delivery of goods, while problems with local public transport and the rail network are identified as a key cause of staff lateness. Poor local roads often result in increased operating costs for the more remote businesses.

Lifeline ferry services are vital to island communities and communities and disruption can cause significant losses to small independent businesses, unable to absorb the cost. The Western Isles of Scotland are remote, sparsely populated and are highly dependent on maritime transport. The economic cost of adverse wave climate in the region is currently of the order of £10 million per annum. These costs are very small compared to the cost of ‘climate change’ globally. However, we can identify the current case as an example of an exceptionally high per capita cost to a particular community (Marine and Fisheries Sector Report). Disruption to these ferry services are detailed further in Section 4.5.1.

An increase in flooding may result in greater disruption to businesses. For the coastal and island communities sea level rise may increase the scale of the impact and result in further disruption. However, warmer winter temperatures may cause a reduction in levels of cold weather disruption, such as witnessed over the last two winter periods (2009/10 and 2010/11). Costs due to cold disruption may therefore be reduced in the future.

Longer and unpredictable journey times, for cars, freight and public transport users have significant economic impacts both from higher direct costs of transport and the cost to businesses of a loss of competitiveness. This may be of most significance to those businesses that rely on the quality of the final product. Delays and disruption to transport may negatively affect farmers sending produce to market or food establishments selling fresh produce. For the remote businesses, an understanding of how future climate may impact on transport links is vital for them to prepare for the changes. Flooding and landslides may increase causing more frequent disruption to the transport and business sector, as discussed in Section 4.5.1.

The disruption in travel also directly relates to workers unable to get to work (as discussed above), with potential impacts on business productivity if there is significant disruption.

**Climate change impacts on the Emergency Services**

When extreme events occur requiring a response from a number of responder agencies, such as the Police, Fire and Rescue service (FRS), Ambulance service, local authorities and health boards; these agencies are required by Scottish Legislation (Civil Contingencies Act 2004, and the Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005) to work together to ensure the response is co-ordinated effectively.

The FRS has a responsibility to respond to serious flooding, wildfires, road traffic accidents and search and rescue incidents, and therefore may be called to act in any
weather event. The police act as a co-ordinator of people and resources, communicate between emergency services and organisations, overseeing investigations and facilitating the work. Unlike the FRS, the police are at the front line less often however, a significant number of officers are required to assist in road closures, traffic directing and informing the public during extreme weather events (Scottish Government, 2011c). The police would also be expected to be deal with increase in civil disorder, as demonstrated for example by arguments and tensions within communities over the scarcity of drinking waters following the Summer 2007 floods across much of the UK (Pitt, 2008).

The rainfall that fell across Scotland on 1st November 2009 (see case study below) clearly indicated the range of incidents attended by the emergency services, with flooding, landslides and traffic accidents occurring as a result of the same rainfall event. With flooding for example likely to increase in frequency and severity in the winter, it is likely that adjacent areas to current floodplains will become flood prone, increasing the number of people at risk. The increase in extreme rainfall may act to increase landslides and road traffic accidents, increasing overall pressures on the emergency services, as well as for other weather induced events noted below. Pressures on the emergency services, and in particular the police, are also likely to be further stretched as warmer summers could potentially result in more, and greater attendance at outdoor events. With summer tourism also likely to increase (discussed earlier), with more people using lochs and rivers for recreation there is also an increased risk of water based accidents (Adaptation Scotland, 2011b), requiring aid from the emergency services.

**Climate change impacts on the Emergency Services - Floods**

Emergency services are called on to respond to floods. The response may be very varied due to the nature and extent of the flood and the wide range of problems that can arise as well as the number of different agencies that may be involved in any particular incident. During and after the event a range of emergency services may be involved in providing assistance. The problems of responding to events differ with the type of flood event and the potential to forecast the event. For floods on major rivers it may be possible to provide two or three days warning of severe flooding. However, flash floods which result from small intense rainfall or rapid thaw and are difficult to predict can lead to severe flooding within a few hours of the start of the rainfall. Thus in these cases there may be little or no advance warning.

Although the location of future floods cannot be determined a long way in advance, areas at risk of future flooding can be identified (see Figure 4.27 below). Such an analysis can identify the magnitude of the risk, the nature of the flooding and the likely impacts. The assessment currently being carried out by SEPA (see Appendix C1) will indicate areas where the risks are at there greatest, and where the concentrations are likely to be.
Currently there appears to be no readily accessible statistics on the effort put in by emergency services in responding to flood events. Though minor flood events occur relatively frequently, major flood events occur infrequently. This means that there must be a significant variation in the required response from year to year and also from location to location. However based on the assumption that the effort required by emergency services is proportional to the number of people at risk, and that the change in risk for Scotland is similar to England and Wales, this effort could be anticipated to approximately double by the 2050s, and approximately triple by the 2080s. Similar increases in the value of damage caused to property would also be expected.

However, these figures could be exacerbated by the loss of important infrastructure, or the flooding of emergency service premises themselves (e.g. hospitals) during a flood, which will impact on the ability of the emergency services to respond to the main event. For example, loss of power may affect communications and the ability to carry out specific rescue work. In addition, the loss of the infrastructure may significantly affect the plight of those already impacted by the flood event and may also affect those who have not themselves been flooded. For example, loss of power may cause a significant deterioration in conditions for those flooded and those who have been evacuated. It may also cause region-wide problems. This will mean that the impact on those who have been flooded will be made more severe and there may be wider impacts.

**Climate change impacts on the Emergency Services - Heatwaves**

Although indications from the Health Sector Report suggest that pressures on the ambulance service will increase in proportion to the number of emergency hospital admissions, published statistics corresponding to hot years (e.g. 2003) indicate that the increased occurrence of heatwaves may not significantly increase the pressure on the ambulance service. In addition, projected mean rises in winter temperatures is likely to result in a reduced demand for the emergency services in the winter months.

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141 http://go.mappoint.net/sepa/
Overall, the pressures on emergency services are likely to reduce mainly as a result of milder winters, and therefore less cold related emergencies.

*Climate change impacts on the Emergency Services - Wildfires*

The occurrence of wildfires varies through the year with a minimum in the winter and two peaks, one in the spring and a second in the autumn. These are times when the weather is warmer and when fuel is available, either dead vegetation from winter or plants dried by summer heat. Statistics also indicate that fires occur more often on Saturdays, Sundays and Mondays compared with the rest of the days of the week, which would suggest that visitor numbers may be a factor in the frequency of wildfires (Albertson et al., 2010).

The number of wildfires varies between years. An analysis of secondary fires (Palutikof et al., 1997 and Fire Research Technical Report, 2006) for the period 1973 to 2003 shows an overall increasing trend in the numbers of fires per year but with significantly larger numbers of fires in those years with warm summers, such as 1989, 1990 and 1995. It is argued in Palutikof et al. (1997) that this increase in the number of secondary fires in these years can be attributed to an increase in the number of outdoor fires, such as grassland fires.

Analysis carried out by Albertson et al. (2010) and Palutikof et al. (1997) imply that the incidence of wildfires will increase significantly in the future and for a few months of the year these may provide a significant workload for the Fire and Rescue Service. These wildfires can often occur simultaneously and over a wide area stretching the emergency services resources as was demonstrated for example in early May 2011, when 29 wildfires were reported across Scotland.

On a UK wide basis these increases are projected to be of the order of 150% by the 2080s, which would represent an increase of approximately 20% in the number of incidents attended by the Fire and Rescue Service. As wildfires occur mainly during a few months of the year, the percentage increase in the number of incidents during those months will be substantially greater. It is likely that the main period for wildfires will be in the autumn and that the wildfire season may extend to later in the year.

**Case Study : The Emergency Response to Rainfall and Flooding on 1st November 2009**

On 1st November 2009 torrential rain fell across large parts of Scotland, causing significant flooding and closure of many roads and rail regions across the country.

In the town of Stonehaven Aberdeenshire, a flood event estimated as having a return period of 1 in 200 years resulted in a large rescue operation by the emergency services. One hundred properties had to be evacuated, and another fifty homes across Aberdeenshire experienced flooding (Aberdeenshire Council, 2010). In total, Grampian FRS received over 330 calls within 12 hours due to this rainfall event.

Many roads across Grampian and Tayside were closed by the police due to floodwaters, and the police received reports of motorists trapped within their vehicles (Adaptation Scotland, 2011a). Car accidents, due to the bad weather required police and ambulance services to attend. The police also had responsibility of organising and starting evacuation procedures, as well as keeping the council updated. A council

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143 [http://www.guardian.co.uk/world/2011/may/03/wildfires-highlands-ireland-england%20](http://www.guardian.co.uk/world/2011/may/03/wildfires-highlands-ireland-england%20)

spokesman admitted that throughout the event resources were “stretched to the limit”\textsuperscript{145}.

In Angus the emergency services were under similar strain, with fire crews rescuing trapped motorists, pumping burst culverts and property, and the police responding to flood incidents, car accidents and closure of roads (Adaptation Scotland, 2011a). Furthermore, landslides occurred in Arbroath and Brechin.

**International aid**

The UK and Scottish Governments are committed to providing aid to promote sustainable development and to eliminate world poverty. UK government, led by the Department of International Development, is committed to a long-standing promise to deliver development aid equal to 0.7\% of its Gross National Income (GNI) from 2013, which in 2010 was estimated to be £8,354m, 0.56\% of GNI\textsuperscript{146}. The Scottish Government delivers aid via its International Development Fund which for 2011/12 has been set at £9 million\textsuperscript{147}. In addition to development aid, additional ad-hoc humanitarian aid is also given for both natural and climate related disasters, as well as man-made disasters. This includes for example the severe drought in East Africa, the most severe climate related disaster this year, for which the UK Government has pledged £52.25 million\textsuperscript{148}. UK Governments also have a duty to help their citizens and their interests where disasters occur, as for example in Japan following the 2011 earthquake. In addition to Governmental aid, a number of charitable organisations raise aid from the British people for disasters abroad. The most significant of these is the Disasters Emergency Committee (DEC), which unites the 14 leading UK aid agencies. In the last 5 years, the DEC has raised in the region of £400 million for various disasters around the world\textsuperscript{149}.

With a changing climate, the number and level of climate-induced disasters is likely to change. The number of people affected by these extreme events has doubled in the last 30 years, and projections indicate that these are likely to increase by a further 50\% over the period 2009-1015, affecting in the region of 375 million people. This is expected to almost double worldwide aid (from its 2008 level) to approximately £17 billion (Taylor and Schuemer-Cross, 2009).

Based on the work carried out by Oxfam in assessing climate-related disasters over the last 30 years, it is likely that the number and level of these will increase over the coming century, putting a greater strain on both Government resources, and charitable requirements. However, despite the requirements suggested by Taylor and Schuemer-Cross (2009). It is difficult to assess how these would change for the UK and Scotland in particular. The economic and political situation in other, richer western countries may well dictate the level of international aid from the UK in the future. Increased levels of aid from those countries with significantly greater GNI than the UK, but who currently contribute a much smaller percentage of their GNI, would probably noticeably change the levels of commitment pledged by the UK; although the levels of aid pledged is still likely to significantly increase.

\textsuperscript{145} http://news.bbc.co.uk/1/hi/8337149.stm
\textsuperscript{147} http://www.scotland.gov.uk/Publications/2010/11/17091127/7
\textsuperscript{148} http://www.dfid.gov.uk/Media-Room/Press-releases/2011/Mitchell-to-announce-help-for-1-million-drought/
\textsuperscript{149} http://www.dec.org.uk/sites/default/files/files/Annual\%20Reports/DEC_AR_2010\%E2\%80\%9311\_v6.pdf
Decommissioning liabilities and end of life costs

Decommissioning of large fixed assets is a complex and expensive procedure. Due to the long-lifespan of such assets, it is unlikely that climate change impacts have been considered in decommissioning obligations, with the danger that costs have been underestimated. Given the number of assets across industrial sectors that will be decommissioned over coming decades, the economic consequences could be significant. Furthermore, poorly scoped decommissioning could have environmental consequences. However, due to a lack of currently available data, it has not been possible to assess this risk.

Summary of results

The results of the analysis are shown in Table 4.10.
Table 4.10 Climate change impacts on Business and Services

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>An expansion of tourist destinations in Scotland</td>
<td>Flooding of non-residential property</td>
</tr>
<tr>
<td>Key workers unable to get to work due to extreme events or infrastructure failure (snow and ice)</td>
<td></td>
</tr>
<tr>
<td>Customer demands (opportunities)</td>
<td>Insurance industry exposure to UK flood risks</td>
</tr>
<tr>
<td>Ability to obtain flood insurance for residential properties</td>
<td>Ability to obtain flood insurance for residential properties</td>
</tr>
<tr>
<td>Emergency response to events (floods)</td>
<td>Emergency response to events (floods)</td>
</tr>
<tr>
<td>Mortgage provision threatened due to increased flood risk</td>
<td>Loss of natural tourism assets</td>
</tr>
<tr>
<td>Monetary losses due to tourist assets at risk from flooding</td>
<td>Cultural heritage at flood/erosion risk</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for industry</td>
<td>Risks of business disruption due to flooding</td>
</tr>
<tr>
<td>Emergency response to events (floods)</td>
<td>Energy demand for cooling</td>
</tr>
<tr>
<td>Loss of natural tourism assets</td>
<td>Impacts on angling, gaming, or course fishing</td>
</tr>
<tr>
<td>Underestimation of decommissioning liabilities and end of life costs</td>
<td>Climate risks to investment funds</td>
</tr>
<tr>
<td>Key workers unable to get to work due to extreme events or infrastructure failure (flooding)</td>
<td></td>
</tr>
<tr>
<td>Cost of international emergency aid</td>
<td>Loss of productivity due to ICT disruption</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>A decrease in output for businesses due to supply chain disruption</td>
</tr>
</tbody>
</table>

**Central estimate**

<table>
<thead>
<tr>
<th>Coverage of analysis</th>
<th>Method of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Analysis undertaken for Scotland only</td>
</tr>
<tr>
<td>UK</td>
<td>Analysis undertaken for the UK</td>
</tr>
</tbody>
</table>

**High consequences (positive)**

**High confidence**

**Medium consequences (positive)**

**Medium confidence**

**Low consequences (positive)**

**Low confidence**

**Medium consequences (negative)**

**Too uncertain**

**Low consequences (negative)**

**Too uncertain**

**High consequences (negative)**

**Too uncertain**

S Analysis undertaken for Scotland only IJ Informed judgement

UK Analysis undertaken for the UK Q Quantitative
The potential for increases in future flooding is a major risk to business, with the number of non-residential properties at significant likelihood of flooding increasing by at least 40% by the 2050s and by at least 60% by the 2080s. This will affect business premises and supply chains, and disrupt operations. Some smaller companies may not have the resilience to recover. The business sector is also vulnerable to infrastructure failure and disruption.

The insurance and mortgage markets are likely to be affected by the increased occurrence of extreme events, potentially resulting in greater insurance losses and a reduction in insurance and mortgage business. The mortgage fund at risk due to insurance becoming unaffordable or unavailable may be of the order of £100 million to £800 million by the 2050s. However, opportunities for new markets will also emerge.

The effects of climate change on businesses and the natural environment could have potentially significant effects on tourism. Although many of these could be positive, linked to (for example) warmer weather, there are potentially a number of negative effects as a result of (for example) increased levels of flooding and erosion. This includes a projected reduction in beach area by the 2080s of 45 to 225 hectares, approximately 3% to 12% of the total beach area of Scotland.

There is an increased risk of erosion to a number of coastal tourist assets. This includes many of Scotland’s golf courses, as well as more than 10,000 ancient and historical sites.

A potentially large but unquantified risk is the failure of the financial sector to adequately take account of climate change, resulting in poor financial performance which could have widespread consequences for business and other sectors.

There is an increased risk to rural communities and businesses for extreme weather events, who are often reliant on limited transport options and power supplies.

Pressures on the emergency services could increase as a result of changes in floods, heatwaves and wildfires. The most significant increase in effort relates to changes in floods, with the level of effort estimated to approximately double by the 2050s, and triple by the 2080s.

Warming seas are likely to lead to shifts in the distribution of commercial fish stocks presenting both threats and opportunities to the Scottish fishing industry (discussed in Section 4.2.4.).

The increased opening of new sea routes in the summer as a result of increased melting of Arctic sea ice may provide a major boost for Scottish ports (discussed in Section 4.5.1.).

### 4.5 Infrastructure and Buildings

This section relates to the human-made surroundings that provide the setting for human activity, including cities, neighbourhoods, and buildings, together with their
supporting infrastructure. It is often considered at individual building level, although it also covers the urban environment including streets and open spaces.

The predominant climate risks to infrastructure and buildings in Scotland are energy demand, subsidence and landslips, flood damage, water availability and demand, and transport disruption. Other risks have been identified including waterlogging, disruption due to snow and ice, rainwater penetration of buildings etc, and a discussion of the most notable issues in this category is included for completeness.

Scotland’s transport network comprises approximately 56,000km of road and 2,800km of rail. There are 4 international airports (Edinburgh, Glasgow, Glasgow Prestwick and Aberdeen) which in 2009 were responsible for 94% of terminal passengers. In addition, there are a number of smaller airports, many of which service the far flung islands off the Scottish mainland. There are also over 80 ports in Scotland and a number of ferry terminals connecting the country with the continent and the inhabited Scottish Islands. All modes of transport are affected by the weather, in particular extreme weather conditions, and the variability from day-to-day. Extreme weather can cause serious disruption to the transport system. It may be possible to accommodate mitigation measures in new transport infrastructure but extreme weather is likely to remain a challenge for the maintenance and operation of existing infrastructure.

Scotland’s Energy sector, including oil and gas, coal and electricity, plays an important role in the Scottish and UK economies, contributing £18.7 billion to Scotland’s GDP and employing 41,900 people (Mackay, 2011) in 2010. Scotland’s oil and gas reserves make the energy sector vital for both Scotland’s and the UK’s power generation and supply. Scotland’s natural environment also provides excellent opportunities for renewable energy generation. Indeed new targets to meet an equivalent of 100% demand for electricity from renewable energy by 2020, as well as a target of 11% renewable heat that has recently been established (Scottish Government, 2011e).

With changes in summer rainfall and water supply-demand, Scotland’s water resource may become under greater pressure in the future. Scotland has the goal of achieving 98% of water bodies to be in ‘good’ or ‘better’ condition by 2027. This includes reducing the current 427 waterbodies affected by water supply based abstraction and impoundment pressures, to 8 (Scottish Government, 2009).

The impacts of climate change on infrastructure and buildings in this section are covered under the following headings: transport; water supply; energy supply and buildings and the urban environment. ICT is discussed under Business and Services (Section 4.4) and is not covered here.

4.5.1 Transport

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Transport; Floods and Coastal Erosion; and Marine and Fisheries Sector Reports.

Road and rail transport are generally more vulnerable to a changing climate than air and water transport. This is because road and rail infrastructure has been designed to work in the existing UK climate whereas air and water transport have international networks and aircraft and ships operate in a range of global climates. For Scotland, the obvious exception to this general rule is for the lifeline ferry services. Although these only provide in the region of 1% of public transport journeys in Scotland (Scottish

151 http://www.scotland.gov.uk/Publications/2010/12/17120002/112
152 http://www.portsofscotland.co.uk/
Government, 2010b), these are a vital transport link for many of the remote and island communities in the most peripheral communities. In combination with road and rail transport, these are the most vulnerable to climate change (see case study below). Airports and the larger sea ports are also vulnerable to climate change, but these impacts are generally small.

Case Study: Ferry Disruption on the Western Isles

The Western Isles of Scotland are remote, sparsely populated and are highly dependent on maritime transport. The economic cost of adverse wave climate in the region is currently of the order of £10 million per annum (Marine and Fisheries Sector Report). Although these costs are very small compared to the cost of ‘climate change’ globally, they do have an exceptionally high per capita cost to the particular community affected.

Since June 2000, Caledonian MacBrayne Limited has operated services on 26 routes utilizing 28 ships and 28 slipway, harbour and terminal facilities. Each year, they carry approximately 4.8 million passengers, 903,000 accompanied cars, 84,800 commercial vehicles and 12,750 service buses and coaches. Routes vary in susceptibility to the weather and certain routes are particularly susceptible to distinct weather patterns. Among the most disrupted routes are those from Oban on the mainland to some of the small islands around the Sea of the Hebrides. Up to about 5% of services to Barra (population: about 1300) and South Uist (about 2000) and to Tiree (about 1000) and Coll (about 150) can be cancelled, diverted or delayed by more than one hour due to adverse weather in a bad year. Based on the assumption that the winter North Atlantic Oscillation remains largely positive in nature then it is likely that there would be major disruption to one in 10 services during the winter (December to March) and minor disruption to one in 8 on the routes between Oban / Barra /South Uist and between Oban / Coll / Tiree (Marine and Fisheries Sector Report). This indicates that disruption could increase from around 5% of services to 12.5% of services, with economic costs increasing by approximately £15 million per annum for the Western Isles.

As 90% of transport needs are provided by roads in the UK, most of the CCRA analysis has concentrated on road transport, particularly flooding which is considered the largest risk to the road, as well as the wider transport network. Road transport needs for Scotland are also large, where the road network is approximately 65% greater than the rest of Great Britain relative to the size of the population (Scottish Government, 2010b). Recent events such as the severe snowfall event of December 2010 and the large winds of December 2011, discussed in Section 4.4, also highlight how vulnerable Scotland’s transport network is to disruption, particularly for the most remote of communities.

There are an increasing number of passengers using rail travel, meaning that more passengers would be delayed as a result of weather and climate related train delays in the future as more services are provided on a fixed infrastructure. Increasing summer temperatures could also increase the risk to rail buckling, although based on an assessment carried out for Great Britain by the CCRA, this is considered a low risk for Scotland when compared to other risks to the transport network. Conversely, with warmer winter temperatures projected it is possible that there will be less disruption caused by snow and ice, as occurred in December 2010. This may act to improve winter commuting times and prevent days missed due to extreme weather.

The mix of Road/Rail/Air and Water transport will change in the future. The UKCIP/BESEECH socio-economic scenarios have estimated the Air/Rail/Road transport mix for the UK by the 2050s as shown in Table 4.11. Ferry services are not included in this list. However, use of ferry services has remained relatively stable over...
the last 35 years (Scottish Government, 2010b), and it is likely that this will not show a noticeable increase over the rest of this century.

Table 4.11 Projected road, rail, air and water transport mix by the 2050s (UKCIP/BESEECH socio-economic scenarios)\(^{153}\)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Air</th>
<th>Rail</th>
<th>Road (public transport)</th>
<th>Road (private transport)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Enterprise</td>
<td>1%</td>
<td>7%</td>
<td>7%</td>
<td>85%</td>
</tr>
<tr>
<td>Local Stewardship</td>
<td>0.5%</td>
<td>15%</td>
<td>14.5%</td>
<td>70%</td>
</tr>
<tr>
<td>World Markets</td>
<td>3%</td>
<td>10%</td>
<td>2%</td>
<td>85%</td>
</tr>
<tr>
<td>Global Sustainability</td>
<td>1.5%</td>
<td>15%</td>
<td>19.5%</td>
<td>64%</td>
</tr>
</tbody>
</table>

Whilst some of the scenarios indicate a greater dependence on public transport, roads are projected to remain the main form of transport into the future.

Flooding of transport infrastructure

Flooding of roads and rail in particular and the associated disruption is anticipated to be the most significant impact on these networks. Projections of the future extent of the transport networks in Scotland at risk from flooding have not been determined as part of the CCRA as no data was available to assess this risk (see Appendix C1). However, based on the analysis carried out for England and Wales, it is likely that there could be an increase of at least 10% and 20% in the length of road and rail lines at significant likelihood of flooding by the 2050s and 2080s respectively, although these estimates could be up to 30% larger. Rural communities will be particularly at risk as they often rely on access roads that could result in their isolation if these roads flood.

Projected increases in winter rainfall and heavy rainfall days may result in increased runoff from urban and transport surfaces entering watercourses more frequently, as well as pollutants as a result of forestry operations. The main diffuse pollutants from urban sources are toxic metals, oil and other hydrocarbons, which are associated with hydrocarbon spills and especially with the combustion of hydrocarbons. These can coat river beds with a toxic film which kills invertebrates and fish. Herbicides used to control weeds along roadsides and pavements can kill plants in rivers.

Sewers may also back up if they are overwhelmed by heavy rainfall or they become blocked. This can lead to flooding by water contaminated by raw sewage, causing further damage to land and property. Rivers can also become polluted by sewer overflows. Spill volumes from combined sewer overflows (CSOs) are projected to increase, which can be considered as an indicator of sewerage performance, i.e. if the CSOs are discharging, the sewers will be operating at or greater than design capacity, which will mean that there is an increased likelihood of flooding. This is potentially significant, with projected increases of up to 80% by the 2080s for the central estimate of the Medium emissions scenario.

\(^{153}\) Current estimates from DfT (2009) indicate that by distance travelled in Great Britain, approximately 84% is by road (cars, vans and taxis), 7% by rail, 6% by buses and coaches, 1% by air, 1% by motorcycle and 1% by pedal cycles.
Case Study: Combination Flooding in Glasgow

The majority of Glasgow's sewers form combined sewerage systems draining both surface water and foul water to wastewater treatment plants. When these systems are full due to heavy rain, excess flows are discharged via combined sewer overflows (CSOs). These discharges can cause pollution problems in the receiving watercourses. In extreme events, flooding can occur from manholes, which in the worst cases can result in water contaminated with sewage entering properties.

As a result of population increase and urbanisation, Glasgow's sewerage systems are having to drain greater flows more regularly and CSO discharges exacerbate water quality issues in the Clyde and its tributaries, which have pollution levels above EU limits.

In June 2002, 75mm of rain fell in 10 hours in Glasgow causing widespread flooding from both the sewers and watercourses in the East End. This resulted in £100 million worth of damage with 1,500 residents and 500 properties affected (Ellis, 2010). This event prompted greater awareness in Glasgow of surface water and sewer flooding problems and the interactions between rainfall and drainage.

Following this event, drainage modelling was undertaken and a Glasgow Strategic Drainage Plan (GSDP) was developed. This focused on sustainable flood reduction and water quality and habitat improvements using a holistic drainage management approach. The East End of Glasgow was found to have areas ideal for SUDS (sustainable drainage systems) retrofitting and in-line pond attenuation to reduce the volume and concentration of urban runoff (Tufail et al., 2004).

Increases in CSO spill frequency and volume in the future would have implications for water quality in the receiving watercourses, especially if this were to occur when river flows are low, offering less dilution.

In 2009 two stretches of the river Clyde had ‘moderate’ water quality status (Scottish Government, 2011b), as a result of low oxygen levels and greater organic waste. By 2015, all watercourses must achieve ‘good’ ecological status. The projected changes in climate may affect the ability for Scotland to comply with this legislation.

CSOs also discharge into the sea, which can impact upon bathing water quality and therefore, have consequences for health and the status of beaches for tourism.

The implementation of the GSDP may result in fewer CSO spills and less flooding in Glasgow, as a focus on SUDS, attenuation and separate sewers reduces the volume of water to be drained and needing treatment. However, currently there is no timescale for completion.

Bridge scour

Bridge scour is often associated with flooding and is therefore an area of concern. 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. 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 an associated danger of structural damage or failure. In the

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154 Assuming no separation of surface water from combined systems occurs over the same period.
156 Where sediment is moved irrespective of a man-made structure this is usually termed erosion.
Climate Change Risk Assessment For Scotland

last 10 years there have been at least 7 road or rail bridge failures in the UK and one fatality. Older bridges (especially pre 20\textsuperscript{th} century) tend to be more vulnerable to scour; major modern bridges are rarely vulnerable due to advances in structural design and understanding of scour.

The CCRA analysis looked at scour under conditions of changed flood risk (Transport Sector Report). The rate of increase in scour 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. Table 4.12 shows the projected increase in scour for piers and abutments in both sand and gravel beds. Although increases in flows have not been assessed for Scotland as part of the CCRA, recently Kay et al., (2011) indicated similar increases in flow by the 2080s for Scotland for the Median emissions scenario as for England and Wales. Increases of about 5-10\% may therefore be expected by the 2020s, whereas 15-20\% and 20-30\% increases may be expected by the 2050s and 2080s respectively (see Section 3.1.4 and Appendix C1). However, west coast flows are projected to increase more than east coast flows, so these increases may be greater in these regions.

Table 4.12 Estimated percentage increase in scour from present day conditions

<table>
<thead>
<tr>
<th>Increase in flow (%)</th>
<th>Sand bed Pier</th>
<th>Abutment</th>
<th>Gravel bed Pier</th>
<th>Abutment</th>
<th>Pier (with armouring)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>150</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td>30</td>
<td>9</td>
<td>5</td>
<td>8</td>
<td>65</td>
<td>170</td>
</tr>
</tbody>
</table>

For an armoured bed, the increase in scour can be dramatic once the armour layer is eroded. However, the effects of bed armouring are still an uncertain science. Therefore, these projections should only be considered as indicative. Despite this, it was possible for the CCRA analysis to conclude that, based on currently projected climate change, some bridges that are currently classed as being adequately protected from scour would be moved into the scour critical category. However, at present there is insufficient data available to estimate the number of bridges that may be affected in this way.

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.

Landslips

The length of road currently under threat from landslides was noted for the UK as a whole as running into thousands of kilometres, with a greater risk associated with increases in severe weather and precipitation. The evidence base for this metric indicates that landslip is considered a greater risk than erosion, which is generally managed as part of the existing road maintenance programmes, and which is more likely to result in the relocation of coastal roads. The evidence base for landslip is more robust with both economic and social consequences, in particular through isolation of some relatively remote communities.

For Scotland, there have been a number of significant landslides in recent years, and some of these are outlined in the case studies below. As a direct result of these landslides, there have been a number of in-depth studies of slope stability and
landslide. For example, the BIONICS\textsuperscript{157} project investigated the impact though use of controlled experiments. Following a number of significant events the Scottish Executive commissioned the ‘Scottish Road Network Landslide Study (Winter \textit{et al.}, 2005). Both of these studies underlined the complexity in the determination of a landslide risk.

In 2005 the Scottish Executive published a Climate Change Study (Scottish Executive, 2005) to identify issues which may face Scotland’s road network as a result of a changing climate. The overall conclusion, based on the predicted consequences for the 2020s, was that the predicted changes for Scotland were relatively small. One specific area of concern was increased rainfall, with respect to drainage systems, with most landslides tending to occur within or adjacent to significant drainage lines or hollows.

Values for the length of trunk road in a ‘severe’ risk category were published in the Transport Scotland \textit{Scottish Road Network Landslides Study (part 2), (Transport Scotland, 2005). These concern the trunk road network only, which constitutes around 3,400 km of roads, 6\% of the Scottish road network. The remainder of the road network, around 40,830 km, is of a priority risk classification, with the vast majority of the high priority roads (approximately 90\%) being within Scotland’s northwest. However, sufficient data to estimate risks for all roads (in addition to trunk roads) was not identified for the CCRA, and hence the increase in risk for Scotland’s trunk road network only was considered.

Based on the analysis carried out in the CCRA, Table 4.13 below shows the length of trunk road (km) projected to be impacted by landslide per year for the different time periods in Scotland. This indicates that up to 200km of road could be impacted by landslide by the 2020s, and 330km by the 2050s and 2080s.

Table 4.13 Qualitative assessment of the length of trunk roads (km) impacted by landslide in Scotland

<table>
<thead>
<tr>
<th></th>
<th>Low emissions scenario</th>
<th>Medium emissions scenario</th>
<th>High emissions scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P10 (dry)</td>
<td>p50 (mid)</td>
<td>p90 (wet)</td>
</tr>
<tr>
<td>2020</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2050</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2080</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

0 Very low – 16 to 50 km per year
1 Low – 50 to 200 km per year (current extent)
2 Medium – 200 to 330 km per year
3 High – 330 to 750 km per year
4 Very high – 750 to 1,650 km per year (occurrences at maximum frequency and magnitude in all identified risk areas)

Despite the large areas of road at risk in Scotland however, it should be recognised that there is good working knowledge in place regarding the extent of the threat and adaptation is well managed.

\textsuperscript{157} BIOlogical and eNgineering Impacts of Climate Change on Slopes, part of the ‘Building Knowledge for a Changing Climate’ initiative, led by EPSRC and UKCIP
### Case Studies: Landslides at Glen Ogle and Rest and Be Thankful

#### Glen Ogle

There were a number of landslide events across Scotland in August 2004 following unusually heavy rainfall (both long in duration and locally intense). The most dramatic of these occurred on 18th August at Glen Ogle on the A85, a busy tourist route in central Scotland.

Thousands of tonnes of mud and debris were swept down the hillside in two separate debris flows. After the first slip BEAR Scotland staff were on the scene offering advice to motorists. Then the second slip came trapping 20 vehicles and washing away a BEAR Scotland vehicle.

The RAF, Royal Navy and emergency services spent three hours at the scene airlifting 57 people (including several children) to safety before any further landslides occurred. Thanks to their rapid evacuation, nobody was seriously hurt.

Many of those rescued were accommodated in Bed and Breakfast accommodation and private homes in nearby Lochearnhead and Killin, where the local communities, including the Women’s Rural Institute, doctors, nurses, schoolteachers and the general public, did everything they could to help.

#### Figure 4.28 Landslide at Glen Ogle, August 2004

![Landslide at Glen Ogle](source:运输Scotland)

The A85, which in August usually carries about 5,600 vehicles a day, was closed for four days. This resulted in significant disruption and inconvenience to local, tourist and commercial road users. The resultant isolation of relatively remote communities not only impacted on the local residents and businesses, but the event occurred during the height of the tourist season trapping visitors and preventing others from arriving.

Further details of this event and others that have taken place in recent years can be found in Galbraith et al., (2005) and Winter et al., (2008).

#### Rest and Be Thankful

The A83, known as the Rest and Be Thankful Pass, is an important trunk road in Argyll and Bute. It is to the west of Loch Lomond and serves as the main route to and from

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158 Some areas of Scotland received more than 300% of the average 30-year August rainfall. In Perth and Kinross figures of the order of between 250% and 300% were typical and parts of Stirling and Argyll and Bute received between 200% and 250% of the monthly average. The 30-year average rainfall in August varies in Scotland between 67mm on the east coast and 150mm in the west of Scotland (Winter et al., 2005).

159 The trunk road operating company.

Glasgow for the towns and villages in southern Argyll. As a known high risk route, this road is already subject to a £470,000 drainage project funded by Transport Scotland which started in June 2010 and aims to minimize this risk.

On 28th October 2007, 400 tonnes of soil and rock, loosened by several months of rainfall, tumbled down onto the road. A subsequent landslip on the underside of the road then took place. Fortunately, as this took place at 3am, no vehicles were on the road at the time. The road had to be closed for two weeks. Further details of this event can also be found in Winter et al., (2008).

On the 8th September 2009, after a sustained period of heavy rain, there was a landslide that brought over 600 tonnes of rock and mud onto the road, blocking it for two days and causing a 55-mile detour.

On 13th September 2010, again after heavy rain, the A83 suffered its third significant landslide in three years, closing the road for a few hours. This latest fall was further west along the road from the events of 2007 and 2009.

When the road is closed and traffic has to be diverted, some journeys can be as much as two hours longer. Such closures are very costly for businesses, especially hauliers forced to take lengthy diversions and hotels, restaurants, etc. that rely on passing trade.

The changing climate

Observations indicate that, within the recent past, debris flow landslide activity in Scotland has occurred largely during the summer months of July and August and the winter months from November to January (although the winter season is occasionally extended to October and February) (Winter et al., 2008).

Rainfall levels are projected to increase in the winter and decrease in the summer, with
intense rainfall events increasing in frequency. If this happens, it is possible that the frequency and annual pattern of debris flow events would also change.

In recent years debris flow events appear to have had an increasing effect on the Scottish road and rail networks, but detailed records are not available to determine whether such events are actually becoming more common, as data is not generally collected where an event does not impact on human activities.

All transport infrastructure is threatened by the effects of climate change. Landslips and flooding obstruct roads and railway lines and coastal erosion could necessitate the relocation of coastal roads.

Key challenges for Scotland’s transport infrastructure include the identification of roads and railway lines at greatest risk of flooding or damage due to erosion or landslips. This will also require the development of a risk management plan including an assessment of communities most in danger of isolation. The location and design of new infrastructure, whether for road, rail or cycle, must take account of an increased likelihood of risks from flooding and landslips (Scottish Government, 2009c).

The predicted trends in climate change for coastal flooding, including an increase in rainfall and sea level rise suggests that this has the potential to affect low lying roads in coastal areas. This may result in damage to the road, road closure, or the occurrence of road safety hazards, as seen following the severe winter storms of January 2005 (Ball et al., 2009) and December 2011 (see Figure 4.30). It should be noted that the roads at risk are predominantly part of the local, rather than the trunk road network (Scottish Government, 2005b).

Figure 4.30  Road damage on Orkney after the December 2011 storms
Source: BBC news

http://www.bbc.co.uk/news/uk-scotland-16108672
**Northern Arctic sea routes**

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 periods during the Arctic summer. The projections suggest that there could be ice free Arctic summers by the 2080s. Results showed that the Northeast Passage could be open for up to 120 days by the 2050s and 180 days by the 2080s, while the Northwest Passage may be open for up to 90 days by the 2050s and 120 days by the 2080s.

Ports in the north of the UK might therefore expand in the future to benefit from these changes in shipping routes as well as the provisioning of arctic vessels. Scottish ports particularly in the Northern Isles would be expected to be the main beneficiaries, although there could also be damaging effects to marine biodiversity.

### 4.5.2 Water supply

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Water Sector Report.

Water supply is likely to become increasingly stressed in the future, although the nature of Scotland’s geography means that impacts will vary in magnitude across the country. Whilst overall rainfall is not projected to change significantly, there is projected to be an overall reduction in rainfall in the summer, and an overall increase in rainfall in the winter (Section 2.3.2), although these may not be consistent regionally. In addition, domestic water demand is projected to increase as a result of increases in aridity (Section 3.1.2) and population.

![Figure 4.31 Loch Ness](image)

*Source: Nathan Wield*
Overall it is estimated that the supply demand balance in the UKCP09 Scottish river basins will change from a surplus of about 200Ml/day at present to a surplus of about 170Ml/day (range 60Ml/day deficit to 370Ml/day surplus) in the 2020s, a deficit of about 100Ml/day (range 290Ml/day deficit to 170Ml/day surplus) by the 2050s and a deficit of about 200Ml/day (range 420Ml/day deficit to 10Ml/day surplus) by the 2080s (Table 4.14).

| Table 4.14 Impacts of climate change alone on water supply change, surplus/deficit (Ml/day), in each UKCP09 Scottish basin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low emissions | Medium emissions | High emissions |
| | | $P_{10}^{(wet)}$ | $P_{50}^{(mid)}$ | $P_{90}^{(dry)}$ | $P_{10}^{(wet)}$ | $P_{50}^{(mid)}$ | $P_{90}^{(dry)}$ | $P_{10}^{(wet)}$ | $P_{50}^{(mid)}$ | $P_{90}^{(dry)}$ |
| Argyll | 2020 | 14 | 9 | 4 | 14 | 9 | 4 | 14 | 9 | 4 |
| | 2050 | 11 | 4 | -4 | 10 | 3 | -5 | 9 | 1 | -7 |
| | 2080 | 9 | 1 | -8 | 7 | -3 | -8 | 4 | -3 | -8 |
| Clyde | 2020 | 84 | 62 | 35 | 85 | 62 | 34 | 84 | 62 | 35 |
| | 2050 | 67 | 34 | -6 | 61 | 25 | -17 | 54 | 15 | -32 |
| | 2080 | 57 | 16 | -34 | 40 | -9 | -68 | 20 | -37 | -109 |
| Forth | 2020 | 39 | 34 | 26 | 39 | 34 | 26 | 38 | 34 | 27 |
| | 2050 | 35 | 26 | 15 | 34 | 23 | 12 | 32 | 21 | 8 |
| | 2080 | 32 | 21 | 8 | 28 | 14 | -2 | 23 | 7 | -12 |
| North East Scotland | 2020 | 36 | 32 | 27 | 36 | 32 | 27 | 36 | 32 | 27 |
| | 2050 | 33 | 27 | 20 | 33 | 26 | 18 | 31 | 24 | 16 |
| | 2080 | 31 | 24 | 15 | 29 | 20 | 9 | 25 | 15 | 2 |
| North Highland | 2020 | 24 | 4 | -16 | 23 | 4 | -16 | 22 | 4 | -15 |
| | 2050 | 11 | -16 | -33 | 7 | -21 | -33 | 1 | -24 | -33 |
| | 2080 | 2 | -24 | -33 | 1 | -24 | -34 | 0 | -2 | -3 |
| Orkney and Shetland | 2020 | 5 | 2 | -1 | 5 | 2 | -1 | 5 | 2 | -1 |
| | 2050 | 3 | -1 | -3 | 3 | -1 | -3 | 2 | -2 | -3 |
| | 2080 | 2 | -2 | -3 | 1 | -2 | -3 | 0 | -2 | -3 |
| Solway$^{162}$ | 2020 | 96 | -16 | -144 | 98 | -16 | -147 | 96 | -16 | -143 |
| | 2050 | 5 | -150 | -225 | -23 | -165 | -227 | -54 | -166 | -228 |
| | 2080 | -42 | -165 | -228 | -106 | -169 | -233 | -108 | -172 | -238 |
| Tay | 2020 | 18 | 2 | -16 | 18 | 2 | -16 | 17 | 2 | -15 |
| | 2050 | 6 | -16 | -42 | 3 | -20 | -47 | 0 | -25 | -54 |
| | 2080 | -1 | -27 | -59 | -10 | -41 | -77 | -20 | -56 | -88 |
| West Highland | 2020 | 8 | 4 | -1 | 8 | 4 | -1 | 8 | 4 | -1 |
| | 2050 | 5 | -1 | -6 | 4 | -2 | -6 | 3 | -3 | -6 |
| | 2080 | 3 | -3 | -6 | 1 | -3 | -6 | 0 | -3 | -6 |
| Tweed | 2020 | 41 | 36 | 29 | 42 | 36 | 29 | 41 | 36 | 29 |
| | 2050 | 37 | 28 | 18 | 36 | 26 | 15 | 34 | 24 | 11 |
| | 2080 | 34 | 23 | 10 | 30 | 17 | 2 | 24 | 10 | -8 |
| Scotland | 2020 | 366 | 170 | -56 | 367 | 170 | -61 | 361 | 170 | -52 |
| | 2050 | 214 | -65 | -266 | 168 | -105 | -293 | 112 | -133 | -328 |
| | 2080 | 130 | -135 | -338 | 9 | -198 | -419 | -46 | -265 | -504 |

The time of greatest water stress is expected to be in the summer, when there will be a reduction in the availability of water. It is provisionally estimated that about 40% of the population of Scotland might be affected by a supply-demand deficit by the 2020s rising to over 70% by the 2080s, although the uncertainty associated with these estimates is large.

$^{162}$ Note that the figures for the Solway are from the contributing water companies in England as well as Scotland
An indication of the likely future stress on water supplies is the number of river abstraction sites with sustainable abstraction. This is likely to reduce, however no data was available for Scotland to indicate by what levels. A reduction in water quality may impact on water infrastructure. An assessment of water quality is given in Section 4.2.2.

Water supply infrastructure is likely to increase in vulnerability to flooding as flood risk increases. This in turn will affect water supplies and potentially lead to failures of supplies, as occurred in England during the July 2007 floods. This has not been analysed in the CCRA owing to a lack of suitable data, but is considered to be an important potential impact of climate change.

Rising sea levels could also affect treatment works and at a smaller, but more numerous and rural level, septic tanks, a number of which are particularly exposed to future projected rises in sea level.

4.5.3 Energy supply

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Energy Sector Report and the Floods and Coastal Erosion Sector Report.

Wind farms are a developing economy in Scotland, with the Scottish Government aiming to generate the equivalent of 31% of Scotland’s gross annual energy consumption from renewable energy by 2011, rising to 100% by 2020, most of which is anticipated to come from wind energy. Currently Scotland has more than 60% of the UK capacity, with over 80% of those under construction in Scotland (Table 4.15 and Figure 4.32). Wind farms consented or in planning are also greater than the rest of the UK put together.

Table 4.15 Onshore wind energy generation for Scotland (MW)  
(as of 16/01/12)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Scotland</th>
<th>UK Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>2,768</td>
<td>4,427</td>
</tr>
<tr>
<td>Under Construction</td>
<td>1,206</td>
<td>1,446</td>
</tr>
<tr>
<td>Consented</td>
<td>2,076</td>
<td>3,990</td>
</tr>
<tr>
<td>In Planning</td>
<td>4,534</td>
<td>7,711</td>
</tr>
</tbody>
</table>

Although it is expected that a large proportion of additional wind power will come from new offshore wind farms, there will still be a need to construct many more onshore wind farms. As shown in Table 4.15, the total capacity of wind energy projects that are proposed, but not yet operational for Scotland greatly exceeds the capacity of projects that are already operational.

Scotland has nine active power stations. The largest of these (capacity greater than 1,000 MW) include two nuclear at Hunterston B and Torness, two coal-fired at Cockenzie and Longannet and one oil and gas fired at Peterhead. Despite the aim of 100% equivalent renewable energy generation, fossil fuel power stations will still be required to allow the exporting of green energy.

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163 http://www.bwea.com/ukwed/google.asp - as of 13/1/12
Scotland has great potential for other renewable energy. Aside from wind, hydro, wave and tidal and biomass are able to contribute to Scotland’s energy generation. There are also several hydro-electric schemes in the Highlands as well as an experimental wave power generator on Islay and the UK’s largest wood fired biomass power station at Steven’s Croft near Lockerbie.

Hydro generation has been long established in Scotland. Currently it contributes around 10% to Scotland’s total current energy generation with most of this output produced by large scale hydro schemes, the largest currently being at Cruachan, Argyll which generates 440MW. Early proposals to develop hydro power near Loch Ness could see generation of more than 900MW. There are also increasing numbers of proposals for small run of river hydro projects with it being estimated that there are 1,019 financially viable locations\textsuperscript{164} estimated to potentially provide 1.2GW of electricity (SEPA, 2010) These projects, together with the continuing refurbishment of the large hydro schemes will ensure that hydro will continue to play its part in Scotland’s renewable energy mix.

Many of the areas with greatest potential for new capacity are located towards the North West of the country and, as a result, are subject to many of the system capacity constraints placed upon incremental wind generation in Scotland. Hydro generation resources must also compete with wind for the attention of potential investors and developers, in a market where the latter technology is strongly positioned as the first choice for new renewable generation projects (Wood Mackenzie, 2008).

Scotland’s offshore renewables resource has been estimated at 206GW. By harnessing around a third of this resource, installed offshore renewables capacity could reach 68GW by 2050 - more than ten times Scotland’s peak demand. In particular Scotland’s wind and seas hold some of the most concentrated potential not only across the UK, but also Europe and the world with an estimated 25% of Europe's offshore wind and wave potential and 10% of tidal.

\textsuperscript{164} \url{http://www.hi-energy.org.uk/Renewables/Hydro-Energy.htm}
Scotland possesses a huge wave and tidal energy resource with the potential to generate much more than Scotland needs, allowing the excess to be exported. Wave energy is intermittent but relatively predictable, whereas tidal current energy is intermittent but largely predictable. Some of the best resources are located off the north-west coast and northern tip of Scotland - the world’s first commercial wave energy device is still producing power on the shoreline at Islay, despite Scotland’s wave generation not developing as quickly as possible due to financial and technological constraints (Wood Mackenzie, 2008).

In September 2008 the Pentland Firth off Scotland’s northern coast was opened up for commercial scale development and the Crown Estate announced a goal of generating more than 700MW from marine developments in this area by 2020 (Wood Mackenzie, 2008).

Biomass is the only other naturally-occurring, energy-containing carbon resource known that is large enough to be used as a substitute for fossil fuels. Biomass includes plant matter, vegetation and trees, as well as waste biomass such as municipal solid waste (MSW), municipal biosolids (sewage) and animal wastes (manures), forestry and agricultural residues, and certain types of industrial wastes. Unlike fossil fuels, biomass is renewable in the sense that only a short period of time is needed to replace what is used as an energy resource. Biomass is also held to be "carbon neutral", in that the amount of carbon it absorbs while growing is the same as the amount it produces when burned. Scotland’s biomass capacity may be further divided into waste-derived landfill gas and dedicated biomass installations.

Figure 4.34 shows an increase in woodfuel usage of approximately 300% between 2005 and 2010. Forecasts indicates a slight increase for 2011 from 2010, with an approximate 33% increase to approximately 900,000 oven dried tonnes (odt) by 2012, equivalent to approximately 1.7 million green tonnes of timber.

Biomass could be extremely valuable in Scotland given its lack of intermittency, its ability to meet local and small-scale energy needs and its potential to provide and

Figure 4.34   Total Wood Fuel Use - All Industry/Commercial - 2004/05 to 2010 and forecast for 2011 and 2012

165 http://www.usewoodfuel.co.uk/supplying-woodfuel/market-demand.aspx
sustain jobs. Biomass is also noted as having a big part to play in the Renewable Action Plan for Scotland published in 2009 (Scottish Government, 2009d).

**Flood risk**

Although some power stations in Scotland are in potential flood risk areas, it is believed that these are defended against very extreme floods and are understood to not be at significant likelihood of flooding. However, the risk is not considered significant. With no proposed new nuclear power stations in Scotland\(^{166}\), and with the projected increase in renewable wind energy, future flood risk to energy is anticipated to be less of an issue for Scotland than for the rest of the UK.

The energy distribution and transmission system is vulnerable to flooding. Currently for the south of the country\(^{167}\), 15 substations with operating voltages of 132kV and above and 38 Primary (33/11kV) substations have been identified from SEPA indicative flood maps as in a flood risk area (source Scottish Power). No information was available from Scottish and Southern Energy who cover the area north of this line. It is not known how this risk might change for the rest of this century, however, any new substations would not normally be located within flood risk areas up to a 1 in 1000 year return period (ENA, 2009).

**Precipitation Changes**

Changes in precipitation may have significant impacts on Scottish Hydro energy generation. Changes in precipitation and river flow may result in existing reservoir levels being above or below design capacity more often than planned. Reservoir sizing for future large-scale projects will need to consider what effect projected changes in precipitation, and potential increases in flood and drought events will have on future flows. Hydro energy scheme will have to be designed accordingly. Changes in precipitation patterns and extreme events may alter the viability of catchments to support certain sizes of reservoirs.

Projected lower summer precipitation would result in low river flows, potentially causing a reduction of energy generation potential within the catchment. Furthermore, the impact of extreme drought effects may exacerbate low flow problems, and result in continued low reservoir levels in following years.

Favourable precipitation patterns are important to maximise the contribution from hydro energy; therefore a change in rainfall and flows may impact on the current potential output of 1.2 GW from hydro energy sources. Although not assessed in the CCRA, further investigation of climate change effects on potential energy generation would be desirable due to the importance of Scotland’s renewable energy sector.

**Energy demand**

Currently, winter energy efficiency is the focus of both new-build design and retrofit/refurbishment programs, such as the “Warm Front” scheme. However, with future warmer winters, a reduction in heating demand is expected. This reduced requirement for space heating provides an opportunity for innovative design, e.g. of building plant. On the other hand, it does not justify a reduction in current recommended insulation levels. Good levels of insulation will still be required in colder spells and may also help to reduce overheating in summer.

\(^{166}\) [http://www.scotland.gov.uk/Publications/2007/10/Nuclear](http://www.scotland.gov.uk/Publications/2007/10/Nuclear)

\(^{167}\) This is the area covered by Scottish Power, and encompasses all areas below a line running approximately from the Firth of Tay in the east to Greenock in the west.
Table 4.16 shows the change in domestic heating demand for the different emission scenarios and population projections considered for the CCRA for East, North and West Scotland. These indicate a reduction in space heating demand, up to 8,000 GWh/yr for West Scotland for example by the 2080s, directly correlated with increasing average temperatures.

### Table 4.16 Household Space Heating Energy Consumption (‘000 GWh/yr) - including climate change

<table>
<thead>
<tr>
<th></th>
<th>2025</th>
<th>2055</th>
<th>2085</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>p10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Scotland (2008 baseline 12)</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
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<td></td>
<td>13</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>12.5</td>
<td>11</td>
</tr>
<tr>
<td>North Scotland (2008 baseline 5)</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>4</td>
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<tr>
<td></td>
<td>5</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>West Scotland (2008 baseline 14)</td>
<td>13</td>
<td>12</td>
<td>10</td>
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<tr>
<td></td>
<td>13</td>
<td>12</td>
<td>10</td>
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<td>13</td>
<td>12</td>
<td>10.5</td>
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<tr>
<td></td>
<td>13.5</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

*Current population projection* | *Principal population projection* | *Low population projection* | *High population projection* |

**Impacts of increasing temperatures**

Demand for energy for cooling is directly linked to temperature increases, especially in the summer, for example through the use of air conditioning in offices or cooling systems on IT infrastructure. The UKCP09 projections indicate that average temperatures are projected to increase in the future and therefore it is anticipated that the level of air conditioning use will increase to cope with extreme temperatures or more hot days in a year. Although good building design may improve natural ventilation and passive cooling, there is a lot of existing building stock where air conditioning is already installed, or may be retrofitted.

To assess how the demand for cooling services may change in the future, the CCRA considered how the number of cooling degree days could change under a changing climate (see Section 3.1.10). Currently there are less than 25 cooling degree days in Scotland. Although these are projected to increase by the end of the current century, as stated above these are not significant, and only the most southern parts of Scotland...
are projected to have more than 25 cooling degree days by the 2080s. Although the analysis noted considerable changes in southern England by the 2080s, changes in Scotland were not significant (Energy Sector Report), therefore this impact may only be of importance for those living and working in the South of Scotland.

For the UK as a whole, the increased demand is expected to be met with current capacity and to be more than offset by the planned increased capacity in the next 5-10 years. Overall consumption is anticipated to be driven by heating demand, particularly in Scotland where overall future projected temperatures are lower than the rest of the UK.

Considering social economic implications, increased demand linked to a larger population is still within the levels of planned adaptation under current government policies.

Increasing temperatures could potentially cause heat damage to energy infrastructure and ICT resulting in disruption to supplies and operations. However this is not expected to be a major climate change risk in Scotland, and less as a whole than for other regions of the UK. Additionally, increasing winter temperatures may also reduce the risk of ICT disruption to snow and ice events. Such disruption had been analysed by Alan Speedie Associates for SNH, with a reported £450,000 loss due to sever weather (see Section 4.4).

Distribution and transmission equipment could however suffer a capacity de-rating because of higher temperatures. Projected percentage capacity losses for the UK for different UKCP09 scenarios are given in Table 4.17 below.

**Table 4.17 Projected percentage capacity losses for different emission scenarios and electricity infrastructure (UK wide)**

<table>
<thead>
<tr>
<th>Projection</th>
<th>Overhead Line Conductors</th>
<th>Power Transformers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distribution Trans 400 Trans 500</td>
<td>11kV 33-132kV</td>
</tr>
<tr>
<td></td>
<td>Min Max Min Max Min Max</td>
<td>Min Max Min Max</td>
</tr>
<tr>
<td>2020s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Med p10</td>
<td>0.5 1.0</td>
<td>0.2 0.4</td>
</tr>
<tr>
<td>Med p50</td>
<td>2.4 3.5</td>
<td>1.0 1.1</td>
</tr>
<tr>
<td>Med p90</td>
<td>4.5 6.4</td>
<td>1.6 2.0</td>
</tr>
<tr>
<td>2050s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>1.3 1.9</td>
<td>0.5 0.6</td>
</tr>
<tr>
<td>Low p50</td>
<td>3.7 5.6</td>
<td>1.3 1.6</td>
</tr>
<tr>
<td>Low p90</td>
<td>4.0 6.1</td>
<td>1.5 1.8</td>
</tr>
<tr>
<td>Med p50</td>
<td>5.3 6.9</td>
<td>1.6 2.0</td>
</tr>
<tr>
<td>High p90</td>
<td>8.5 12.0</td>
<td>2.9 3.6</td>
</tr>
<tr>
<td>2080s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low p10</td>
<td>1.4 2.1</td>
<td>0.8 0.9</td>
</tr>
<tr>
<td>Low p50</td>
<td>4.5 6.6</td>
<td>1.7 2.1</td>
</tr>
<tr>
<td>Med p50</td>
<td>5.9 8.8</td>
<td>1.9 2.4</td>
</tr>
<tr>
<td>High p90</td>
<td>7.5 11.0</td>
<td>2.3 2.9</td>
</tr>
<tr>
<td>High p90</td>
<td>13.3 19.0</td>
<td>4.3 5.3</td>
</tr>
</tbody>
</table>
The efficiency of thermal power stations may be affected by increases in temperature. High temperatures result in lower air density, which may reduce the amount of air drawn into a turbine and consequently the amount of fuel burnt (Linnerud et al., 2009, Mideksa and Kallbekken, 2010). How much this may affect thermal power station outputs is currently unknown and further research is needed. However, for a temperature increase of 1°C, coal and gas power output may decrease by 0.6% due to the thermal efficiency loss, with potentially higher decreases with nuclear power stations (Energy Sector Report). An increase of 6.4°C for example, an increase that may happen by the end of the current century, could result in a 3.84% output drop for each of Scotland’s coal and gas power stations.

Offshore gas is processed and brought to shore by gas processing companies and fed into the gas transmission system. The transmission system operates at high pressure (70-94 units of gauge pressure), which in Scotland is maintained by 5 compressor stations at Aberdeen, Bathgate, Kirriemuir, Moffat and St Fergus, ensuring that gas delivered to coastal terminals is available at the point of demand (National Grid Gas, 2011). Compressor stations are not designed to run at elevated temperatures and consequently in high temperatures the pressure may have to be reduced. The operation of some stations is already an issue in the summer and this could be exacerbated by climate change. Of course this should be considered in combination with pressures of changing patterns of demand. Currently National Grid Gas (2011) are monitoring this issue to understand whether parts of compressor stations may need to be modified or replaced in the future.

The efficiency of thermal power stations depends upon the temperature interval of the steam/gas upstream and downstream. Water is the most effective cooling medium and, in Scotland, sea water is extracted for this process. Projected sea water and air temperature increases could result in a decrease in the efficiency of thermal power stations, particularly coal-fired and nuclear power stations. Although sea temperature increases have not been considered, water can only be extracted and discharged at or below regulated threshold temperature values. Increased temperatures may result in
these thresholds being met more frequently. This could be reduced by changing the cooling system used or reducing the total electricity production (Greis et al., 2009). It is likely that a site-specific analysis would be necessary to carry out a quantitative analysis on this risk since it is likely to depend on many local factors. The ability to provide quantitative information is also dependent on the ability for climate projections to capture climatic conditions such as droughts and hot spells, which is a limitation of the UKCP09 projections.

4.5.4 Infrastructure: summary

Summary of results

The results of the analysis are shown in Table 4.18.
### Table 4.18 Climate change impacts on Infrastructure

<table>
<thead>
<tr>
<th>Threats</th>
<th>Opportunities</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
<th>Confidence</th>
<th>Coverage</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN1</td>
<td>Energy infrastructure at significant risk of flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>FL11b</td>
<td>Sub-stations at significant risk of flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>FL8a</td>
<td>Roads at significant risk of flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>FL8b</td>
<td>Railways at significant risk of flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN2/FI11a</td>
<td>Power stations at significant risk of flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>WA10</td>
<td>Combined Sewer Overflow spill frequency</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>TR1</td>
<td>Coastal erosion</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN2</td>
<td>Energy demand for cooling</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>TR6</td>
<td>Scouring of road and rail bridges</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN4</td>
<td>Risk of restrictions in water abstraction for energy generation</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN10</td>
<td>Energy transmission efficiency, capacity losses due to heat - over ground</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>UK</td>
<td>Q</td>
</tr>
<tr>
<td>TR1</td>
<td>Disruption to road traffic due to flooding</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>TR2</td>
<td>Landslide risks on the road network</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>EN5</td>
<td>Demand by water suppliers</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>UK</td>
<td>U</td>
</tr>
<tr>
<td>WA4</td>
<td>Change in household water demand</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>BUS</td>
<td>Loss of productivity due to ICT disruption</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN6</td>
<td>Electricity turbine efficiency</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN7</td>
<td>Gas pipe compressor rating</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td>EN8</td>
<td>Power station cooling process</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>Too uncertain</td>
<td>S</td>
<td>U</td>
</tr>
</tbody>
</table>

**Summary of the main impacts of climate change on infrastructure**

- The reliance of many communities in Scotland on a limited number of transport links means that increased disruption due to climate change is a major potential impact for many rural communities, with significant effects for many homes and businesses.

- A potential increase in the population affected by a supply-demand deficit in summer which will affect domestic users, industry and business. If adaptation measures are not taken this could have severe consequences for homes, businesses and other water users, although this is not
anticipated to be a significant problem in Scotland.

- It is projected that there will be a reduced demand for energy in the winter for warming, and an increased demand in summer for cooling. However, initial estimates indicate that this increased summer demand can be met with current capacity, and will be more than offset by planned increased capacity levels.

- Increased transport disruption due principally to flooding, but also including landslides and other extreme events. This includes an increase of at least 10% to 20% of the length of roads and railways at significant likelihood of flooding, and up to 330km of road impacted by landslide by the 2050s. This will have particular impacts for rural communities, affecting many homes and businesses. However, there will be a decrease in disruption due to snow and ice due to higher winter temperatures.

- Northern (Arctic) sea routes may become open in the near future (up to 120 days by the 2050s and 180s days by the 2080s for the Northeast Passage for example) and remain open for longer periods during the Arctic summers. This will benefit Scottish ports from a reduction in certain sea routes.

- A reduction in household energy consumption of up to 6,000GWh/yr for East Scotland, 3,000GWh/yr for North Scotland and 8,000GWh/yr for West Scotland by the 2080s.

4.5.5 Buildings and the urban environment

The projections and relevant discussion of climate change risks in this section have mainly been drawn from the Built Environment Sector Report and the Floods and Coastal Erosion Sector Report.

Buildings and the urban environment provide houses, as well as work, leisure and culture properties to Scotland’s population. Climate change may impact in a variety of ways on buildings, with the main issues as a result of flood damage and over heating, although other impacts such as damp and mould and rainwater penetration also need to be considered.

Buildings are implicitly tied to Scotland’s economy (worker productivity, flood damage and insurance and mortgage costs), health and wellbeing (damp, mould, condensation and over heating) and energy demand (demand for cooling and heating). Climate change may negatively impact on historic buildings directly and indirectly (e.g. through rainwater penetration damage or reduction in visitor numbers), or positively through more people enjoying time outdoors and changes to tourist destinations.

Urban spaces are vital to reducing the Urban Heat Island effect, and providing cooling and recreation for those in towns and cities. The impact of climate change on green spaces is less of an issue than in other parts of the UK but it is still important to understand and consider the implication of a changing climate and the role urban spaces play both socially and environmentally.

Flood risk

Scotland’s archaeology and coastal landscapes are particularly vulnerable to coastal erosion, rises in sea level and flooding. A good example is the Heart of Neolithic Orkney World Heritage Site including Skara Brae, which is particularly at risk. Many
other previously unknown historic sites are being found as the sea advances (Scottish Government, 2009b).

Flooding from a combination of different sources would also be expected to increase with climate change. This could be a particular problem in coastal areas where rising sea levels would make the discharge of the increasing sewer and surface waters more difficult due to tide locking, particularly under the High++ scenario of sea level rise (see Section 2.3.3). This would be a particular concern for larger cities and towns, most of which are on the coast. The potential increasing incidence of tide-locking, the closure of drainage outfalls caused by high tidal water levels, would contribute to this problem.

Pluvial or surface water flooding occurs when heavy rainfall overwhelms the drainage capacity of the local area. It is much more difficult to predict and pinpoint than river or coastal flooding. Large impermeable areas within the built environment or urban system will exacerbate the risk of pluvial flooding. On the other hand, the risk can be reduced by careful design. Surface-water run-off can be managed through the use of green infrastructure and sustainable urban drainage systems (e.g. sustainable cities). In Scotland this is enforced through Building Regulations that require any constructed hard surface more than 50m² to use SUDs or other appropriate techniques to deal with the collection and discharge of surface water from paved areas.

Snowmelt often magnifies the impact of winter rainfall (extreme events and seasonal flow patterns), with the combined effect being known to produce many of the largest floods on Scotland's main rivers such as the Tay, Dee, Spey, Ness, Tweed and Clyde. Very occasionally, snowmelt alone may produce floods without significant accompanying rainfall (Scottish Natural Heritage and Institute of Hydrology Scotland, date unknown). In addition, snow can impact flow variability in higher altitudes, reducing peak flows and increasing low flows (see Appendix C3). This can have the effect of reducing flood risk in these regions, although this is difficult to quantify.

Probabilistic projections of snowfall rate were not provided in UKCP09 (although these were provided by UKCIP02). In the absence of this data, UKCP09 Briefing Report (Jenkins et al., 2009) refers to typical reductions of 65-80% over mountain areas and 80-95% elsewhere by the 2080s under the Medium emissions scenario (averaged over the 11 members of the Met Office Hadley Centre RCM ensemble). On the basis of such reductions, and, in combination with milder winters, the likelihood of snowmelt floods is expected to decrease, although the magnitude of extreme floods in high catchments could increase.

Coastal flooding due to high tides and storm surges can also cause damage, particularly around tidal estuaries. This is potentially a significant problem, particularly in low lying urban areas with significant coastal development. The option of building new or expanding existing coastal defence structures may also not be a viable option in the future (as it so often has in the past), and natural flood management may become a more attractive option from both an environmental and economic perspective. This may be further exacerbated due to the projections of sea level rise (Section 2.3.3).

Vulnerability to flooding is influenced both by location and by construction type. Traditionally, a large amount of new development has been on flood plains. This is often partly a consequence of the existing geography; towns and cities are often based around rivers as they are good connection points.

The damage caused to property by flooding will depend on the building type. Much of the property damage caused by flooding will be internal, to decoration, internal plasterwork, woodwork including wooden floors and goods and appliances. External damage may be caused by sea water, corrosive agricultural run-off. Massive masonry constructions will withstand light flooding with relatively little damage but will be much
harder to reinstate in the case of major floods. Lightweight, framed or modular constructions may suffer more severe damage but will be easier to reinstate (Austin et al., 2008 and Sanders and Phillipson, 2003).

In addition services may be disrupted by flooding, making reinstatement of the building more difficult (Austin et al., 2008 and Sanders and Phillipson, 2003).

In the past, it has always been assumed that, given sufficient investment, we can engineer our way out of flood risk. In future this will not always be possible.

Currently there are approximately 130,000 properties (of which 118,000 are residential) at risk of flooding to a 1 in 200 year return period in Scotland. These figures include both river and coastal flooding and Weighted Average Annual Damages (WAAD) are estimated at almost £1bn (Appendix C1). This equates to approximately 50,000 to 55,000 properties (of which about 45,000 to 50,000 are residential) in the 75 year floodplain, i.e. at significant likelihood of flooding. SEPA holds flood risk data on an indicative river and coastal flood map (see Figure 4.27), however, as no flood risk assessment for Scotland currently considers climate change, results based on the England and Wales analysis indicates that the number of properties at significant likelihood of flooding could increase by at least 40% by the 2050s and 60% by the 2080s, although the risk could be significantly greater (possibly 2-3 times greater by the 2080s).

Although the National Flood Risk Assessment for Scotland is currently being undertaken by SEPA, reference to Figure 3.5 highlights the potential risk to Scotland. Based on this figure (using the central estimate of the Medium emissions scenario), properties flooding now at least every 100 years could be expected to flood at least once every 80 years by the 2020s and in the region of once every 40 years by the 2050s and once every 15 years by the 2080s. However, with changing probability of flooding highly dependant on location and future coastal processes, the level of risk to different properties will vary as sea levels increase. Some properties not currently at significant likelihood of flooding, or which historically have not previously flooded, may therefore be expected to flood on a more regular basis in the future, possibly on a more regular rate than some currently at significant likelihood of flooding.

**Rainwater**

Increased levels of winter rainfall, wind-driven rain and rainfall events resulting in damage and increased rates of deterioration, could result in an increase in rainwater penetration of buildings with consequent negative effects on the health of occupants. This was highlighted as a high-risk concern for Scotland by the Scottish Government (2009b). This was also highlighted as a concern for Heritage Buildings (response from The National Trust for Scotland) as there are a significant number of Historic brickwork buildings in Scotland (see below). These types of buildings are potentially more susceptible to water penetration than those constructed of sandstone (Cessar and Hawkins, 2007). Scotland does not have many exposed brick buildings (nearly all are rendered) and how permeable they are/are not will depend on the type of brick and the type of sandstone. In Scotland generally bricks are harder and rendered, making the structure more water resistant than sandstone, unless the render is defective.

Building materials selected for the external fabric of new buildings are designed and constructed for their resistance to potential rain penetration (as were historic/traditional materials). Increases in wind driven rain and increased levels of rainfall can raise the severity of expected rain penetration (e.g. from moderate to severe) to a level where a building’s external elements, materials or joints, may no longer provide the precipitation

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168 Current Building Regulations include requirements to include flood resilience measures in new buildings and in the reinstatement of buildings (see for example CLG, (2007) and CIRIA (2005).
resistance needed. This increased effect of wind driven rain will be particularly relevant where external walls do not have a suitable cavity or rain screen, Scottish Government (2009b). For example, driving rain will affect rubble stone and built properties to a greater extent than those with render or cladding (Lisø et al., 2003). Dependent on its exposure rating, cavity wall insulation (often recommended to increase the thermal efficiency of buildings) may actually render buildings more vulnerable to rain penetration in certain conditions of driving rain (Stirling, 2002; Austin et al., 2008). Increased cavities and gaps in the insulation may be needed to address this problem (Sanders and Phillipson, 2003) (although not really feasible for existing structures). Buildings are also struggling to cope with the volume and power of torrential downpours (also see below). Roofs and rainwater goods are overwhelmed, especially where basic maintenance has been neglected, leading to an increased likelihood of rainwater penetration into buildings through (for example) roofs and flashings and around windows. An assessment of wind-driven rain for Scotland (see Appendix C4) indicates that this is likely to become an increasing risk for Scotland, particularly in the east and north of the country, putting an added maintenance burden on buildings of all types. For the upper estimate of the High emissions scenario, this could become a more significant problem for most of the west and south of the country by the 2080s, although the lack of research in this area means this is difficult to quantify. However, there is a suggestion that the perceived risk is over-emphasised, and the risk to Scotland’s infrastructure may be limited (University of Waterloo, 2011).

A projected increase in winter rainfall would also increase waterlogging of construction sites, with consequent effects on construction activities. However, suitable data was not available to assess this metric.

**Historic and traditionally constructed buildings**

Scotland’s historic buildings are culturally important, and were built to withstand the harsh northern climate. With the added loading discussed above, these will come under additional pressure, and will be vulnerable to extreme weather events particularly when repair and maintenance work has been overlooked. With a lack of maintenance they are susceptible to damp and condensation, as are any structures. The fabric of traditionally built structures is generally vapour permeable, allowing moisture to pass through the fabric of the building and regulate internal humidity. Modern impermeable materials can exacerbate the problem. Moisture proof plaster or insulation, trap moisture internally increasing the risk of damp and condensation (English Heritage, 2002).

Historic and traditional buildings can also be vulnerable to damp problems arising from water ingress, occurring due to a lack of maintenance such as damaged gutters, downpipes, windows and roofing, causing decay of the traditional construction materials (Historic Scotland, 2007). This can cause algal and fungal growth, as well as accelerated weathering of stone and corrosion of metals. Increases in winter rainfall and extreme weather events would be expected to cause greater damage to the building fabric. Traditionally constructed buildings rely on a degree of water exchange between weather events – a mass wall absorbs and then looses water as the weather changes. With increased precipitation, these walls may never dry out and could become progressively saturated, leading to binder migration and loss of structural integrity. Furthermore, milder winters may reduce prolonged heating of historic buildings, as recommended to manage or prevent damp (English Heritage, 2002). In

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169 Current research into rainfall penetration is scarce, with the majority of the literature looking at the impact of climate change on urban drainage (personal communication, Dr David Kelly, Heriot-Watt University). Ongoing research as part of the DOWNPIPE project (http://www.ukcip-arcc.org.uk/content/view/591/517) may confirm the findings of the University of Waterloo study, however the initial results of this study are not due for release until after this report has been issued.

170 [http://www.historic-scotland.gov.uk/index/heritage/climatechange/effectonenvironment.htm](http://www.historic-scotland.gov.uk/index/heritage/climatechange/effectonenvironment.htm)
addition, with fewer frosts to kill off species that live some of their life cycles outdoors, infestations of species including Webbing Clothes Moth and Carpet Beetle are likely to become more common (although this problem will not be unique to older buildings). Higher relative humidity levels resulting from likely increased probability and levels of flooding and rainwater penetration are also likely to cause an increase in the number of insect pests (National Trust response, also see Appendix C4).

**Condensation, Damp and Mould**

Damp caused by cold houses and condensation (Scottish Government, 2005a) or by warm, humid environments (Howieson, 2003), can lead to an increase in algal and fungal growth in buildings (NHS Scotland, 2002). This can play a significant role in respiratory health, greatly exacerbating susceptibility to asthma; probably the most commonly discussed respiratory disease after the common cold.

Condensation, damp and mould is directly related to moisture within the air. It is of a greater problem in cold houses where condensation can form on cold walls and windows, common in buildings with poor insulation. Moisture problems may be exacerbated by rainwater penetration and therefore are directly linked to the building fabric and climate. An increase in extreme weather events may cause more houses to suffer rainwater ingress caused by storm damage. Additionally, for historical buildings which ‘breathe’ the addition of modern damp proof layers may trap moisture within the structure increasing the risk of damp and mould growth. Climate projections indicating an increase in heavy rainfall days and extreme events suggest that rainwater penetration may increase for Scotland in the future.

**Urban space**

In the context of the urban system, green infrastructure can provide a valuable cooling resource due to the exacerbating effect of the Urban Heat Island (UHI), and a key resource for habitats. To alleviate UHI effects adequate open space is needed within the urban matrix. The Commission for Architecture and the Built Environment (CABE) is doing a lot of work on green infrastructure. Localities with less useable green space, i.e. open space deficit - which CABE research suggests are poorer areas – will be more vulnerable. Therefore the UHI could be an additional effect for this sector of society, as they have neither the option to mechanically cool nor the option to go out into a local green space to cool off. However, during extremely hot periods or hot years, green spaces can become so parched that their cooling capacity is effectively shut down. However, with in general lower projected temperatures, this is expected to be less of a problem for Scotland than for the rest of the UK. Indeed, warmer weather could result in a net immigration into Scotland, which would result in an increased demand for all services including water, food, energy and health services etc. However, the Foresight project “Global Environmental Migration” due for publication later this year, currently indicates that there is little evidence for climate change causing inter-border migration. In terms of places, city centres and densely built urban areas will be most affected, due to the exacerbating effect of the Urban Heat Island, when conditions in Scotland allow.

Additional benefits of a healthy green space are their ability to act as sustainable drainage during heavy rain. Green spaces will allow infiltration and percolation of water through the ground and vegetation will provide evaporation of water reducing the runoff into watercourses, helping to reduce the risk of flooding. Parched green spaces may be limited in their efficiency to drain runoff and rainfall, reducing their attenuation potential.

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171 Mould growth occurs when the relative humidity reaches 80% (BS 5250) causing moisture to condense on cold surfaces.
The risk of subsidence poses an indirect threat to the green infrastructure of built-up areas. However, there is a definite risk that insurers will demand that individual trees are taken out because of subsidence risks in vulnerable areas. Although this risk in Scotland is in general relatively low, the cumulative effect on green infrastructure could be significant.

Figure 4.35 Urban green space: Princes Street Gardens, Edinburgh.

The main adverse impact identified in the CCRA analysis is the effect of higher summer temperatures and reduced rainfall on urban green space. The capacity of green space to provide cooling benefits within urban environments is likely to reduce as temperatures rise, although this may be less of an issue in Scotland than other areas of the UK. The landscape will also be affected as vegetation dries out.

The effect of climate change on urban green space was represented in the CCRA by a reduction in the effective area of green space. It is projected that the reduction could be about 15% by the 2050s rising to over 30% by the 2080s.

4.5.6 Buildings and the urban environment: summary

Summary of results

The results of the analysis are shown in Table 4.19.
Table 4.19 Climate change impacts on Buildings and the urban environment

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
<th>Time Horizon</th>
<th>Confidence</th>
<th>Coverage</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowmelt flooding (reduction in snow cover)</td>
<td>Property at risk of flooding</td>
<td>2020s</td>
<td>S</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>BE10, BE11, BE12, BE15, BE18, FL6, FL24</td>
<td>Effectiveness of green space for cooling</td>
<td>2050s</td>
<td>S</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>BE5</td>
<td>Increase in damp, mould and insect pests in buildings</td>
<td>2080s</td>
<td>S</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>BE13</td>
<td>Rainwater penetration</td>
<td></td>
<td>S</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>FL41</td>
<td>Snowmelt flooding (reduced attenuation)</td>
<td></td>
<td>S</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>BE32</td>
<td>Waterlogging</td>
<td></td>
<td>Too uncertain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIN7</td>
<td>Immigration to EU countries</td>
<td></td>
<td>Too uncertain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Coverage of analysis**
- S: Analysis undertaken for Scotland only
- UK: Analysis undertaken for the UK

**Method of analysis**
- IJ: Informed judgement
- Q: Quantitative

**Summary of the main impacts of climate change on buildings**

Impacts of the projected increases in flooding on buildings are potentially a major consequence of climate change. Although figures for Scotland are not available, in the region of at least 40% more residential properties could be at significant likelihood of flooding by the 2050s, and at least 60% more residential properties by the 2080s.

The effects of heat in the urban environment are projected to become increasingly important including both the environment within buildings and the wider urban environment. Green spaces may become less effective at providing cooling, and providing rainwater and runoff drainage.
4.6 Health and Wellbeing

Scotland has a population of about 5.2 million people. This is projected to rise to about 5.5 million by the 2080s (range 3.6 to 8.1 million). Climate change may affect Scotland’s population in the home, the workplace and at the community level.

Wellbeing is a broad concept which can be difficult to measure. It determinates may include (NEF 2011):

- External conditions, including economic conditions that affect income and material wealth, the places that people live and work and access to green space and the natural environment.
- Personal resources, including people’s physical and mental health, resilience or ability to recover from extreme events, knowledge and personal outlook.
- Functioning and satisfaction of needs, including awareness and ability to plan for and respond to risks, staying safe and secure and being part of the local community.

Some of the conditions that affect these aspects of wellbeing have been covered by the previous themes in this report. However, methods for measuring wellbeing directly are still in their infancy, so it is not yet possible to link climate change directly to these measures.

The impacts of climate change on human health may include:

**Risks:**

- Increased flooding from sea level rise, higher winter precipitation and more intense summer storms
- Higher temperatures, causing adverse impacts in summer including an increase in heat-related deaths (referred to as premature deaths) and additional respiratory hospital admissions
- Higher temperatures, leading to an increase in fungal and algae growth in buildings and greater risks to certain water, food and vector-borne diseases

**Benefits:**

- Higher temperatures, causing beneficial impacts in winter including a reduction in cold-related deaths (referred to as premature deaths avoided) and a reduction in respiratory hospital admissions
- Higher temperatures will lead to a reduced reliance on heating and consequently may help alleviate the effects of fuel poverty

These risks and benefits will not however be evenly spread, with pockets of dense urban development that are more at risk of surface water flooding and summer heat stress, in addition to remote communities that are more vulnerable to transport disruption and interruption to critical services from extreme weather (also discussion in sections 4.4 and 4.5).
Human health effects of climate change are likely to have the greatest impact on vulnerable people; particularly in Scotland which generally has areas of higher deprivation than the rest of the UK. For example, approximately three times as many people in Scotland are in fuel poverty relative to England\textsuperscript{180}, although projected warmer temperatures would be expected to reduce fuel poverty.

The negative health effects of climate change are also likely to be disproportionately severe in areas of high deprivation (such as some areas of Glasgow), because of the ability of individuals and communities to prepare, respond and recover\textsuperscript{173}. However, the Scottish Index of Multiple Deprivation (SIMD)\textsuperscript{174} which is an area measure of multiple deprivation by rank may provide some indication of areas where there is particular vulnerability to climate related environmental change. The elderly population, who are less resilient to changes in climate and associated weather events, are also projected to increase during the 21\textsuperscript{st} century, putting an additional burden on health and social care services (Health Sector Report).

The effects of weather and climate on human health have been widely researched and are relatively tangible. Because of this, the CCRA analysis has focused on health related impacts, which is reflected in the following sections. It should be noted that the health impacts quantified in this section assume no advancement in medical science and no level of adaptation to the changing level of risks.

4.6.1 Floods

As the frequency and magnitude of floods increase, there will be an increase in the level of risk and hence potential deaths\textsuperscript{175}, injuries\textsuperscript{176} and mental health effects\textsuperscript{177} of people who are affected by both fluvial and coastal flooding. In addition to fluvial and coastal flooding, there is an additional risk associated with storm action at the coast resulting in people getting struck by waves and sometimes washed out to sea during periods of heavy wave action. Risk during flooding is also generally greater amongst the vulnerable, as noted for the elderly in the 1953 flood by Baxter (2005). However, there is also a suggestion that the elderly of the current/recent generation have more of an inbuilt resilience as a result of past experiences, including living through the 2\textsuperscript{nd} World War (Tunstall \textit{et al.}, 2006).

The general small number of flood related deaths in the UK meant current day estimates of flood related deaths and therefore change in risk as a result of a changing climate was difficult to assess. This was particularly the case on the coast, where there have been no known deaths due to coastal flooding in the UK since 1953\textsuperscript{178}. This therefore also applies to flood related injuries which were assessed as a direct relationship to flood related deaths. The small number of deaths due to wave action

\textsuperscript{173} Recent research by the Joseph Rowntree Foundation found that Glasgow is the most highly vulnerable area in Scotland to flooding and heat stress, in large part as a result of the high levels of deprivation. Vulnerability was also found to be higher in the north and central Highlands due to their remoteness (Lindley \textit{et al.}, 2011).
\textsuperscript{174} http://www.scotland.gov.uk/Topics/Statistics/SIMD
\textsuperscript{175} A flood death is defined as any death that can be considered to have taken place as a result of a flood, whether as a direct or indirect result (see for example Health Protection Agency (2010).\textsuperscript{181}
\textsuperscript{176} For the CCRA, a flood related injury was defined as an injury sustained during a flood event that required medical attention as a result of a hospital admission.
\textsuperscript{177} An (unspecified) mental health effect due to flooding has been defined in the CCRA as a person who goes from a 12 item Global Health Questionnaire (GHQ-12) score of below 4 to 4 or above as a result of a flood event. This is covered in detail in the Health Sector report.
\textsuperscript{178} A family of five tragically lost their lives as they fled flooding of their home in the Western Isles on 11\textsuperscript{th} January 2005. These deaths, although caused by an attempt to escape the flooding, were as a result of severe wave action as they drove across the causeway between Benbecula and South Uist. These deaths are therefore attributed to storm activity as a result of wave overtopping, as opposed to flooding, or more specifically inundation (see Health Sector report).
caused by storms is also very specific to the location, and the conditions on the day as well as the behaviour of the people involved. No regional estimates of additional potential deaths, or injuries as a result of flooding or coastal wave action (storms) were made for the CCRA. However, additional flood related deaths and injuries are small, unlikely to exceed on an annual basis approximately 5 and 100 respectively for Scotland by the 2080s based on the High emissions scenario.

For those additional people who suffer a mental health effect due to flooding, no regional estimates have been made, although the total number of people affected was estimated in the CCRA to be 30-40% of those flooded. On a UK basis, estimates of the increased number of people to suffer a mental health effect due to increased levels of flooding as a result of climate change were estimated as 4,000 to 7,000 by the 2050s and 5,000 to 8,000 by the 2080s for the present day demographics. For Scotland, it is likely that these estimates will be in the region of up to a tenth of these figures based on the current flood risk to Scotland (Appendix C1), and linked to the number of properties that may be at flood risk outlined in Section 4.5.5.

### 4.6.2 Increased temperatures

If summer temperatures increase in the future as projected, this may have a consequent effect on the number of premature deaths and additional hospital admissions as a result of heat related illnesses (cardio-vascular and respiratory diseases). These numbers tend to increase above normal summer temperatures.

If winters become milder in the future as projected, the number of premature deaths avoided may increase and the number of additional cold related hospital admissions may reduce. These numbers tend to increase as the temperature falls. However, in winter there are increased numbers of cases of infectious diseases such as influenza and pneumonia, which means that deaths and hospital admissions are more difficult to attribute to cold weather alone.

The temperature thresholds for which deaths increase for summer and winter vary for each region of the UK, and a level of natural adaptation means that the thresholds are generally lower for colder regions and higher for hotter regions. This would mean that future cold snaps of the level experienced in recent winters (2009/10 and 2010/11) would be expected to result in a significant increase in premature deaths as a future population would be expected to be less naturally adapted to these temperatures.

Based on current population figures for Scotland, the numbers of additional premature deaths due to higher summer temperatures were projected to be approximately 100 (range 25 to 285) by the 2050s and 200 (range 50 to 660) by the 2080s. Based on future (principal) population projections, these figures increase by approximately 10%. In 2009 there were approximately 52,500 deaths in Scotland (10.1 deaths per 1,000 population), with the average age of death 75.4 years (see Health Sector Report). Therefore, these projected increases in deaths are very small in relation to the number of deaths likely for all causes in any particular year.

Based on current population figures for Scotland, the numbers of premature deaths avoided due to milder winters were projected to be approximately 550 to 890 (range 200 to 1,570) by the 2050s and approximately 800 to 1,310 (range 330 to 2330) by the 2080s. Based on future (principal) population projections, these figures increase by approximately 10%.

Evidence presented in the CCRA analysis indicated that heat and cold related hospital admissions were of the order of 100 times greater than the number of deaths, with 179 This is the number of separate patient admissions.
the effects being particularly felt by the elderly, very young and sick (Vassallo et al., 1995).

Mortality and Morbidity statistics

The mortality and morbidity statistics used in this section have been based on a variety of officially recorded statistics published by various Government departments. Further details of the source of these data sets are given in the Health Sector Report, Table A6.4.

4.6.3 Fuel poverty and algal fungal growth in buildings

Fuel poverty is the inability to heat a home to an acceptable level for reasons of cost. Each household has a specific requirement for heat and for energy more generally, depending on the number of occupants, their age and their lifestyle. Three key factors influence the ability of the household to pay for that energy: income, energy efficiency and energy costs. Fuel poverty can impact negatively on quality of life and health, with a compromise to pay for heating leading to a poor diet and a reduction in social, leisure and recreation activities. A failure to heat homes or heating of parts of homes can also lead to an increase in condensation and an increase in fungal growth with a consequential knock-on effect on those vulnerable to asthma and other respiratory diseases.

Fuel poverty is a real issue for thousands of Scottish households who are struggling to heat their homes in the coldest region of the UK and to pay their fuel bills. The Scottish Government (2008) estimate that as of 2005/06 3 times more households in Scotland were fuel poor than in England, despite the fact that houses in Scotland are generally more energy efficient than in England (Scottish Government, 2008). Currently about a third of households in Scotland suffer fuel poverty (National Statistics, 2010). Additionally, more than 80% of those earning £100 per week or less and 38% of council house occupants experience fuel poverty.

In the face of continuing high fuel prices, including substantial increases in 2011 alone of up 24%181, more and more people are falling into fuel poverty particularly in many of the large Scottish cities.

An increase in mean temperatures would therefore be seen as an opportunity for Scotland to reduce heating requirements in winter, and therefore potentially reduce fuel poverty (although as stated above, this will also depend on other factors, including fuel prices and income levels etc.). However, future cold spells of the levels experienced in recent winters (2009/10 and 2010/11) would be expected to exacerbate fuel poverty, particularly for a future population less used to these levels of temperature. Warmer wetter winters, and increased flood risk of subfloor and basement areas may be anticipated to result in buildings being wet for longer, with increased fungal growth (discussed below). Fungal spores are respiratory allergens with implications for the initiation and exacerbation of allergic respiratory disease including asthma (NHS Scotland, 2002 and Sanders et al., 2004). House dust mites are also known to proliferate in warm, humid conditions and the allergic potential of house dust mite faeces is known to exceed even that of fungi. It may therefore be hypothesised that

180 There are several definitions of fuel poverty. The one used by Scotland was defined by the 2002 Scottish Fuel Poverty Statement as a household that in order to maintain a satisfactory heating regime, would be required to spend more than 10% of its income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use. The definition of fuel poverty is also currently being reviewed by UK Government, with an interim report published in October 2011 (Hills, 2011) with the final report due in January 2012.
181 [Link to article: http://www.independent.co.uk/news/business/news/soaring-energy-bills-hit-home-2339309.html]
climate change will have implications for domestic allergen load and, by extension, human health and wellbeing.

**Effect of housing conditions on respiratory conditions**

The links between respiratory health and damp are complex and not fully understood. However, damp caused by cold houses and condensation (Scottish Government, 2005a) or by warm, humid environments (Howieson, 2003), can lead to an increase in algal and fungal growth in buildings (NHS Scotland, 2002). This can play a significant role in respiratory health, greatly exacerbating susceptibility to asthma; probably the most commonly discussed respiratory disease after the common cold. Respiratory conditions, aches and pains and nerves may also be attributed to damp housing (Scottish Government, 2005a). With national surveys in Scotland indicating dampness affecting in the region of 430,000 houses (National Statistics, 2010), this could result in a significant health risk for Scotland.

Within Scotland there are approximately 390,000 people with asthma (Asthma UK, 2005) affecting about 20% of households (National Statistics, 2010). Of these, approximately 100 people a year die of asthma. Correlating people with asthma against dwellings within Glasgow, Williamson et al., (1997) indicated a clear link between damp housing and asthma, and for the analysis carried out, indicated that you were in the region of 50-60% more likely to have physician diagnosed asthma if you lived in a property affected by damp or condensation than if you didn’t (Wilkinson, 1999). This suggests that approximately 10% of people in Scotland, who have physician diagnosed asthma, have it as a result of living in a damp property, although this cannot be quantified accurately.

The impact of damp and mould on respiratory conditions is also greater in children (Williamson et al., 1997, Evans et al., 2000, Shelter Scotland, 2011) and recent surveys have shown a 20% increase in the number of children living in a damp home in Scotland (Shelter Scotland, 2011). As links between fuel poverty and dampness are well documented (Barnados, 2005, Olsen, 2001) it is unsurprising that respiratory conditions are more prevalent amongst those from low income backgrounds and poorer societies.

Warmer, wetter climate projected for Scotland by the end of the current century would provide conditions favourable to mould and dampness, and it would therefore be expected that the number of respiratory problems, and therefore the number of asthma cases would increase. However, in reality the Scottish Government aims to remove substandard housing by 2015 (Housing (Scotland) Act, 2006) with the aim to eradicate fuel poverty by 2016, reducing damp homes and the effect on respiratory conditions. This would therefore negate the impact of climate change.

**4.6.4 Vector, food and water borne diseases**

Vector reproduction, parasite development and bite frequency generally rise with temperature. Therefore, malaria, tick-borne encephalitis, and dengue fever at a global level are very likely to become increasingly widespread due to projected rises in temperatures (Costello et al., 2009 and IPCC, 2007). Combined with projected changes in rainfall, this could also pose significant problems regarding the occurrence of microbial pathogens in the marine environment. The risk of new vector species being introduced to the UK is relatively low (Medlock et al., 2005 and Rogers et al., 2008), although citizens visiting vector-borne endemic countries overseas would be

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182 based on the 2007, 2008 and 2009 Scottish house condition surveys
183 this is based on an assessment of recent death rates for asthma, and is discussed in more detail in Appendix C, Section C8
expected to be at higher risk. Although malarial transmission from mosquitoes cannot currently be supported in the Scottish climate (Rogers et al., 2008), based on UKCP02 projections, Rogers et al., 2008 indicated that this could change with some parts of the Central Lowlands “potentially” supporting climate conditions favourable to increases in the prevalence of certain vector-borne diseases such as malaria towards the end of the current century.

However, future outbreaks of certain vector-borne diseases such as malaria would still be expected to be rare and limited in number (Rogers et al., 2008), and it is likely that the public health infrastructure in Scotland would prevent the indigenous spread of these diseases (Kuhn et al., 2003 and Hunter, 2003).

Tick-borne encephalitis and Lyme disease may present local problems in Scotland due to changes in the ecosystem. However, the increase in their overall impact is likely to be small and would mainly be dependant on agricultural and wildlife management practices (see also Section 4.3.2). There is also no conclusive evidence indicating that climate change substantially contributes to tick-borne encephalitis in Europe (Randolph, 2004 and 2010).

Visitors to vector-borne endemic countries overseas will be at highest risk, and changes in the regional climate of Northern Europe may also lead to an increased risk of the introduction of new diseases. 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 (‘autochthonous cases’). 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, 2011).

Prompt action to any outbreaks will also reduce the chances of endemic malaria transmission in the UK.

In the marine environment, cases of gastrointestinal and respiratory illness, ear and wound infections have been reported following bathing (Fleisher et al., 1996; Oliver, 2005). In addition, a number of shellfish-related illness are reported in the UK each year, most of which are attributed to noroviruses which cause gastroenteritis (Lees, 2000). The majority of these outbreaks are associated with consuming raw oysters (Lees, 2000). Cockles and mussels have also been responsible for some large outbreaks in the UK (Lees, 2000), but they have not occurred in recent years possibly due to improvements in sewage treatment. These outbreaks usually arise from shellfish harvested from class B areas (and are therefore subject to post-harvesting purification treatments) or shellfish that have not met statutory public health controls.

In the UK, the existing evidence shows seasonal variation in levels of water-related pathogens and increases that may relate to warmer summer temperatures (Nichols and Kovats, 2008). This could increase future *Vibrio vulnificus* and *Vibrio parahaemolyticus* infections, although sustained warming events (>20°C) are the most significant risk factor associated with vibrio outbreaks; temperatures unlikely to be regularly reached (or sustained) in Scottish coastal waters before the end of the current century. There is little evidence as yet that climate change has affected incidence rates of water and shellfish-related illness. However, there is good evidence internationally that norovirus outbreaks are linked to rainfall driven pollution events (Lees, 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\(^{184}\) with significant associated precipitation events. This

\(^{184}\) http://www.metoffice.gov.uk/climate/uk/2010/winter.html
period was associated with an unprecedented number of shellfish related norovirus illness outbreaks (Westrell et al., 2010).

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 and Box 4.2). Higher temperatures as a result of climate change might exacerbate the food borne disease problem (food poisoning, Salmonellosis, Salmonella Typhimurium infections and Salmonella Enteritidis infections) in the UK (Kovats et al., 2004). Given the current level of food poisoning notifications, an increase of 1°C, would result in an approximate 4,000 additional notifications in the UK\footnote{There are currently in the region of 100,000 reported cases of food poisoning cases in the UK every year, NHS (2011).}, although due to under reporting, the real level of additional cases could be around nine times this figure (Stanwell-Smith, 2008). 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. Despite this, the impact of climate change on this aspect of UK public health is likely to be relatively small compared to other factors such as improved food hygiene (Lake et al., 2009).

Box 4.2 The effect of rising temperatures on food poisoning (adapted from Stanwell-Smith, 2008)
The food poisoning risk will increase with climate change, accelerating the already established seasonal variation:

- increased multiplication of pathogens at high temperatures e.g. Salmonella growth occurs above 7°C, optimum at 37°C and Campylobacter growth increases above 30°C.
- higher temperatures also increase rate of infection in animals (e.g. multiplication of bacteria in animal feeds), thus adding risk to the food chain.
- change in food eating behaviour e.g. more barbecues and outdoor eating.
- studies have shown that food poisoning rates correlate with temperature a month earlier, consistent with time taken for the food chain to be affected and cases to emerge.
- a mean temperature increase of 1°C (expected within the next 30 years or so) is estimated to increase food poisoning by 4.5% across the UK, with a higher risk of that due to Salmonella of approximately 12.5% (Kovats et al., 2004). An increase of 2°C would increase food poisoning notifications by approximately 9.5%, while an increase of 3°C would raise them by approximately 14.8% (Bentham, 2008).
- The evidence is sufficiently strong for public warnings about food poisoning to be considered during hot weather periods: Salmonella is strongly related to temperature in the range 7-37°C and the common threshold for the 1 week lag effect in the study of 13 European countries (Kovats et al., 2004) was 6°C.

Although there have been several outbreaks of cryptosporidiosis and E. coli O157 in recent years (See Appendix C5), these have been associated with failures in the treatment of public and private drinking water supplies (Mukherjee, 2002; Licence et al., 2002). In major urban centres, effective forms of water treatment exist, and it is likely that the environmental and public health infrastructure in Scotland would prevent
the indigenous spread of any water borne diseases. However, there are a number of rural communities served by drinking water supplies, where current treatment is inadequate at removing Cryptosporidium oocysts. This currently represents 3% of the Scottish population, and with these areas often surrounded by farmed and/or wild animals, are at most risk (see for example Pollock et al., 2008; Pollock et al., 2010).

Current activities undertaken to improve private water supplies may also inadvertently mitigate against climate change effects.

Given that Scottish Water has a water safety programme for all of its water supplies by the end of 2011, it is likely that municipal drinking water will largely be free of waterborne pathogens such as Cryptosporidium and verotoxin-producing Escherichia coli (VTEC). Assessing the UKCP09 projections, it is unlikely that the number of cases of cryptosporidiosis or VTEC associated with drinking water should significantly change by the 2020s. However, by the 2050s and 2080s, potential increases in temperatures of up to 2.8°C and 4.4°C for the upper estimate of the High emissions scenario may have a bearing on pathogen survival on land and in drinking water (Chief Medical Officer, 2001). 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 not possible to predict how climate change may affect waterborne disease. However, 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.
**Summary of results**

The results of the analysis are shown in Table 4.20. Note that heat and cold mortality and morbidity have been added to this table to reflect feedback received on early drafts of this report, despite these not being in the original Tier 2 list for Scotland.

### Table 4.20 Climate change impacts on Health and Wellbeing

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
<th>Confidence</th>
<th>Coverage</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE5</td>
<td>Decline in winter mortality due to higher temperatures</td>
<td>Central estimate</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>HE6</td>
<td>Decline in winter mortality due to higher temperatures</td>
<td>Central estimate</td>
<td>S</td>
<td>Q</td>
</tr>
<tr>
<td>ENr1</td>
<td>Fuel poverty (people affected)</td>
<td>Too uncertain</td>
<td>S</td>
<td>IJ</td>
</tr>
<tr>
<td>HE10</td>
<td>Effects of floods/storms on mental health</td>
<td>UK</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>FL2</td>
<td>Vulnerable people at significant risk of flooding</td>
<td>S</td>
<td>IJ</td>
<td></td>
</tr>
<tr>
<td>MA2a</td>
<td>Decline in marine water quality due to sewer overflows</td>
<td>UK</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>HE3</td>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>UK</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>FL1</td>
<td>Number of people at significant risk of flooding</td>
<td>S</td>
<td>IJ</td>
<td></td>
</tr>
<tr>
<td>HE1</td>
<td>Summer mortality due to higher temperatures</td>
<td>S</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>HE2</td>
<td>Summer morbidity due to higher temperatures</td>
<td>S</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>HE7</td>
<td>Extreme weather event (flooding and storms) injuries</td>
<td>S</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td>HE19</td>
<td>Increased algal or fungal/mould growth in buildings affecting respiratory conditions</td>
<td>S</td>
<td>IJ</td>
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<tr>
<td>MA2b/HE16</td>
<td>Incidents of human illness due to hosts and pathogens</td>
<td>S</td>
<td>IJ</td>
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<tr>
<td>HE11/17</td>
<td>Increase in prevalence of certain vector borne diseases (ticks and lymes)</td>
<td>S</td>
<td>IJ</td>
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<td>HE15</td>
<td>Foodborne diseases</td>
<td>Too uncertain</td>
<td>S</td>
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<table>
<thead>
<tr>
<th>Central estimate</th>
<th>Timing 2020s</th>
<th>2050s</th>
<th>2080s</th>
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</tr>
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<td>Threats</td>
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<td>HE19</td>
</tr>
<tr>
<td></td>
<td>MA2b/HE16</td>
<td>HE11/17</td>
<td>HE15</td>
</tr>
</tbody>
</table>

*Coverage of analysis | **Method of analysis* 
S | Analysis undertaken for Scotland only | IJ | Informed judgement |
UK | Analysis undertaken for the UK | Q | Quantitative |

**Summary of the main impacts of climate change on health and wellbeing**

- The projected increase in floods would on an annual basis result in a greater proportion of people at risk of death, injury or mental health effects. Although this could result in a significant increase for mental health effects (with up to approximately 800 additional people suffering a mental health effect due to flooding by the 2080s), the projected increase in deaths or injuries due to flooding is small; unlikely to exceed approximately 5 and 100 respectively for Scotland by the 2080s.

- Higher temperatures may lead to an increase in heat-related deaths in the summer. Projections for the 2050s indicate approximately 100 (range 25 to 285) additional premature deaths as a result of warmer summers by this
Higher temperatures may lead to a reduction in cold-related deaths in the winter. Projections for the 2050s indicate approximately 550-890 (range 200 to 1,570) premature deaths avoided as a result of milder weather by the 2050s.

Hospital admissions are projected to increase in the summer as a result of warmer weather, of the order of 100 times greater than the number of heat related deaths.

Hospital admissions are projected to decrease in the winter as a result of warmer weather, of the order of 100 times greater than the number of cold related deaths.

Fuel poverty is likely to reduce due to higher mean temperatures; however, wetter warmer winters are likely to lead to increased algal and fungal growth in buildings with consequential effects on those vulnerable to asthma and other respiratory diseases.

The number of cases of vector, food and water borne diseases may increase. However, the impact on public health within Scotland is considered to be relatively small, with the indigenous spread of any diseases contained by the environmental and public health infrastructure.
5 Summary of consequences

5.1 Overview of potential consequences

The potential consequences of climate change are assessed by theme in Section 4, based on the Scotland Tier 2 list of impacts. This section considers the main consequences that have the potential to affect different parts of Scotland, based on the following geographical areas:

- Major towns and cities
- The Highlands
- The Islands
- Southern Uplands
- Lowlands
- The coast
- Coastal waters and the marine environment.

Some consequences are not directly related to geographical area and, therefore, are not reflected in this section. For example, climate change impacts on the financial sector would have consequences on investment and business in all parts of Scotland.
5.2 Consequences for different parts of Scotland

Figure 5.1 Scottish population and population density by unitary authority

<table>
<thead>
<tr>
<th>Unitary Authority</th>
<th>Population (1000's)</th>
<th>Area (km²)</th>
<th>People / km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Clackmannanshire</td>
<td>50.5</td>
<td>159</td>
<td>302</td>
</tr>
<tr>
<td>14 Fife</td>
<td>363.5</td>
<td>1,325</td>
<td>265</td>
</tr>
<tr>
<td>15 Dundee City</td>
<td>143.4</td>
<td>60</td>
<td>2,410</td>
</tr>
<tr>
<td>16 Angus</td>
<td>110.3</td>
<td>2,182</td>
<td>50</td>
</tr>
<tr>
<td>17 Aberdeenshire</td>
<td>243.5</td>
<td>6,313</td>
<td>36</td>
</tr>
<tr>
<td>18 Aberdeen City</td>
<td>213.8</td>
<td>186</td>
<td>1,127</td>
</tr>
<tr>
<td>19 Moray</td>
<td>87.7</td>
<td>2,238</td>
<td>39</td>
</tr>
<tr>
<td>20 Highland</td>
<td>220.5</td>
<td>25,659</td>
<td>8</td>
</tr>
<tr>
<td>21 Eilean Siar</td>
<td>26.2</td>
<td>3,071</td>
<td>9</td>
</tr>
<tr>
<td>22 Argyll &amp; Bute</td>
<td>90.0</td>
<td>6,909</td>
<td>13</td>
</tr>
<tr>
<td>23 Perth &amp; Kinross</td>
<td>145.9</td>
<td>5,286</td>
<td>26</td>
</tr>
<tr>
<td>24 Stirling</td>
<td>88.7</td>
<td>2,187</td>
<td>39</td>
</tr>
<tr>
<td>25 North Ayrshire</td>
<td>135.5</td>
<td>885</td>
<td>153</td>
</tr>
<tr>
<td>26 East Ayrshire</td>
<td>120.2</td>
<td>1,262</td>
<td>95</td>
</tr>
<tr>
<td>27 South Ayrshire Dumfries &amp; Galloway</td>
<td>111.4</td>
<td>1,222</td>
<td>91</td>
</tr>
<tr>
<td>28 South Ayrshire South</td>
<td>148.5</td>
<td>6,426</td>
<td>23</td>
</tr>
<tr>
<td>29 Lanarkshire</td>
<td>310.9</td>
<td>1,772</td>
<td>171</td>
</tr>
<tr>
<td>30 Scottish Borders</td>
<td>112.7</td>
<td>4,732</td>
<td>23</td>
</tr>
<tr>
<td>31 Orkney Islands</td>
<td>20.0</td>
<td>990</td>
<td>19</td>
</tr>
<tr>
<td>32 Shetland Isles</td>
<td>22.2</td>
<td>1,466</td>
<td>15</td>
</tr>
</tbody>
</table>

(Source: Office for National Statistics; General Register Office for Scotland)

5.2.1 Major towns and cities

The main population of Scotland is located along a long narrow belt through the centre of the country and along the east coast. The central belt stretches from Inverclyde on the west coast, through to Fife on the east coast. The east coast population is predominantly located between Aberdeen and Edinburgh. These areas house approximately 60% of the population of Scotland and contain the large cities of Glasgow, Edinburgh, Aberdeen and Dundee.
There are a number of potential climate change consequences for these areas, which include the following:

- An increase in flooding from the sea, rivers, surface water and sewers or any combination of these, causing damage to properties and putting lives at risk, with potential consequences for business and tourism (high negative consequence by the 2020s).

- An increase in disruption to infrastructure and services caused by flooding; and, in turn, an increase in disruption and costs for communities, the economy and employment, with the effects being more severe for vulnerable groups and small businesses (medium negative consequence by the 2020s).

- An increase in discharges into urban watercourses from combined sewer overflows, resulting in reduced water quality (high negative consequence by the 2080s).

- Rising winter temperatures leading to a reduced demand for heating (high positive consequence by the 2080s). However, with wetter winters algal and fungal growth in buildings may increase with negative consequences for those vulnerable to asthma and other respiratory diseases.

- A reduction in water availability, which would affect all water users including homes, industry and businesses (high negative consequence by the 2080s).

- An increase in demand for cooling for homes, offices, factories, schools, hospitals and other public buildings (medium negative consequence by the 2080s).

- A potential decrease in premature deaths due to cold and a reduction in fuel poverty may occur due to milder winters (high negative consequence by the 2080s).

### 5.2.2 The Highlands

Many of the potential climate change consequences for the Highlands have less of an impact on human activity than other regions, and indeed communities in the Highlands may be generally more resilient than communities in other parts of Scotland; however they are still of significance. The impacts on forestry are likely to be of most importance due to the extent of the forestry industry in this region. Potential climate change consequences for the Highlands include the following:

- A reduction in soil moisture, resulting in the drying out of blanket bogs and other habitats, leading to a loss of biodiversity and carbon storage (high negative consequence by the 2080s).

- An increased risk of wildfires, particularly affecting woodlands, grassland peat soils and heathlands (medium negative consequence by the 2080s).

- Increased forest productivity (in particular Sitka spruce) benefiting the timber industry and Scotland’s economy (high positive consequence for Sitka spruce by the 2080s).

- An increase in occurrences of pests and invasive non-native species, resulting in potential loss of native species (medium negative consequence by the 2080s).
• A warming climate could result in the movement of the climate space for a number of species, with the potential loss of dominant and iconic species; capercaillie, Scots pine, montane species (high negative consequence by the 2080s). Conversely, a warmer climate could also open up new opportunities for new species using Scotland as part of their migration path.

• An increase in temperatures could increase the risk of pathogen establishment in forest regions (high negative consequence by the 2080s).

• An increase in temperatures could increase the number of people participating in outdoor recreation (e.g. mountain biking, walking), improving the health and well being of Scotland. Conversely a reduction in levels of snowfall could result in an unsustainable Scottish ski industry by the end of the current century.

• Increased ICT disruption could negatively affect businesses throughout the year and limit productivity. Those who work from home and small businesses could suffer disproportionately.

5.2.3 The Islands

Due to the physical geography of the Islands of Scotland may of the biophysical impacts are similar to those of the Highlands. However, due to the remote and fragmented nature of the Islands and their communities the human impacts may be greater.

• An increase in occurrences of marine pests and invasive non-native species, resulting in potential loss of native species (high negative consequence by the 2080s), affecting fishing communities and tourism.

• An increase in sea levels is a significant risk for a number of low-lying properties on many of the Islands, particularly those that are experiencing significant rises in relative sea levels such as the Shetland Isles (high negative consequence by the 2020s). Coastal roads may also flood affecting Island communities and businesses.

• The potential loss of important historical sites located on the islands through sea-level rise (high negative consequence by the 2080s).

• Increased ICT disruption could negatively affect Island businesses and those working remotely.

• An increase in sea level rise if combined with storm surge events may increase travel disruption with particular impacts associated with disruption to ferry services.

• An increase in coastal erosion and flooding may impact on globally important ecosystems, including Machair (70% of the global extent of machair is found in Scotland), and associated ecosystems and biodiversity.

• An expansion of UK tourist destinations may offer opportunities for the Islands' tourism businesses and offer opportunities for new businesses if visitor numbers increase.
Case Study: Eilean Siar (The Outer Hebrides)

The Geography

Eilean Siar (or The Outer Hebrides) comprises an archipelago of over 200 islands. The chain of islands is around 130 miles (210 km) in length from north to south and there is over 1,800 miles (2,500 km) of coastline (based on Ordnance Survey measurements along the mean high water mark).

Many of the islands are very low-lying with large proportions of land below 5mOD. The soft sandy west coast is extremely vulnerable to Atlantic storms and coastal erosion is a major problem, especially for some archaeological and culturally important sites. The machair, see Section 4.2.3, and the inland loch system (7,500 freshwater lochs in total) are particularly ecologically rich and of international importance.

Away from the extensive areas of beach and machair, elsewhere the land is more typically ‘highland’, with mountains, cliffs, lochs and skerries. Most areas are peat-covered and provide a traditional fuel source.

The Community

The population is approximately 26,500 (based on the 2001 census). There are 15 inhabited islands, linked by a network of causeways, ferries and air routes. The majority of the population (18,256) lives on the most northerly island of Lewis with 8,100 living in the town of Stornoway. The next most populated islands of South Uist, Harris, North Uist, Benbecula and Barra have populations of less than 2,000 each. In the 2001 census, most islands were over 50% Gaelic speaking.

The Economy

Ports and harbours and larger towns are situated on the east coast with regular sailings.

Figure 5.2 South Uist, Eilean Siar
Source: www.liv.ac.uk

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186 http://www.liv.ac.uk/~agmclen/view3.html
to mainland Scotland, approximately 50 miles away. Tourism is very important and mostly based on the wildlife, natural landscapes and archaeological heritage.

Comhairle nan Eilean Siar (Western Isles Council) is the largest employer on the islands. The traditional industries of fishing and agriculture (in particular crofting) have been declining over a number of years. Fish farming is locally important and the Ministry of Defence is also a large employer, with a missile defence training and testing installation on South Uist that employs many civilians. The islands are also well known for weaving, including the manufacture of Harris Tweed.

Climate change

The possible effects of climate change in the Outer Hebrides are most likely to be manifested on the low-lying Atlantic coastal zone with its distinctive ancient machair dune system with a long history of dramatic change, almost entirely due to coastal erosion as well as accretion. Machair landscapes are more than landforms, soils, vegetation and wildlife, all of which are distinctive and important on any set of conservational standards. The landscape is also a product of socio-economic and cultural factors, mainly associated with distinctive crofting tenure and agricultural practices; practices that have changed significantly over recent decades.

With large proportions of land below 5mOD as stated above, the implications of future increases in sea levels under the upper range of the High++ scenario of 1.9m (Section 2.3.3) would be expected to be severe, with a significant change or loss of the Machair landscapes.

The Great Storm of January 2005

Severe Atlantic storms batter the islands at intervals. On 11th January 2005, the islands and the west coast of mainland Scotland were hit by the severest storm in living memory. Winds were in excess of 190 km/hr and there was a storm surge of around 2m, resulting in extensive coastal flooding.

Five members of the same family lost their lives when their cars were swept away as they were trying to escape (see Section 4.6.1). Roads, causeways and harbours connecting the low-lying islands were destroyed; fishing boats were wrecked and livestock drowned.

There was between £15 and £20 million worth of damage to the Western Isles Council’s (Comhairle nan Eilean Siar) infrastructure, damage to private houses and commercial buildings, plus loss of electricity supply and mobile phone communications.

5.2.4 Southern Uplands

The Southern Uplands share many of the same risks that face the Highlands and Islands. However, due to being located near the central belt there is a greater risk from human based activities. Potential climate change consequences include the following:

- A reduction in soil moisture, resulting in the drying out of blanket bogs and other habitats, leading to a loss of biodiversity and carbon storage affecting the higher areas of the central lowlands (high negative consequence by the 2080s).

- A warming climate could result in the movement of the climate space northwards for a number of species, with the potential loss of dominant and iconic species, including montane species (high negative consequence by the 2080s). Conversely, a warmer climate could also open up new...
opportunities for new species entering Scotland as part of their migration path.

- An increase in the agricultural intensification of marginal areas encroaching on the Upland areas (negative consequences to the natural environment are too uncertain to estimate), as the local land classification improves increasing agricultural opportunities (high positive consequence for agriculture by the 2080s).

- An increase in temperatures could increase the risk of pathogen establishment in forest regions (high negative consequence by the 2080s).

- Tree productivity is projected to increase for Sitka spruce, Scots pine and lodgepole pine (high positive consequence for Sitka spruce by the 2080s).

5.2.5 Lowlands

The rural central lowlands is a relatively low lying valley in the centre of the country lying between the Highland and Islands and the Southern Uplands, and excludes all the major towns and cities of this region. This region contains the most agriculturally rich land in Scotland, with a land classification of class 3 typical.

Potential climate change consequences for the rural areas of the central lowlands include the following:

- A projected increase in the number of growing degree days, the length of the growing season, a reduction in frost and an increase in the frost free season would be anticipated to have a positive effect on the development of crops. However, an increase in temperatures could also reduce vernalisation for some crops.

- Pests and diseases are more likely to survive winters, and/or potentially thrive more in warmer summers. New pests and diseases may be present due to a shifting climate space (possibly high, but too uncertain to estimate for plants, medium negative consequence by the 2080s for livestock).

- There is likely to be a significant change in agricultural land classification over the coming century, with a number of land areas moving to a higher land classification. This would increase the potential range of land use with potential increased yields of crops in this region (high positive consequence by the 2080s).

- Crop yields are projected to change, both positively and negatively depending on the crop. For example, wheat and spring barley yields are projected to increase (high positive consequence by the 2080s), but winter barley yields are projected to reduce (medium negative consequence by the 2080s).

- An increase in soil moisture deficits and a greater potential for droughts to occur (medium negative consequence by the 2080s).

5.2.6 The coast

Scotland has a long and varied coastline, with the western coastline of Scotland considered to be the most rugged in the world after Norway. In addition to the mainland, Scotland also has over 790 islands, most of which are to be found in four
main groups; Shetland, Orkney, and the Inner and Outer Hebrides. There are also clusters of islands in the Firth of Clyde, Firth of Forth, and Solway Firth, and numerous small islands within the many bodies of freshwater in Scotland including Loch Lomond and Loch Maree. In contrast, the eastern coastline of Scotland is a lot less rugged, with more beaches and low lying sandy areas.

There are 239 Special Areas of Conservation (SACs), Sites of Community Importance (SCIs) or Candidate Special Areas of Conservation (cSACs) in Scotland, including cross border sites, which cover about 13% of the total land area of Scotland.

Potential climate change consequences for the coast include the following:

- Most soft shores (gravel and sand beaches and saltmarsh) are likely to retreat landwards due to sea-level rise and reductions in coastal sediment supply. This will exacerbate coastal squeeze (affecting intertidal habitats, landuses and flood risk), potentially undermine infrastructure and other static features (including archaeology) which are located on the coast, with a consequential knock-on effect on tourism. Tidal flooding is likely to become more frequent on the open coast, in firths / estuaries and in river mouths. Flooding is expected to worsen along lower reaches of rivers due to more frequent tide locking. These processes will affect all low-lying coastal assets and land uses to varying levels. Although Scotland’s rocky shore is highly resilient to erosion the soft coast (which has been preferentially developed through history) is at risk (high negative consequence by the 2080s).

- An increase in cliff instability and weakening of existing sea defences due to coastal erosion. This may put buildings, including the significant number of cultural heritage sites along the Scottish coastline, infrastructure (such as roads and railway lines, etc) and the coastal landscape at increased risk (high negative consequence by the 2080s).

- Changes in species migration patterns or loss of keystone or dominant species, which may impact on biodiversity and tourist activities (high negative consequence by the 2080s).

5.2.7 Coastal waters and the marine environment

Almost all (99%) of existing marine UK based finfish aquaculture activity is located in Scotland. Scotland is the third largest salmon farming nation in the world, currently producing some 10% of global farmed Atlantic salmon. In total, the fish farming sector in Scotland accounts for around 50% of all Scottish food exports.

Potential climate change consequences for the coastal waters and the marine environment include the following:

- An increase in harmful algal and jellyfish blooms, affecting both people and wildlife.

- Damage to shallow marine habitats, aquaculture and sea fisheries (including shellfish) due to sea-level rise, a change in the susceptibility to disease for some species and ocean acidification (high negative consequence by the 2080s)

- A change in coastal water quality could adversely affect marine habitats and species as well as lead to an increase in the incidence of human disease via bathing and also through the consumption of seafood (high negative consequence by the 2080s).
• A shift in marine species, resulting in a reduction in commonly fished species and the introduction of new species. This would result in both threats and opportunities for the fishing industry (high positive and negative consequences by the 2080s).

• An increase in invasive non-native species, which could result in significant economic and environmental consequences where they occupy the same niche as native or commercial species (high negative consequences by the 2080s).

5.3 Key findings

From the results of this assessment, the potentially most significant threats for Scotland from climate change appear to be:

• Changes in soil conditions, biodiversity and landscape as a result of warmer, drier summers.

• Reductions in river flows and water availability during the summer, affecting water supplies and the natural environment.

• Changes in, or loss of, species with specific threats to native species and migration patterns.

• Changes in coastal evolution affecting people, property, infrastructure, landforms, habitats and species.

• Changes to ocean water temperature and quality, affecting the quality of shellfish and the location of commercial fish stocks.

• Increased risk of pests and diseases affecting agriculture and forestry, and the opportunity for new plants to bring associated new pests and disease causing pathogens.

• Increases in flooding both on the coast and inland, affecting people, property, infrastructure, landforms, habitats and species.

• Increase in insurance losses, ICT disruption and transport network disruption resulting from an increase in the occurrence of extreme weather events.

• An increase in the number of people at risk of death, injury or mental health problems as a result of flooding.

The potentially most significant opportunities identified for Scotland from climate change appear to be:

• Changes in crop, grass and forest productivity and land class leading to potential increases in yields. Central, Eastern and Southern Scotland may benefit the most from these changes.

• Increased tourist numbers and longer tourist seasons, providing an opportunity for new businesses and for established businesses to become more profitable.

• A reduction in the number of cold-related deaths and hospital admissions.

There will also be a number of threats or opportunities that will have a far greater or disproportionate impact for Scotland than for the rest of the UK. These include:
• With the majority of soil organic carbon in Scotland, changes in carbon stored in soils will have a more significant impact on priority habitats and provisioning of ecosystem services.

• Specific threats to species or habitats either more common, or predominantly found in Scotland. For example, 70% of the global extent of machair is found in Scotland.

• The threat to the marine fishing industry to Scotland where almost all existing UK marine based finfish aquaculture activity exists.

• A significant opportunity for crops yields due to a general positive effect on land classification and a longer growing season. Wheat yields in particular are anticipated to increase significantly.

• An opportunity due to increased forest productivity.

• An opportunity due to a reduction in the number of cold-related deaths and hospital admissions.

• A magnification of the increased risks faced by the larger number of rural communities in Scotland reliant on (for example) limited transport or communication links or climate impacted businesses (e.g. fishing) etc.

There are close links between the threats and opportunities listed above and others described in this report. They should therefore not be considered in isolation. An integrated approach will be required to mitigate and/or adapt to these threats and opportunities.
6 Gaps in evidence

6.1 Summary

Gaps in evidence come in a number of forms, including:

- UK-wide gaps identified as part of the CCRA analysis for the UK;
- Scotland specific gaps identified as part of the CCRA analysis for the UK;

and

- Scotland specific gaps identified as part of this assessment for Scotland.

This section summarises all of the above from the perspective of what is believed to be important to Scotland. A separate report is being produced as part of the CCRA that provides recommendations for the next CCRA, which will cover the whole of the UK including Scotland (CCRA, 2011).

The most significant gaps in evidence for Scotland relate to future flooding due to climate change, which may have significant consequences for coastal environments, agriculture, residential and non-residential properties, infrastructure (including transport, energy, water and ICT) and the health and wellbeing of people affected. An assessment of future flood risks due to climate change could not be undertaken for Scotland as part of this first CCRA, as suitable data are not currently available. However, an assessment of present day and future flood risk in Scotland is currently underway. Therefore, this gap could be addressed in time for the next CCRA.

Gaps in evidence relating to each of the five themes namely: Natural Environment; Agriculture and Forestry; Business and Services; Infrastructure and Buildings and Health and Wellbeing, are discussed below.

6.2 Natural Environment

Much of the climate change research conducted to date has, of necessity, been focused either upon individual species or on specific locations or habitat types. Development of systems-based approaches that can improve understanding of the multitude of interactions within the natural environment, and their links to the human environment, remain in the early stages.

The basic knowledge gap is our understanding of change and ecosystem dynamics, including the interaction of people within ecosystems (and the role that biodiversity plays in driving functions and underpinning ecosystem services). This is essentially due to the complexity of responses and feedbacks involved, but also because this has often been a neglected topic in research. As a consequence, key functions and services provided by ecosystems have fundamental uncertainty in terms of how they will respond to change. A coherent baseline is required on the current state of ecosystems, the impacts that can be expected and how they relate to the rest of the UK.

Continuous data records that are comparable across years, or standardized across the UK, are also limited although some very good examples do exist. In Scotland specifically, data and research issues often centre on whether data exist, their accessibility and their comparability and compatibility (NEA, 2011).
The following have been identified as knowledge gaps relevant for Scotland, using this and the UK level CCRA assessment. It should be noted that many of these gaps are applicable to the rest of the UK too which reflects the number of gaps in our knowledge of the natural environment:

**Cross-cutting**

- Integrated modelling of species distributions and interactions, habitat shifts and landscape structure based upon models that combine biological, ecological and climate factors. This would provide a more robust evidence base than the current reliance on bioclimate envelope models to project future changes in range shifts.
- Better understanding of the ecosystem implications of phenological mismatches (mismatches or asynchrony in the timing of species life-cycle events).
- Detailed epidemiological knowledge of different pests and diseases (and their vectors) and their relationship with climate and climate change.
- Detailed knowledge of different non-native species with the potential to become invasive; their associated economic costs and benefits and their relationship with climate and climate change.
- 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.

**Terrestrial**

- Exploration of the role of biodiversity in ecosystem function and services. Of particular concern to Scotland is the role of soil biodiversity in the production and maintenance of soil organic matter, nutrient and water cycling and carbon sequestration (NEA, 2011).
- Climate change mitigation:
  - Opportunities for the natural environment. For example, how efforts to increase carbon storage in soils may benefit soil biodiversity and flora, and how the soil carbon content may be impacted by climate change.
  - Threats for the natural environment: For example, exploration of where future wind farms will be located and the impact that will have on bird and bat strikes.
  - Improving the effectiveness of the protected area network. Evaluation of current protected areas, how they might change (e.g. change in species use due to changes to migration paths) and how they might be strengthened and better integrated into the wider landscape.
  - Develop a baseline understanding of the incidence and consequences of wildfire currently.
  - Suggested uncertainty over Scotland’s isostatic rebound rates may impact on the projected increases in sea level rise. Lower rebound rates would increase relative sea-level rise in areas of Scotland having a larger impact than predicted.
• Improved assessments of climate impacts on ecosystem functions. For example, this is particularly necessary for understanding the key role of soil biodiversity in changing ecosystem processes (such as nutrient cycling) and the implications for habitats and species biodiversity, soil organic matter and carbon storage, with implications for flood risk, water quality, soil erosion risk, habitat conservation and crop production capacities.

• Further work is required on ecosystem response to increased CO\textsubscript{2} and associated feedbacks in conjunction with changing climate variables (e.g. temperature, soil moisture), based upon both modelling and experimental evidence. This has not been incorporated into most climate change impact assessments.

• 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 Griffin, 2010).

• Vulnerability assessment of key locations and pathways for migratory routes (e.g. using space-for-time substitutes based upon current climate variability).

• Evaluation of the effectiveness of landscape-scale initiatives, including measures to improve landscape permeability, in both short-term and long-term. This would act as a bridge between broad-scale modelling studies and site-specific monitoring/modelling to identify strategic maps of habitat creation opportunities that are robust against climate change.

• An understanding of the impact of climate mitigation measures on biodiversity is required. The information needed to improve this understanding is:
  - The spatial strategy for future renewable energy expansion
  - Distribution of important habitats and species in the future.

• Exploration of biodiversity strategies that better integrate adaptation with opportunities from climate mitigation schemes. For example, the development of biomass energy (including short rotation coppice and short rotation forestry) could add to landscape and habitat diversity. Initiatives to enhance carbon storage in soils and biomass could also have significant benefits for biodiversity.

• Further information on the role of genetic diversity within species

• 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.

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**Freshwater**

• Improved understanding of the combined impact of climate change and pollution on ecosystems.

• 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 and the regulation of water quality for the natural environment and human use. Most information is currently only available at site level.

- **Water quality and provision:**
  - Exploration of the role that the environment plays, in addition to climate, in determining raw water quality; how these things may change under future climate and environmental conditions and how water quality changes may be monitored is required. The associated consequences for water provision and on priority habitats and species need to be better understood.
  - Exploration into the combined effects of climate change and the point or diffuse sources of pollutants that may lead to eutrophication and unwanted algal growth.
  - Exploration into the relationship between current abstraction rates and implications for biodiversity under drought conditions and future climate change.

- **Snowmelt has not been considered for UKCP09 due to a lack of data. However, it plays an important part in winter flooding, magnifying rainfall impacts. Additionally snowmelt can act to trigger the emergence of insects in spring. Projections suggest a decrease in snowfall, but up to date data would allow for more robust projections.**

- **Coastal and marine environments**
  - **Coastal flooding and coastal erosion:**
    - Baseline maps of habitats are required. Coupled with quality and biodiversity assessments and investigation of the impacts on ecosystem services.
    - Maps of past erosion, current state and future erosion conditions are required.
    - Habitat loss and gain, and opportunities for new species need to be quantified.
    - Salinity ingress on freshwater coastal habitats is an area of concern however analysis was not able to be undertaken for Scotland as no known data exist. The Defra report in developing risk analysis tools for coastal habitats evaluates the consequences for coastal biodiversity due to climate change, and a similar report for Scotland would help calculate the risks.
- Water Quality
  - More complete monitoring of potential bathing waters
  - Exploration of the potential for Harmful Algal Blooms, specific to the seas around Scotland. Consideration of stratification as well as average temperature increases is important.
  - Impact of CSO spill volume and frequency as a result of flood and high flow events.
- Fish and shellfish stocks. Understanding the future implications of climate change for fishing fleets, fishermen, economies and society with regard to changes in fish ranges, recruitment and the impacts of ocean acidification on shellfish stocks.
- Ocean acidification is a poorly understood topic. The impact of acidification on marine species has not yet been discussed in significant detail and therefore has not been analysed for Scotland. It is thought that a range of species and processes may be affected by acidification, but further evidence is required to analyse the risk.
- Specific research into the risks of alien and invasive species, and species migration as climate space changes in Scotland is required. Similarly a clearer insight into the expected changes in disease and pest occurrences is needed.
- Projected changes in the open ocean (especially the circulation) are particularly uncertain due to the limitations of the ocean model used. These changes are likely to have a marked impact on the Scottish marine environment.

### 6.3 Agriculture and Forestry

A number of key areas relevant to Scotland have been identified, where further work would increase understanding of the consequences of climate change on agriculture and forestry, help remove uncertainties regarding their scale and nature, and aid climate change adaptation. These are the following:

**Agriculture**

- A greater understanding on how climate change is likely to affect food demand and trade for Scotland would allow a more robust assessment of expected changes to agricultural intensification, and the impact of this on biodiversity.
- Currently climate change evidence for impacts on crop pests and disease is qualitative and provides a weak assessment of the risks. A quantitative assessment of new crops, pests and pathogens strains and their relationship to climate change would improve the risk analysis.
- An assessment of climate change effects on livestock is needed. Livestock pests and diseases, stress, yield and productivity metrics currently have little quantification (see for example Moran et al., 2009). The importance of the Scotland agriculture sector means that further research and/or quantification would be desirable.
• Land use classification was not undertaken for the CCRA. Discussion in the report is based on UKCIP02 projections. To be able to provide an updated land capability assessment, UKCP09 results are required.

• An assessment is needed into projected crop suitability and GHG emissions. Changes in CO₂ and nitrogen may have direct effects on plant growth rate and temperature and rainfall changes may alter plant suitability positively or negatively. These alterations could have a large affect on carbon emissions and storage.

• Surface water flooding and waterlogging are serious problems for agriculture, with land stability, crop production and access affected. An indicative analysis has been carried out specifically for Scotland for waterlogging using the workability of land as a proxy, but the other issues have not been analysed because of a lack of suitable information on present day and future risk. Forest soils are more susceptible to winter waterlogging, primarily due to a higher prevalence of peat layers, but existing forest policy and practice pays careful consideration to management practices that mitigate such risk. Forestry has a role to play in alleviating flooding through acting as a hydrological ‘brake’ in designed floodplains.

• Further understanding of the risk to diffuse pollution from agricultural land and the role of climate change. This is also relevant for the forestry sector.

Forestry

• There has been a limited amount of research into the impact of frost and snow damage on tree growth and biodiversity.

• UKCIP02 data has been used by the Forestry Commission to predict forest tree species productivity across the UK. Currently analysis is underway to utilise UKCP09 data with the ESC forest species suitability model, to allow probabilistic assessment of risk to forest species and inform management choices for future climate. ESC considers the full suite of UK forest species and is being updated to include a suite of new species that warrant consideration under projected future climate.

• The impacts of climate change and higher CO₂ concentrations on soils including development, quality, carbon content, soil erosion and oxidation of peatland are poorly understood. Further analysis into climate change effects on carbon flux and storage would allow for a greater understanding.

• Pests and disease impacts through detailed epidemiological information, country-wide data and climate relationships for current and prospective pests and diseases. Additionally the relationships between the host, including forest structure and management, and the impact of potential ‘climatic release’ of existing pests, as well as potential new ones, should be assessed and, if possible, quantified.

6.4 Business and Services

The potentially most significant gaps in knowledge regarding the consequences for business and services in Scotland relate to flooding (see Section 6.1).

In addition to these, a number of key areas where further work would increase understanding of the consequences of climate change on business, help remove
uncertainties regarding their scale and nature, and aid climate change adaptation were identified as part of the UK-wide assessment. Those relevant to Scotland include the following:

- At the moment, there is limited substantive evidence of the consequences of changes in climate on Scotland’s important 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. Further research is needed into the connection between climate change and financial performance.

- 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 overheating. 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 to better understand the likely significance of these impacts, although overheating may be less of an issue for Scotland than for other parts of the UK.

- Seasonal interruptions to construction activities due to rainfall and temperature could be quantified with appropriate data and investigation.

- Currently there are no available statistics regarding the emergency services response to flooding. Clearer data on the response and role of the fire, police and ambulance services would provide a better understanding and allow for a higher confidence when projecting future trends.

- Similarly, greater data is needed to accurately assess the FRS response to wildfires. Currently recent data on wildfires is inclusive of all outdoor fires, including those in rubbish tips or derelict rural buildings. Data on the fire extent, the number of fire fighters needed to control the fire and the cost of damage would enable a more qualitative assessment of future wildfire projections.

- The number of those affected due to heatwaves requires greater and more complete data, especially in relation to hospital admissions. Greater research is needed into heatwave occurrences and ambulance service pressure to establish the strength of the link.

- The effects of climate change could modify Scotland’s tourism industry significantly. Favourable summer weather may increase outdoor activities, but this may be countered by a reduction in biodiversity and natural resources. Coastal erosion, fishing and ecotourism may be badly affected. The link between recreation and climate change needs to be explored further.

- Key workers unable to get to work due to extreme events. More data is needed on work missed due to weather and consequential financial impacts on the companies affected.

- Further understanding of how climate change may affect Scotland’s transport network. Impact of transport disruption to small and remote
businesses is essential as the reliance upon transport vital for their continued operation.

- There is currently a lack of data to assess decommissioning liabilities and end of life costs of large fixed assets.

6.5 Infrastructure and Buildings

Potentially the most significant gaps in knowledge regarding the consequences for infrastructure and buildings in Scotland relate to flooding, with this having a significant impact on transport infrastructure and bridge scour and stability. The following gaps in knowledge for Scotland were identified as part of the UK-wide assessment:

**Buildings and the urban environment**

Areas where further work could underpin more robust projections and adaptation strategies for the built environment sector include:

- Development of a better understanding of the complex cause-and-effect interactions of climate change impacts.
- Development of an improved appreciation of the economic impacts of climate change.
- Rainwater penetration/damage. Little qualitative information is available for rainwater penetration and the performance of building fabrics during wind driven rain episodes (see Appendix C4).
- Condensation, damp, mould, algal/fungal growth in buildings. Research interest reduced after the mid 1990s, therefore there is limited information into the impact of improved housing standards and the occurrences of damp and mould.
- Effect of changes in rainfall patterns on waterlogging of construction sites and activities.

**Energy supply**

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. Whilst the impact on substations at risk from flooding has been considered for Scottish Power, there was no information available on this risk from Scottish and Southern Energy. To consider the risk to Scotland’s power infrastructure as a whole, data would need to be available from all owners of the electricity infrastructure.
- There is a lack of evidence on the positive and negative impacts of warmer temperatures on electricity demand and supply and the interdependence between these impacts. This also applies to the impact of warmer temperatures on electric turbine efficiency and gas pipeline compressor ratings.
- There is a lack of knowledge on future river flows and their effect on station cooling processes and power generation. The impacts of changing precipitation should be investigated regarding current and future reservoirs.
Future projections of wind speeds, in particular over Scotland are uncertain. The consequent impact on the wind energy resource is therefore uncertain.

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.

**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.

Climate change impacts on transport require a more detailed understanding. For example, there is no qualitative landslip information for non trunk roads\textsuperscript{187}, no thermal loading data for Scotland, no national bridge register as well as missing data on the number of bridge failures due to scour\textsuperscript{188}. The result of a lack of data is ultimately the reason behind the low-medium confidence rating.

Due to the currently ongoing Scottish flood risk assessment, projections are not available for future river and coastal flood risk. Additionally, there is limited information on the current risk of coastal erosion on road networks.

The transport sector is integral to the smooth running of society and the economy and transport needs will develop as a result of decisions in other sectors, notably planning. An assessment of where transport is needed or demanded, and how much the network might be at risk, and how this might be managed needs to be considered. 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.

**Water supply**

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. These include:

- The potential impact of climate change on water quality.
- The environmental impacts of drought, and the potential changes in the frequency and severity (and climate modelling of droughts lasting more than one season).
- Mechanisms for encouraging increased efficiency in water use. Impact of low flows on businesses relying on water abstraction.
- The impacts of changes in water demand on river flows.
- 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.

\textsuperscript{187} Although landslide information is not available for non trunk roads, Transport Scotland and the Transport Research Laboratory have been collating this information since 2007 as part of the Landslides Study (see http://www.transportscotland.gov.uk/files/documents/reports/j10107/j10107.pdf).

\textsuperscript{188} Scour surveys of the trunk road bridge network in Scotland are currently being undertaken by Transport Scotland with a programme of remedial action currently being developed.
**Telecommunications**

There is a limited evidence base regarding climate change impacts for the telecommunications sector. This makes forward planning difficult and is compounded by the short-term business models applied by industry.

Telecommunications 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.

### 6.6 Health and Wellbeing

Although a significant amount of research has been carried out into the health effects of climate change for the UK, much of this work has been carried out for England and Wales only, and as such in certain areas there are specific gaps in knowledge pertinent to Scotland. In addition, some future health impacts are very uncertain, as they are an accumulation of several climate variables, and/or mainly driven by human behaviour or actions rather than climate.

Key areas of research 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 Health and Wellbeing for Scotland include:

- There are no known published temperature-mortality relationships for Scotland. As a result, the results presented are likely to be underestimated for heat (although not significantly), yet over-estimated for cold related mortality. Although these relationships would be relatively easy to establish, the data sets required for the analysis cannot be released without ethical clearance, which typically takes six months. In addition, many winter deaths are as a result of infectious diseases such as influenza and pneumonia which means that it is difficult to attribute individual deaths to a cold related disease. Based on current published evidence, this means that any estimate of cold related deaths would be unreliable, although still significant.

- Although there is certain evidence that very high and very cold temperatures have an impact on a range of morbidity outcomes, with an increase in patient-days per year due to heat and cold related illnesses, the rate of change is highly uncertain. In addition, as for cold mortality noted above, winter hospitalisations are clouded by infectious diseases more common in the winter which means that it is difficult to attribute individual hospitalisations (data which is already available) to a cold related disease. Similar to above, this impact is likely to provide a significant opportunity for Scotland due to a reduction in cold, yet a relatively small impact compared to the rest of the UK due to heat.

- Very little research has been carried out into the relationship between extreme weather events and their impacts, and the consequent increased deaths and injuries as a result of these events. This is particularly the case for countries such as the UK that are not exposed to weather events such as hurricanes, and/or the large scale deep flood events experienced in recent decades in places such as the USA, India and Bangladesh.
Mortality and morbidity data sets for extreme weather event flooding and storms are poor, with no central record of deaths or injuries related to individual floods or storms kept in Scotland. There is also no clear accepted definition of what is a flood or storm related injury. With relatively few deaths and injuries due to extreme weather event flooding and storms, as well as the highly clustered nature of these events, it is currently difficult to establish baseline estimates for Scotland. Current and future flood risk is also unknown, although research recently released by SEPA should address this issue. However, the lack of long-term reliable tidal data sets, particularly along the fast moving waters of the North Channel, means that estimates due to coastal flood events would currently remain unreliable.

Although significant progress has been made in recent years researching the mental health effects due to extreme weather events, little is known about the effects long term. The methodology commonly used in Scotland flood studies uses the GHQ-12 (see Health report) 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.

There is a risk that hospitals in Scotland may not be resilient to flooding, particularly during extreme events. It is not currently known how many hospitals are at flood risk in Scotland, or how this is likely to change in the future. However, the research into flood risk for Scotland noted above should start to address this issue.

The more vulnerable members of society are more likely to live in flood risk areas, and are at significantly greater risk due to likely levels of increased flood levels and occurrence under a changing climate. With the potential reduced availability and increased cost of insurance (see Section 4.4), this could have not only consequential economic costs, but also mental health effects as more people do not have the financial resources to cope. More research is required in this area, however, this could only be considered after the future flood risks for Scotland are better understood (see comments under extreme weather event flooding/storms above).

Projected increases in mean temperatures are likely to be an opportunity for Scotland, with lower heating requirements in the winter and reduced probability of people unable to heat their homes adequately. This would have consequential reduced levels of morbidity and mortality. There is little research that has been carried out in this area.

There is little known research into the human health effects due to changes in levels and durations of transport and communications network failure.

Emergency medicine could experience a significant change in demand for its services over and above current annual levels as a result of climate change (Hess et al., 2009). This is likely to result in an increase in levels and variety of demand during extreme weather events, such as floods and heatwaves, as well as the prevalence and severity of allergic and respiratory illness through increases in the frequency, spatial distribution and concentrations of airborne allergens. These effects will show noticeable variations across the UK, which will need to be investigated for Scotland, and will disproportionally affect certain population groups. There is a significant amount of research therefore required to better understand these impacts and how they are likely to change under the climate projected for Scotland with the consequential impacts on emergency medicine.
• Manufactured drugs are in general licensed for storage at temperatures up to 25°C, and these medicines may be exposed to temperatures greater than this either on the premises, or in bags during home visits. However, as temperatures projected for Scotland are typically lower than the rest of the UK, this is not anticipated to be a significant impact. However, additional research at a UK level would still be required to investigate the efficacy of different medicines both on site and during home visits during future heatwaves.

• Cold weather working/travelling would be seen as an opportunity for Scotland, as for warmer winters there would be less frequent and reduced levels of disruption. However, there is currently little known research in this area and how it would impact on working conditions and general morbidity levels.

• There is a lack of research on the impact of improved housing standards on damp and mould occurrences, and thus the impact on respiratory conditions. There seems to be limited data on the link between damp homes and respiratory conditions in Scotland.

• Little quantified research has been carried out into climate change effects on water-borne diseases, in particular cryptosporidium.

• Climate change impacts are likely to have a greater impact on the health and wellbeing status on rural island communities, and these need to be investigated across a range of impacts.

• The UKCP09 regional climate models do not have sufficient resolution to include an explicit representation of urban areas and their effects. Therefore specific projections of the UHI under climate change are not available within UKCP09.
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Appendices
Appendix A    Scotland Tier 2 list of climate change impacts

A.1    Tier 2 list by Sector

This version of the Scotland Tier 2 list shows the 125 impacts/consequences by sector identified in the original consultation with Scottish stakeholders in March 2010. The relevant risk metric numbers (e.g. BU1) are also listed. Risk metric numbers in brackets represent the numbers used in previous releases of this report, where these have subsequently changed.

Based on the original consultation in March 2010, and subsequent feedback from Scottish stakeholders, the impacts/consequences were colour coded as follows:

- Pink impacts/consequences have been analysed for Scotland as part of the UK CCRA
- Orange impacts/consequences indicate where an attempt has been made to look at the impact/consequence in more detail as part of the Scotland assessment
- Blue impacts/consequences were added to the Tier 2 list by Scotland stakeholders, but it was not anticipated that these would be looked at in any more detail
- White impacts/consequences have not been analysed for Scotland as part of the UK CCRA, nor were they anticipated to be looked at in any more detail as part of the Scotland assessment. This has generally been due to relevant data not being available for Scotland, although a lack of data was not considered to mean that the impact is less important. There existence on this Tier 2 list for Scotland means that the impact was highlighted as being important by Scotland stakeholders.

It should be noted that this list has been updated/modified since the original workshop to reflect additional analysis work or changes to the analysis work undertaken for the UK CCRA, as well as to reflect the outcome of additional assessment work undertaken specifically for Scotland. In some cases, additional data or information that has become available since the original workshop means that a number of impacts have been looked at in more detail.
### Agriculture

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in wheat yield (due to warmer springs)</td>
<td>AG1b</td>
</tr>
<tr>
<td>Changes in potato yield (due to combined climate effects and CO₂)</td>
<td>AG1c</td>
</tr>
<tr>
<td>Changes in spring barley yield (due to warmer springs)</td>
<td>AG1d</td>
</tr>
<tr>
<td>Changes in winter barley yield (due to wetter winters)</td>
<td>AG1e</td>
</tr>
<tr>
<td>Flood risk to high quality agricultural land</td>
<td>AG2</td>
</tr>
<tr>
<td>Risk of crop pests and diseases</td>
<td>AG3</td>
</tr>
<tr>
<td>Drier soils (due to warmer and drier summer conditions)</td>
<td>AG4</td>
</tr>
<tr>
<td>Reduction in milk production due to heat stress</td>
<td>AG7a</td>
</tr>
<tr>
<td>Livestock heat stress factors</td>
<td>AG8a/b, AG15</td>
</tr>
<tr>
<td>Changes in grassland productivity</td>
<td>AG10</td>
</tr>
<tr>
<td>Increase in greenhouse gas emissions</td>
<td>AG17, AG59</td>
</tr>
<tr>
<td>Soil erosion and leaching</td>
<td>AG19</td>
</tr>
<tr>
<td>Waterlogging effects</td>
<td>AG21</td>
</tr>
<tr>
<td>Agricultural land classification and crop suitability</td>
<td>AG25, AG51, AG52</td>
</tr>
<tr>
<td>Biodiversity/wildlife changes</td>
<td>AG26, AG27</td>
</tr>
<tr>
<td>Breeding habits/reproductive nature of species</td>
<td>AG30, AG57, AG58</td>
</tr>
<tr>
<td>Livestock pests and diseases</td>
<td>AG44</td>
</tr>
<tr>
<td>Loss of particular landscapes and associated rural communities, previously managed by livestock keepers</td>
<td>AG65</td>
</tr>
<tr>
<td>Human food supply from domestic agriculture</td>
<td>AG66</td>
</tr>
</tbody>
</table>

### Biodiversity & Ecosystem Services

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk to species and habitats due to drier soils</td>
<td>BD1</td>
</tr>
<tr>
<td>Risks to species and habitats due to coastal evolution</td>
<td>BD2</td>
</tr>
<tr>
<td>Risk of pests to biodiversity</td>
<td>BD3</td>
</tr>
<tr>
<td>Risks of diseases to biodiversity</td>
<td>BD4</td>
</tr>
<tr>
<td>Species unable to track changing climate space</td>
<td>BD5</td>
</tr>
<tr>
<td>Environmental effects of climate mitigation measures</td>
<td>BD6</td>
</tr>
<tr>
<td>Changes in soil organic carbon</td>
<td>BD8</td>
</tr>
<tr>
<td>Changes in species migration patterns</td>
<td>BD9</td>
</tr>
<tr>
<td>Biodiversity risks due to warmer rivers and lakes</td>
<td>BD10</td>
</tr>
<tr>
<td>Generalists species more able to adapt than specialists</td>
<td>BD11</td>
</tr>
<tr>
<td>Wildfires due to warmer and drier conditions</td>
<td>BD12</td>
</tr>
<tr>
<td>Water quality and pollution risks</td>
<td>BD13</td>
</tr>
<tr>
<td>Ecosystems risks due to low flows and increased water demand</td>
<td>BD14</td>
</tr>
<tr>
<td>Increased societal water demand</td>
<td>BD15</td>
</tr>
<tr>
<td>Major coastal flood/reconfiguration (includes coastal erosion)</td>
<td>BD20</td>
</tr>
<tr>
<td>Agricultural intensification</td>
<td>BD21</td>
</tr>
<tr>
<td>Asynchrony between species breeding cycle and food supply</td>
<td>BD23</td>
</tr>
<tr>
<td>Saline intrusion</td>
<td>BD44</td>
</tr>
<tr>
<td>Loss of service through loss of keystone species</td>
<td>BD46</td>
</tr>
</tbody>
</table>

### Built Environment

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural heritage at flood/erosion risk</td>
<td>BE4</td>
</tr>
<tr>
<td>Effectiveness of green space for cooling</td>
<td>BE5</td>
</tr>
<tr>
<td>Reduction in energy demand for heating</td>
<td>BE9</td>
</tr>
<tr>
<td>Property at significant risk of flooding</td>
<td>BE10, BE11, BE12, BE15, BE18,</td>
</tr>
<tr>
<td>Rainwater penetration</td>
<td>BE13</td>
</tr>
<tr>
<td>Increase in damp, mould and insect pests in buildings</td>
<td>BE31</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>BE32</td>
</tr>
</tbody>
</table>

### Business, Industry and Services

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate risks to investment funds</td>
<td>BU1</td>
</tr>
<tr>
<td>Monetary losses due to tourist assets at risk from flooding</td>
<td>BU2 (BU3)</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for industry</td>
<td>BU3 (BU4)</td>
</tr>
<tr>
<td>Risks of business disruption due to flooding</td>
<td>BU4 (BU5)</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>BU5 (BU6)</td>
</tr>
<tr>
<td>Mortgage provision threatened due to increased flood risk</td>
<td>BU6 (BU7)</td>
</tr>
<tr>
<td>Insurance industry exposure to UK flood risks</td>
<td>BU7 (BU8)</td>
</tr>
<tr>
<td>An expansion of tourist destinations in Scotland*</td>
<td>BU8 (BU10)</td>
</tr>
<tr>
<td>A decrease in output for businesses due to supply chain disruption*</td>
<td>BU9 (BU11)</td>
</tr>
<tr>
<td>Loss of natural resource which attracts tourists leading to loss of revenue and requirements to shift assets</td>
<td>BU29</td>
</tr>
<tr>
<td>Impacts on angling, gaming or course fishing</td>
<td>BUr1</td>
</tr>
<tr>
<td>Underestimation of decommissioning liabilities and end of life costs</td>
<td>BUr2</td>
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</table>
*New risk metrics for the UK CCRA that are considered important for Scotland and have been added to the Tier 2 list.

### Energy

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy infrastructure at significant risk of flooding</td>
<td>EN1</td>
</tr>
<tr>
<td>Energy demand for cooling</td>
<td>EN2</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for energy generation</td>
<td>EN4</td>
</tr>
<tr>
<td>Demand by water suppliers</td>
<td>EN5</td>
</tr>
<tr>
<td>Electricity turbine efficiency</td>
<td>EN6</td>
</tr>
<tr>
<td>Gas pipe compressor rating</td>
<td>EN7</td>
</tr>
<tr>
<td>Power station cooling process</td>
<td>EN8</td>
</tr>
<tr>
<td>Energy transmission efficiency capacity losses due to heat - over ground</td>
<td>EN10</td>
</tr>
<tr>
<td>Fuel poverty (people affected)</td>
<td>ENr1</td>
</tr>
<tr>
<td>Power stations at significant risk of flooding</td>
<td>ENr2</td>
</tr>
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</table>

### Flooding & Coastal Erosion

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal and coastal flooding</td>
<td>FL1, FL2, FL4, FL6, FL7</td>
</tr>
<tr>
<td>River flooding</td>
<td>FL1, FL2, FL4, FL6, FL7</td>
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<tr>
<td>Roads at significant risk of flooding</td>
<td>FL8a</td>
</tr>
<tr>
<td>Railways at significant risk of flooding</td>
<td>FL8b</td>
</tr>
<tr>
<td>Power stations at significant risk of flooding</td>
<td>FL11a</td>
</tr>
<tr>
<td>Sub-stations at significant risk of flooding</td>
<td>FL11b</td>
</tr>
<tr>
<td>Ability to obtain flood insurance for residential properties</td>
<td>FL13</td>
</tr>
<tr>
<td>Agricultural land lost due to coastal erosion</td>
<td>FL14a</td>
</tr>
<tr>
<td>Priority habitats lost due to coastal erosion</td>
<td>FL14b</td>
</tr>
<tr>
<td>Flood risk for Scheduled Ancient Monument sites</td>
<td>FL15</td>
</tr>
<tr>
<td>Impacts of geomorphological changes</td>
<td>FL17</td>
</tr>
<tr>
<td>Combination flooding</td>
<td>FL24, FL27</td>
</tr>
<tr>
<td>Snowmelt flooding</td>
<td>FL41</td>
</tr>
</tbody>
</table>

### Forestry

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest extent affected by pests and diseases</td>
<td>FO1</td>
</tr>
<tr>
<td>Loss of forest productivity due to drought</td>
<td>FO2</td>
</tr>
<tr>
<td>Windthrow and storm damage</td>
<td>FO3</td>
</tr>
<tr>
<td>Impact/consequence</td>
<td>Metric No.</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Increase of potential yield of Sitka spruce in Scotland</td>
<td>FO4b</td>
</tr>
<tr>
<td>Biodiversity loss</td>
<td>FO5189</td>
</tr>
<tr>
<td>Snow and frost damage</td>
<td>FO7, FO14</td>
</tr>
<tr>
<td>Winter hardening</td>
<td>FO20, FO26</td>
</tr>
</tbody>
</table>

**Health**<sup>190</sup>

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer mortality due to higher temperatures</td>
<td>HE1</td>
</tr>
<tr>
<td>Summer morbidity due to higher temperatures</td>
<td>HE2</td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>HE3</td>
</tr>
<tr>
<td>Decline in winter mortality due to higher temperatures</td>
<td>HE5</td>
</tr>
<tr>
<td>Decline in winter morbidity due to higher temperatures</td>
<td>HE6</td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) injuries</td>
<td>HE7</td>
</tr>
<tr>
<td>Effects of floods/storms on mental health</td>
<td>HE10</td>
</tr>
<tr>
<td>Increase in prevalence of certain vector-borne diseases (ticks and lymes)</td>
<td>HE11, HE17</td>
</tr>
<tr>
<td>Food borne diseases</td>
<td>HE15</td>
</tr>
<tr>
<td>Water quality and water-borne diseases</td>
<td>HE16</td>
</tr>
<tr>
<td>Increased algal or fungal/mould growth in buildings affecting respiratory conditions</td>
<td>HE19</td>
</tr>
</tbody>
</table>

**Marine & fisheries**

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of Harmful Algal Blooms due to changes in ocean stratification</td>
<td>MA1</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
</tr>
<tr>
<td>Risks of human illness due to marine pathogens</td>
<td>MA2b</td>
</tr>
<tr>
<td>Increased ocean acidification</td>
<td>MA3</td>
</tr>
<tr>
<td>Changes in fish catch latitude/centre of gravity</td>
<td>MA4a/b</td>
</tr>
<tr>
<td>Opening of Arctic shipping routes due to ice melt</td>
<td>MA5b</td>
</tr>
<tr>
<td>Distribution of marine alien/invasive species</td>
<td>MA6</td>
</tr>
<tr>
<td>Plankton Blooms</td>
<td>MA23</td>
</tr>
<tr>
<td>Damage to cultured aquatic species</td>
<td>MA30</td>
</tr>
<tr>
<td>Physical effects of extreme events (flooding) on shallow marine habitats</td>
<td>MA39</td>
</tr>
<tr>
<td>Species migration</td>
<td>MAr1</td>
</tr>
</tbody>
</table>

<sup>189</sup> Forest biodiversity was not subsequently included in the analysis at the UK or DA scale due to a lack of robust correlations with climate drivers.

<sup>190</sup> Summer and winter mortality and morbidity (risk metrics HE1, HE2, HE5 and HE6) were not on the original Tier 2 list for Scotland. However, based on feedback received, these were subsequently added.
<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disruption to road traffic due to flooding</td>
<td>TR1</td>
</tr>
<tr>
<td>Landslide risks on the road network</td>
<td>TR2</td>
</tr>
<tr>
<td>Scouring of road and rail bridges</td>
<td>TR6</td>
</tr>
<tr>
<td>Coastal erosion</td>
<td>TRr1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer and drier conditions</td>
<td>WA1</td>
</tr>
<tr>
<td>Lower summer river flows (Q95)</td>
<td>WA2</td>
</tr>
<tr>
<td>Change in household water demand</td>
<td>WA4</td>
</tr>
<tr>
<td>Public water supply-demand deficits</td>
<td>WA5</td>
</tr>
<tr>
<td>Raw water quality</td>
<td>WA9</td>
</tr>
<tr>
<td>Combined Sewer Overflow spill frequency</td>
<td>WA10</td>
</tr>
<tr>
<td>Changed recharge and groundwater levels</td>
<td>WA13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency response to events (floods)</td>
<td>GNr1</td>
</tr>
<tr>
<td>Emergency response to events (fires)</td>
<td>GNr2</td>
</tr>
<tr>
<td>Customer demands (opportunities)</td>
<td>GNr3</td>
</tr>
<tr>
<td>Changes in global trading patterns</td>
<td>GNr4</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
</tr>
<tr>
<td>Key workers unable to get to work due to extreme events or infrastructure failure</td>
<td>GNr6</td>
</tr>
<tr>
<td>Immigration to EU countries (including UK) and northwards migration within EU space; UK citizens living abroad may return to the UK, leading to increased demand for water, food, energy, health services etc.</td>
<td>GNr7</td>
</tr>
<tr>
<td>Cost of international emergency aid</td>
<td>GNr8</td>
</tr>
</tbody>
</table>
A.2 Tier 2 list by Theme

This version of the Tier 2 list shows the impacts/consequences by theme.

The sector impacts/consequences have been allocated to one or more themes. For example, there is no specific theme for ‘water’, but elements of the water sector appear in all of the themes.

### Natural Environment - Terrestrial

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk to species and habitats due to drier soils</td>
<td>BD1</td>
</tr>
<tr>
<td>Risk of pests to biodiversity</td>
<td>BD3</td>
</tr>
<tr>
<td>Risks of diseases to biodiversity</td>
<td>BD4</td>
</tr>
<tr>
<td>Species unable to track changing climate space</td>
<td>BD5</td>
</tr>
<tr>
<td>Environmental effects of climate mitigation measures</td>
<td>BD6</td>
</tr>
<tr>
<td>Changes in soil organic carbon</td>
<td>BD8</td>
</tr>
<tr>
<td>Changes in species migration patterns</td>
<td>BD9</td>
</tr>
<tr>
<td>Generalists species more able to adapt than specialists</td>
<td>BD11</td>
</tr>
<tr>
<td>Wildfires due to warmer and drier conditions</td>
<td>BD12</td>
</tr>
<tr>
<td>Asynchrony between species breeding cycle and food supply</td>
<td>BD23</td>
</tr>
<tr>
<td>Loss of service through loss of keystone species</td>
<td>BD46</td>
</tr>
<tr>
<td>Agricultural intensification</td>
<td>BD21, AG26, AG27</td>
</tr>
<tr>
<td>Changed recharge and groundwater levels</td>
<td>WA13</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
</tr>
</tbody>
</table>

### Natural Environment – Freshwater

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity risks due to warmer rivers and lakes</td>
<td>BD10</td>
</tr>
<tr>
<td>Water quality and pollution risks</td>
<td>BD13</td>
</tr>
<tr>
<td>Ecosystems risks due to low flows and increased water demand</td>
<td>BD14</td>
</tr>
<tr>
<td>Increased societal water demand</td>
<td>BD15</td>
</tr>
<tr>
<td>Asynchrony between species breeding cycle and food supply</td>
<td>BD23</td>
</tr>
<tr>
<td>Warmer and drier conditions</td>
<td>WA1</td>
</tr>
<tr>
<td>Lower summer river flows (Q95)</td>
<td>WA2</td>
</tr>
<tr>
<td>Raw water quality</td>
<td>WA9</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
</tr>
</tbody>
</table>
### Natural Environment – Coastal

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks to species and habitats due to coastal evolution</td>
<td>BD2</td>
</tr>
<tr>
<td>Changes in species migration patterns</td>
<td>BD9</td>
</tr>
<tr>
<td>Water quality and pollution risks</td>
<td>BD13</td>
</tr>
<tr>
<td>Major coastal flood/reconfiguration (includes coastal erosion)</td>
<td>BD20</td>
</tr>
<tr>
<td>Saline intrusion</td>
<td>BD44</td>
</tr>
<tr>
<td>An expansion of tourist destinations in Scotland</td>
<td>BU8 (BU10)</td>
</tr>
<tr>
<td>Priority habitats lost due to coastal erosion</td>
<td>FL14b</td>
</tr>
<tr>
<td>Impacts of geomorphological changes</td>
<td>FL17</td>
</tr>
<tr>
<td>Physical effects of extreme events (flooding) on shallow marine habitats</td>
<td>MA39</td>
</tr>
</tbody>
</table>

### Natural Environment – Marine

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of service through loss of keystone species</td>
<td>BD46</td>
</tr>
<tr>
<td>Risk of Harmful Algal Blooms due to changes in ocean stratification</td>
<td>MA1</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
</tr>
<tr>
<td>Increased ocean acidification</td>
<td>MA3</td>
</tr>
<tr>
<td>Changes in fish catch latitude/centre of gravity</td>
<td>MA4a/b</td>
</tr>
<tr>
<td>Distribution of marine alien/invasive species</td>
<td>MA6</td>
</tr>
<tr>
<td>Plankton blooms</td>
<td>MA23</td>
</tr>
<tr>
<td>Damage to cultured aquatic species</td>
<td>MA30</td>
</tr>
<tr>
<td>Species migration</td>
<td>MAr1</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
</tr>
</tbody>
</table>

### Agriculture

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in wheat yield (due to warmer springs)</td>
<td>AG1b</td>
</tr>
<tr>
<td>Changes in potato yield (due to combined climate effects and CO₂)</td>
<td>AG1c</td>
</tr>
<tr>
<td>Changes in spring barley yield (due to warmer springs)</td>
<td>AG1d</td>
</tr>
<tr>
<td>Changes in winter barley yield (due to wetter winters)</td>
<td>AG1e</td>
</tr>
<tr>
<td>Flood risk to high quality agricultural land</td>
<td>AG2, FL4</td>
</tr>
<tr>
<td>Risk of crop pests and diseases</td>
<td>AG3</td>
</tr>
<tr>
<td>Drier soils (due to warmer and drier summer conditions)</td>
<td>AG4</td>
</tr>
<tr>
<td>Reduction in milk production due to heat stress</td>
<td>AG7a</td>
</tr>
<tr>
<td>Livestock heat stress factors</td>
<td>AG8a/b, AG15</td>
</tr>
<tr>
<td>Changes in grassland productivity</td>
<td>AG10</td>
</tr>
<tr>
<td>Increase in greenhouse gas emissions</td>
<td>AG17, AG59</td>
</tr>
</tbody>
</table>
### Climate Change Risk Assessment For Scotland

#### Soil erosion and leaching
- AG19

#### Waterlogging effects
- AG21

#### Agricultural land classification and crop suitability
- AG25, AG51, AG52

#### Biodiversity/wildlife changes
- AG26, AG27

#### Breeding habits/reproductive nature of species
- AG30, AG57, AG58

#### Livestock pests and diseases
- AG44

#### Loss of particular landscapes and associated rural communities, previously managed by livestock keepers
- AG65

#### Human food supply from domestic agriculture
- AG66

#### Agricultural land lost due to coastal erosion
- FL14a

#### Public water supply-demand deficits
- WA5

#### Changes in global trading patterns
- GNr4

### Forestry

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildfires due to warmer and drier conditions</td>
<td>BD12</td>
</tr>
<tr>
<td>Forest extent affected by pests and diseases</td>
<td>FO1</td>
</tr>
<tr>
<td>Loss of forest productivity due to drought</td>
<td>FO2</td>
</tr>
<tr>
<td>Windthrow and storm damage</td>
<td>FO3</td>
</tr>
<tr>
<td>Increase of potential yield of Sitka spruce in Scotland</td>
<td>FO4b</td>
</tr>
<tr>
<td>Biodiversity loss</td>
<td>FO5189</td>
</tr>
<tr>
<td>Snow and frost damage</td>
<td>FO7, FO14</td>
</tr>
<tr>
<td>Winter hardening</td>
<td>FO20, FO26</td>
</tr>
</tbody>
</table>

### Business and Services

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural heritage at flood/erosion risk</td>
<td>BE4, FL15</td>
</tr>
<tr>
<td>Climate risks to investment funds</td>
<td>BU1</td>
</tr>
<tr>
<td>Monetary losses due to tourist assets at risk from flooding</td>
<td>BU2 (BU3)</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for industry</td>
<td>BU3 (BU4)</td>
</tr>
<tr>
<td>Risks of business disruption due to flooding</td>
<td>BU4 (BU5)</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>BU5 (BU6)</td>
</tr>
<tr>
<td>Mortgage provision threatened due to increased flood risk</td>
<td>BU6 (BU7)</td>
</tr>
<tr>
<td>Insurance industry exposure to UK flood risks</td>
<td>BU7 (BU8)</td>
</tr>
<tr>
<td>An expansion of tourist destinations in Scotland</td>
<td>BU8 (BU10)</td>
</tr>
<tr>
<td>A decrease in output for businesses due to supply chain disruption</td>
<td>BU9 (BU11)</td>
</tr>
<tr>
<td>Impact/consequence</td>
<td>Metric No.</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Loss of natural resource which attracts tourists leading to loss of revenue and</td>
<td>BU29</td>
</tr>
<tr>
<td>requirements to shift assets</td>
<td></td>
</tr>
<tr>
<td>Energy demand for cooling</td>
<td>EN2</td>
</tr>
<tr>
<td>Flooding of non-residential property</td>
<td>FL7, FL24, FL27</td>
</tr>
<tr>
<td>Ability to obtain flood insurance for residential properties</td>
<td>FL13</td>
</tr>
<tr>
<td>Impacts on angling, gaming or course fishing</td>
<td>BUr1</td>
</tr>
<tr>
<td>Underestimation of decommissioning liabilities and end of life costs</td>
<td>BUr2</td>
</tr>
<tr>
<td>Emergency response to events (floods)</td>
<td>GNr1</td>
</tr>
<tr>
<td>Emergency response to events (fires)</td>
<td>GNr2</td>
</tr>
<tr>
<td>Customer demands (opportunities)</td>
<td>GNr3</td>
</tr>
<tr>
<td>Key workers unable to get to work due to extreme events or infrastructure failure</td>
<td>GNr6</td>
</tr>
<tr>
<td>Cost of international emergency aid</td>
<td>GNr8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impact/consequence</strong></td>
</tr>
<tr>
<td>Reduction in energy demand for heating</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
</tr>
<tr>
<td>Energy infrastructure at significant risk of flooding</td>
</tr>
<tr>
<td>Energy demand for cooling</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for energy generation</td>
</tr>
<tr>
<td>Demand by water suppliers</td>
</tr>
<tr>
<td>Electricity turbine efficiency</td>
</tr>
<tr>
<td>Gas pipe compressor rating</td>
</tr>
<tr>
<td>Power station cooling process</td>
</tr>
<tr>
<td>Energy transmission efficiency capacity losses due to heat - over ground</td>
</tr>
<tr>
<td>Power stations at significant risk of flooding</td>
</tr>
<tr>
<td>Sub-stations at significant risk of flooding</td>
</tr>
<tr>
<td>Opening of Arctic shipping routes due to ice melt</td>
</tr>
<tr>
<td>Road and rail at significant risk of flooding</td>
</tr>
<tr>
<td>Landslide risks on the road network</td>
</tr>
<tr>
<td>Scouring of road and rail bridges</td>
</tr>
<tr>
<td>Coastal erosion</td>
</tr>
<tr>
<td>Change in household water demand</td>
</tr>
<tr>
<td>Combined Sewer Overflow spill frequency</td>
</tr>
</tbody>
</table>
### Buildings

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness of green space for cooling</td>
<td>BE5</td>
</tr>
<tr>
<td>Rainwater penetration</td>
<td>BE13</td>
</tr>
<tr>
<td>Property at risk of flooding</td>
<td>BE10, BE11, BE12, BE15, BE18, FL6, FL24</td>
</tr>
<tr>
<td>Increase in damp, mould and insect pests in buildings</td>
<td>BE31</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>BE32</td>
</tr>
<tr>
<td>Snowmelt flooding</td>
<td>FL41</td>
</tr>
<tr>
<td>Immigration to EU countries (including UK) and northwards migration within EU space; UK citizens living abroad may return to the UK, leading to increased demand for water, food, energy, health services etc.</td>
<td>GNr7</td>
</tr>
</tbody>
</table>

### Health and Wellbeing

<table>
<thead>
<tr>
<th>Impact/consequence</th>
<th>Metric No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel poverty (people affected)</td>
<td>ENr1</td>
</tr>
<tr>
<td>Number of people at significant risk of flooding</td>
<td>FL1</td>
</tr>
<tr>
<td>Vulnerable people at significant risk of flooding</td>
<td>FL2</td>
</tr>
<tr>
<td>Summer mortality due to higher temperatures</td>
<td>HE1</td>
</tr>
<tr>
<td>Summer morbidity due to higher temperatures</td>
<td>HE2</td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>HE3</td>
</tr>
<tr>
<td>Decline in winter mortality due to higher temperatures</td>
<td>HE5</td>
</tr>
<tr>
<td>Decline in winter morbidity due to higher temperatures</td>
<td>HE6</td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) injuries</td>
<td>HE7</td>
</tr>
<tr>
<td>Effects of floods/storms on mental health</td>
<td>HE10</td>
</tr>
<tr>
<td>Increase in prevalence of certain vector-borne diseases (ticks and lymes)</td>
<td>HE11, HE17</td>
</tr>
<tr>
<td>Food borne diseases</td>
<td>HE15</td>
</tr>
<tr>
<td>Increased algal or fungal/mould growth in buildings affecting respiratory conditions</td>
<td>HE19</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
</tr>
<tr>
<td>Incidents of human illness due to hosts and pathogens</td>
<td>MA2b, HE16</td>
</tr>
</tbody>
</table>
Figure B1 Patterns of change in average temperature (°C) between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B2  Pattern of change for average 24-hour maximum temperature for summer and winter (°C) between 1961 and 2004
Source: SNIFFER, 2006

Figure B3  Pattern of change for 24-hour average minimum temperature (°C) for summer and winter between 1961 and 2004
Source: SNIFFER, 2006
Figure B4  Pattern of change in heating degree Days (%) between 1961 and 2004 for each season
Source: SNIFFER, 2006

Figure B5  Pattern of change in growing degree days (%) between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B6  Pattern of change in the length of the growing season (days) between 1961 and 2004 for each season
Source: SNIFFER, 2006

Figure B7  Patterns of change in the start (left) and end (right) of the growing season (in days) between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B8 Pattern of change in extreme temperature range (°C) between 1961 and 2004 for each season
Source: SNIFFER, 2006

Figure B9 Pattern of change (days) in the length of winter cold spells (left) and summer heatwaves (right) between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B10  Pattern of change in annual days of air frost (days) between 1961 and 2004 for each season  
Source: SNIFFER, 2006
Figure B11  Patterns of change in ground frost (days) between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B12 Patterns of change in average precipitation (%) between 1961 and 2004 for each season
Source: SNIFTER, 2006
Figure B13: Pattern of change in snow cover (days) in each year between 1961 and 2004 for each season

Source: SNIFFER, 2006
Figure B14  Patterns of change in the number of days with heavy rain (at least 10mm) between 1961 and 2004 for each season

Source: SNIFFER, 2006
Figure B15  Pattern of change in maximum number of consecutive dry days each year between 1961 and 2004 for each season
Source: SNIFFER, 2006

Figure B16  Pattern of change in rainfall intensity (%) each year on days with at least 1mm of rain between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B17  Pattern of change in maximum five-day precipitation (%) each year between 1961 and 2004 for each season
Source: SNIFFER, 2006

Figure B18  Patterns of change in average sea level pressure (hPa) each year between 1961 and 2004 for each season
Source: SNIFFER, 2006
Figure B19 Patterns of change in sunshine hours (%) between 1961 and 2004 for each season

Source: SNIFFER, 2006
Appendix C  Additional Risk Analysis Work

C.1  Flooding (fluvial and tidal)

The Scottish Environment Protection Agency (SEPA) has recently undertaken a flood risk assessment for Scotland that was due to finish in December 2011, as this report was being finalised. Limited preliminary results from this assessment were made available for this report, and these are outlined below. These are supplemented by information on UKCP09 projections of sea level rise.

Present flood risk

Current flood risk maps are given on the SEPA website\textsuperscript{191}, which give details of the numbers of properties at risk for a 1 in 200 year return period (0.5% or greater probability of being flooded in any particular year) by district for river and tidal\textsuperscript{192} flooding in the absence of flood defences. Flooding from other sources such as surface water runoff is not included. A district breakdown of the properties at risk is given in Table C1.1 below.

Table C1.1 Properties at risk for current 1 in 200 year return period of flood

<table>
<thead>
<tr>
<th>District</th>
<th>Area (km\textsuperscript{2})</th>
<th>Residential Properties at Risk</th>
<th>Non-Residential Properties at Risk</th>
<th>Total Properties (approximate)</th>
<th>WAAD (£m)\textsuperscript{193}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highland and Argyll</td>
<td>28,670</td>
<td>4,840</td>
<td>1,280</td>
<td>121,000</td>
<td>15,360</td>
</tr>
<tr>
<td>Comhairle nan Eilean Siar</td>
<td>3,050</td>
<td>440</td>
<td>160</td>
<td>14,520</td>
<td>2,080</td>
</tr>
<tr>
<td>Orkney</td>
<td>1,010</td>
<td>310</td>
<td>90</td>
<td>10,540</td>
<td>1,620</td>
</tr>
<tr>
<td>Shetland</td>
<td>1,450</td>
<td>40</td>
<td>30</td>
<td>10,920</td>
<td>1,380</td>
</tr>
<tr>
<td>Findhorn, Nairn and Speyside</td>
<td>4,800</td>
<td>4,340</td>
<td>590</td>
<td>43,400</td>
<td>5,310</td>
</tr>
<tr>
<td>Aberdeenshire and Aberdeen City</td>
<td>6,780</td>
<td>4,800</td>
<td>880</td>
<td>216,000</td>
<td>18,480</td>
</tr>
<tr>
<td>Tay Estuary and Montrose Basin</td>
<td>1,080</td>
<td>5,880</td>
<td>680</td>
<td>152,880</td>
<td>10,880</td>
</tr>
<tr>
<td>Tay</td>
<td>2,710</td>
<td>7,410</td>
<td>1,000</td>
<td>74,100</td>
<td>8,000</td>
</tr>
<tr>
<td>Forth</td>
<td>1,610</td>
<td>4,610</td>
<td>380</td>
<td>59,930</td>
<td>4,940</td>
</tr>
<tr>
<td>Forth Estuary</td>
<td>3,260</td>
<td>29,360</td>
<td>2,360</td>
<td>616,560</td>
<td>40,120</td>
</tr>
<tr>
<td>Clyde and Loch Lomond</td>
<td>4,840</td>
<td>37,090</td>
<td>2,560</td>
<td>853,070</td>
<td>48,640</td>
</tr>
<tr>
<td>Ayrshire</td>
<td>3,060</td>
<td>10,090</td>
<td>1,490</td>
<td>171,530</td>
<td>11,920</td>
</tr>
</tbody>
</table>

\textsuperscript{191} http://www.sepa.org.uk/flooding/flood_map.aspx
\textsuperscript{192} Tidal flooding is based on extreme sea levels based on POL (1997). This methodology has recently been superseded by Environment Agency (2011).
\textsuperscript{193} Weighted Annual Average Damages (WAAD) are a means of assessing damages where there is little or no understanding of the potential flood depths and return periods (see Penning-Rossell et al., 2005). These estimates will be further updated and refined as part of SEPA’s Flood Risk Management Strategies in 2013 (SEPA, 2011c).
Table C1.1 indicates that for a 1 in 200 year return period, approximately 130,000 properties are in the 1 in 200 year floodplain. There are in the region of 1.25 million properties in the 1 in 200 year floodplain in England and Wales (Environment Agency, 2009). Of these, about 500,000 properties are considered at significant risk based on the 75-year floodplain and taking into consideration the performance of flood defences. Assuming a similar proportion for Scotland, this would indicate that in the region of 50,000 to 55,000 properties in Scotland are in the 1 in 75 year floodplain.

**Future flood risk**

Kay et al., (2011) have assessed the vulnerability of Scotland’s river catchments to the impacts of climate change\(^\text{195}\). This is a development of two previous Defra/EA projects, FD2020 titled “Regionalised impacts of climate change on flood flows” and FD2648 titled “Practicalities for implementing regionalised allowances for climate change on flood flows”. The latter report includes graphs that show increases in flood flows for the 2020s, 2050s and 2080s for England and Wales which is the basis for flood flows in the CCRA analysis.

Kay et al., (2011) provided information on flow projections for the 10 river basin regions in Scotland (see Figure 3.2) for the 2080s only. These results indicated that:

- Overall increase in flow projections of between 15% and 37% (median estimate), compared to between 21% to 28% for England and Wales.
- Projected flow increases are much higher for the west coast than the east coast.
- Results for the Tweed and Solway (which overlap with England) appear to be reasonably consistent with FD2648. The increase for the Solway is about 23% (range 12% to 60%) and the Tweed is about 21% (range 10% to 44%).

Sea level rise projections are available from UKCP09, and these are given in Table C1.2 for the Medium emissions scenario for a number of locations around the Scottish coastline.

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\(^{194}\) The total area of Scotland is estimated as 78,800 km\(^2\) (Section 1.3) which is larger than the figure given here.

\(^{195}\) Although the report by Kay et al., (2011) is titled “An Assessment of the Vulnerability of Scotland’s River Catchments and Coasts to the Impacts of Climate Change”, it appears to cover rivers only.
Table C1.2 Relative sea-level rise for several locations (1990 baseline) for the Medium emissions scenario (cm)

<table>
<thead>
<tr>
<th>Location</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
<th>2095</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p5</td>
<td>p50</td>
<td>p95</td>
<td>p5</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>0.9</td>
<td>5.7</td>
<td>10.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Aberdeen</td>
<td>1.7</td>
<td>6.6</td>
<td>11.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Wick</td>
<td>2.3</td>
<td>7.1</td>
<td>12.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Lerwick</td>
<td>5.9</td>
<td>10.8</td>
<td>15.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Ullapool</td>
<td>1.5</td>
<td>6.4</td>
<td>11.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Stornoway</td>
<td>3.0</td>
<td>7.9</td>
<td>12.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Tobermory</td>
<td>0.6</td>
<td>5.5</td>
<td>10.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Millport</td>
<td>0.1</td>
<td>5.0</td>
<td>9.9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Although information on projected future changes in river flows and sea level are available, it is not possible to currently project how the flood risk in Scotland may change in the future, based solely on the extrapolation of these results. Additional work is required, which is included in SEPA’s future planned work, however, based on the results for England and Wales, suggestions on how the flood risk may change for Scotland are given where appropriate in this report.

Future planned work on climate change impacts

Future work is currently planned by SEPA that should be completed by 2013. This work, in addition to the work due to be delivered by the end of 2011 includes the following, and would be available for use in the next CCRA. This would enable analysis for Scotland to be undertaken that would be similar to that which has been possible for England and Wales this time round.

- National flood hazard and flood risk modelling and mapping covering tidal, river and pluvial flooding. These models will be suitable for climate change assessments.
- Selection of climate change scenarios for assessing potential future flood risk.
- Determination of projected changes in rainfall, river flows and sea level for the selected scenarios.
- Modelling of the scenarios in order to determine potential future risk.
C.2 Waterlogging

With rainfall levels projected to increase significantly in the winter months (up to 21% by the 2080s under the central estimate of the Medium emissions scenario from the 1961-1990 baseline), there is the potential for an increased frequency and extent of waterlogging of high grade (floodplain) agricultural land. This would impact negatively on agricultural productivity (Johnson et al., 2009), although warmer drier summer periods would be expected to reduce times of waterlogging during these periods. Changes in levels of waterlogging would also impact on work on construction sites, and present both opportunities and threats to biodiversity.

Impacts of Climate Change on waterlogging of agricultural land

Waterlogging has been represented by the proxy measure of workable days on the land for this indicative analysis. Workability of the land and access to it are the practical issues of concern for farmers, rather than waterlogging per se (although it is recognised that waterlogging can of itself damage crops and trees). Due to the timescale limitations of this study, a representative site was considered:

- A typical agricultural site in the east of Scotland growing winter barley

The workable limit of the land has been defined on the basis of a literature review, and particularly Cooper et al. (1997), which defined the workable limit to be 110% of Field Capacity (FC). Field Capacity is the amount of water that can be held in a soil against the force of gravity and is usually stated as a percentage. We have adopted this definition for this analysis.

The WASIM model (Hess and Counsell, 2000) was selected for use in this study. WASIM can simulate a daily soil moisture balance for a range of soil, crop, climatic and field management conditions. It can be readily adapted for use in large modelling ensembles for investigating climate change uncertainty, and is appropriate for indicating the likely direction and magnitude of climate change impacts.

The soil characteristics for the study site are shown in Table C2.1 based on typical data provided by Dr Allan Lilly at the James Hutton Institute.

<table>
<thead>
<tr>
<th>Parameter values used to represent the soil types in the WASIM model</th>
</tr>
</thead>
<tbody>
<tr>
<td>% water at saturation</td>
</tr>
<tr>
<td>% water at field capacity</td>
</tr>
<tr>
<td>% water at PWP&lt;sup&gt;196&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hydraulic Conductivity (m/day)</td>
</tr>
<tr>
<td>Curve Number (a measure of the proportion of runoff)</td>
</tr>
</tbody>
</table>

Daily baseline precipitation data were downloaded from the Hadley Centre regional precipitation data website<sup>197</sup> and monthly temperature data were downloaded from the

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<sup>196</sup> PWP – Permanent wilting point. The minimal amount of soil moisture that a plant requires not to wilt.

<sup>197</sup> http://www.metoffice.gov.uk/hadobs/hadukp/data/download.html
Met Office UKCP09 baseline data website, with the Oudin (2005) formula used to calculate potential evapotranspiration. For future climatology, nineteen samples of monthly change factors were selected for each epoch (2020s, 2050s, and 2080s) and emission scenario (Low, Medium, and High) based on ranking all 10,000 values available, by totalling winter rainfall (October – March) and identifying the scenarios from the 5th to the 95th probability levels at intervals of a 5th.

Each simulation was run for the period 1960-1990, allowing one ‘warm-up’ year to minimise the influence of initial conditions. The following outputs (averages over 1961-1990 period) were used in the analysis:

- average date of first unworkable day of autumn (i.e. water content at or above 110% of field capacity);
- average date of last unworkable day of spring;
- average number of unworkable days per year.

The average number of workable days per year includes those days during the winter when the soil moisture content temporarily drops below the threshold used (i.e. 110% of field capacity). The number of unworkable days per year was used to rank the results for each emissions scenario/decadal period and the results corresponding to the p10, p50, and p90 probability levels are presented below to provide an indication of the range of results across all simulations.

Results

The trend for this site is towards an increase in the length of the ‘summer’ period when soil moisture is maintained below the 110% field capacity threshold. This trend generally becomes stronger further into the future as a result of increases in emission concentrations, with the change in the start of the unworkable period in autumn more pronounced than the change in the end of the unworkable period in spring (Figure C2.1). This impact is attributed to the general tendency towards projected increases in temperatures and decrease in precipitation during the summer period.
With regards to the average number of unworkable days per year (Table C2.2), the results indicate a trend towards a reduction in the total number of unworkable days per year into the future. This reduction in unworkable days is concentrated in the spring and autumn periods, with the proportion of days with soil moisture below the 110% field capacity during winter also tending to decrease (i.e., an increase in unworkable days is projected). This is attributed to the tendency towards increased winter precipitation in future climate change projections.

Table C2.2 Average number of unworkable days per year, for a typical agricultural soil used for Barley in the east of Scotland (baseline 1961-90) is 94 days (probability levels are of results, not of climate inputs to the model)

<table>
<thead>
<tr>
<th></th>
<th>Low emissions</th>
<th>Medium emissions</th>
<th>High emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>2020s</td>
<td>77</td>
<td>91</td>
<td>96</td>
</tr>
<tr>
<td>2050s</td>
<td>71</td>
<td>85</td>
<td>94</td>
</tr>
<tr>
<td>2080s</td>
<td>79</td>
<td>88</td>
<td>103</td>
</tr>
</tbody>
</table>
In interpreting these results, it should be noted that the time of year when the land first becomes workable is later than has been observed. The sensitivity of the projections to changes in model parameters was explored as part of this study and, whilst changes in absolute results were recorded, the direction and magnitude of the trends remained consistent.

Conclusions

The key conclusions from this analysis are that climate change can be expected to have the following impacts across the study site:

- an increase in the unbroken period of workability between spring and autumn;
- a decrease in total unworkable days per year, but an increase in the number of unworkable days in winter.

Acknowledgements

The assistance of Dr Allan Lilly at the James Hutton Institute in defining representative Scottish soil types and reviewing the results of the work is gratefully acknowledged, as is the help of Dr Fiona Burnett in outlining the crop development of winter barley. Dr Tim Hess, Cranfield University, also provided support in adapting WASIM to support large ensemble simulations.

C.3 Snowmelt

Measurements of days of snow cover in Scotland indicate a significant reduction over the last 40-50 years, with an approximate 30-45% reduction in the spring and winter months and a 70-80% reduction in the autumn, with the most significant reductions noted in the west of Scotland, (SNIFFER, 2006). This is consistent with rising mean temperatures, which is likely to reduce snow cover, which has risen by just over 1°C over this same time period (SNIFFER, 2006). With this reduction in snow cover, and temperatures reducing at higher altitudes (see for example Barry, 1992), flows in Scottish rivers with a large proportion of their catchments above the typical winter freezing level are most likely to be affected. This has recently been confirmed by Kay et al. (2011) who based on model runs of all catchments in Scotland, indicated that the higher the maximum, mean and minimum altitude of a catchment, the greater it was affected by snowmelt.

With snow regulating flows by storing and releasing water slowly, reductions in snow cover is likely to lead to an increase in flow peaks, and a reduction in low flows. This was shown by SEPA (2009), who assessing three high and three low level catchments in Scotland with record lengths greater than 40 years, indicated that there was a noticeable increase in the variability of flow of high level catchments (consistent with a reduction in snow cover in these regions), with no noticeable trends in low level catchments. However, rapid thaws combined with significant rainfalls in spring months could see increases in peaks flows although changes in the seasonality of periods of intense rainfall may mask these changes.

A further contributory factor in the role of snowmelt is likely to be the effects of climatology. Catchments draining westerly have a warmer and wetter climate than those draining easterly, and as a consequence westerly draining catchments tend to have extreme floods caused by sustained rainfall events, little influenced by snow (Kay et al., 2011). Extreme floods for easterly draining catchments could, however, change

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199 Personal Communication with Dr Alan Lilly, September, 2011.
in the future depending on whether the main influence is the regulating influence of the snow or rapid thaw during periods of significant rainfall.

The trends indicated by SNIFFER, (2006) are likely to continue for the rest of this century, with Jenkins et al., (2009) projecting typical reductions of snowfall of 65-80% over mountain areas and 80-95% elsewhere by the 2080s under the Medium emissions scenario. Based solely on the change in snow cover, this would be most likely to lead to larger flood peaks in the winter months for high level catchments, resulting in an increase in the number of flood warnings and consequentially a change in the flood risk. If this then results in lower river flows in late spring and early summer (as the flows would not include snowmelt by this time of year), this may lead to water abstraction issues.

C.4 Rainwater Penetration

Wind-driven rain (WDR) is a large source of moisture problems for buildings causing water ingress (Blocken and Carmeliet, 2007), and this is expected to become of greater significance in the future. The two driving parameters of WDR intensity are rainfall and wind speed, although building design and orientation as well as rainfall duration and raindrop size may also have an affect.

WDR can cause damage by water penetration, frost damage, salt migration and cracking, potentially causing structural problems (Blocken and Carmeliet, 2004). Water penetration can occur as a result of WDR. Moisture may be forced through facades and conduits causing dampness, mould, etc. indoors. Pressure increases may have a small influence in the water penetration rate, but recent research suggests that this may not be that significant, with any increase in water entering the building during rainfall events being more often a result of a change in rainfall direction (due to wind) rather than pressure forcing the leak (University of Waterloo, 2011). Many cases of rainwater penetration are a result of damaged or ill fitting materials, which can exacerbate the impact of wind-driven rain on the building, causing water ingress.

Whilst winter rainfall is projected to increase and greater incidences of heavy rainfall days in winter and summer may occur, UKCP09 suggest that projected changes in wind speeds are uncertain, and likely to be small, with the direction of change uncertain (Gethin, 2010). On this basis, although there may be an increase in wind driven rain, wind speed changes would not exacerbate this.

Rain penetration problems are often linked to prolonged wet seasons, coupled with high winds, rather than intense spells of rainfall (Pountney et al., 1988). On this basis, average winter rainfall has been analysed here to provide an indication of how the scale of the problem may change in the future. WDR maps based on projected winter rainfall and analysis of the British Standard BS8104 are given in Figure C4.1, which calculates the average volume of water a wall is exposed to on an annual basis. These maps give an indication of how the exposure to WDR may change in the future. A value of 170 l/m² or less indicates a relative low exposure (sheltered), 171 to 275 l/m² is a moderate exposure, 276 to 540 l/m² is severe, and over 540 l/m² is very severe.

With little research post-1980 and little quantitative data for WDR, it is difficult to give an assessment of what impact these changes will have on buildings within Scotland. It has been reported that due to a lack of quantitative research, innovative new building designs and materials may fail to accurately appreciate WDR, potentially increasing water penetration events. An increase in wind driven rain will be particularly relevant where external walls do not have a suitable cavity or rain screen, Scottish Government (2009b). For example, driving rain will affect rubble stone and built properties to a greater extent than those with render or cladding (Lisø et al., 2003). Dependent on its exposure rating, cavity wall insulation (often recommended to increase the thermal
efficiency of buildings) may actually render buildings more vulnerable to rain penetration in certain conditions of driving rain (Stirling, 2002; Austin et al., 2008).

This was also highlighted as a concern for Heritage Buildings (response from The National Trust for Scotland) as there are a large number of historic brickwork buildings in Scotland (see below). These types of buildings are potentially more susceptible to water penetration than those constructed of Sandstone (Cessar and Hawkins, 2007). Scotland does not have many exposed brick buildings (nearly all are rendered) and how permeable they are/are not will depend on the type of brick and the type of sandstone. Increases in winter rainfall and extreme weather events would be expected to cause greater damage to the building fabric. Traditionally constructed buildings rely on a degree of water exchange between weather events – a mass wall absorbs and then looses water as the weather changes. With increased precipitation such walls may never dry out and become progressively saturated, leading to binder migration and loss of structural integrity.
Figure C4.1 Wind Driven Rain (WDR) maps for Scotland for Medium emissions, p50 scenario (170 or less indicated sheltered exposure, 171-275 moderate, 276-540 severe, 540+ very severe)
The WDF maps show that projected changes are minimal. It is likely that large areas in the west may see a change from moderate to severe conditions, but this is unlikely to have a noticeable impact. More pronounced changes may be seen in the East of Scotland where larger areas may experience a slight increase in exposure to wetter conditions. Based on the projections, this is most likely to occur in the Edinburgh and Lothian regions, where there may be a change from 'sheltered' conditions to 'moderate' conditions. The effect this may have on water penetration is unknown. However, the higher population density associated with these areas may result in a larger number of cases of building damage.

The High emissions scenario p90 projections map in Figure C4.1 shows only a small change in the areas experiencing 'very severe' exposure. However, large areas of Southern and Eastern Scotland, which currently experience moderate exposure, would experience severe exposure under this scenario, which is a significant change from current conditions. This could have a significant impact on properties designed for a more sheltered climate.

![Absolute change in wind driven rain from 1992 baseline](image)

**Figure C4.2 Absolute changes in wind driven rain volume**

(p50 Medium emissions scenario)

![Percentage change in wind driven rain from 1992 baseline](image)

**Figure C4.3 Percentage changes in wind driven rain volume**

(p50 Medium emissions scenario)
Figure C4.2 shows that the projected volume of WDR increases in the future, with the greatest increases at Oban, Kyle of Lochalsh, Stornoway, Lerwick and Kirkwall.

Figure C4.3 shows the projected percentage change in WDR. With the exception of Fort William and Kingussie all Northern locations show an increasing percentage change between the 2020s to 2050s and the 2050s to 2080s. Comparing figures, Kingussie shows little or no change indicating that unsurprisingly, central locations are less likely to experience change than coastal locations.

Although changes in wind speeds are uncertain, it is unlikely that WDR would become a significant problem within Scotland. The increase in rainfall days and average winter rainfall may result in historic building experiencing increased water penetration, however for modern buildings a large negative impact is unlikely. The lack of publications and reports into current water penetration of buildings in Scotland indicates that this may not have been regarded as a significant risk at least under the current climate. Additionally, with evidence indicating that wind pressure is possibly over-emphasised (University of Waterloo, 2011), the risk to Scotland’s infrastructure may be limited.

C.5 Water-borne Diseases

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 (Tam et al., 2011), costing the economy over £750 million (Wheeler et al., 1999). 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). In Scotland, the zoonoses which generate the most significant public health and political concern are Cryptosporidium and verotoxin-producing Escherichia coli (VTEC), of which E. coli O157 is the most well-known.

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. In turn, this could result in increased transmission to animals and humans. 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 and water-borne zoonoses

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.

200 Current research into rainfall penetration is scarce, with the majority of the literature looking at the impact of climate change on urban drainage (personal communication, Dr David Kelly, Heriot-Watt University). Ongoing research as part of the DOWNPIPE project (http://www.ukcip-arcc.org.uk/content/view/591/517) may confirm the findings of the University of Waterloo study, however the initial results of this study are not due for release until after this report has been issued.

201 This figure is probably in the region of twice as large now based on the recent research by Tam et al., (2011).
In Scotland, the water industry and public health agency response to Cryptosporidium contamination of municipal drinking water has focused on establishing effective multiple barrier water treatment systems to eliminate this pathogen from drinking water supplies. Indeed, most public drinking water supplies have effective forms of water treatment capable of significantly reducing the concentration of Cryptosporidium in final tap water. These include coagulation, rapid gravity filtration (RGF), dissolved air flotation (DAF) and more recently, membrane filtration (Goh et al., 2005).

Inadequate disinfection and/or filtration of drinking water may expose consumers to a risk of infection from water-borne disease and has previously resulted in large outbreaks of cryptosporidiosis and E. coli O157, particularly in North America (MacKenzie et al., 1994; Clark et al., 2003; Olsen et al., 2002). In Scotland, there have been several outbreaks of cryptosporidiosis and E. coli O157 which have been associated with failures in the treatment of public and private drinking water supplies (PWS) (Mukherjee, 2002; Licence et al., 2002).

Cryptosporidium

Cryptosporidiosis is caused by a number of species or genotypes of the genus Cryptosporidium although the most important appear to be C. parvum and C. hominis. While C. hominis infection is mainly restricted to humans, C. parvum infects a variety of mammals (especially neonatal cattle and sheep) as well as humans. Oocysts can be shed for several days by infected animals, with up to 10 million oocysts per gram of faeces (Xiao and Herd, 1994) and shedding is especially pronounced during the calving and lambing season. During periods of precipitation, it is highly likely that infectious oocysts are washed into nearby watercourses (Nichols et al., 2010).

Characteristic symptoms of cryptosporidiosis are profuse, watery diarrhoea, often accompanied by bloating, abdominal pain and nausea or vomiting. While illness is normally self-limiting, it can be prolonged and studies have shown an association with long-term health sequelae such as reactive arthritis (Hunter et al., 2004). Furthermore, people with severely compromised immune systems, particularly with reduced T-lymphocyte counts, may develop severe, chronic diarrhoea or even fatal infection in the absence of immunotherapy (Hunter and Nichols, 2002).

VTEC

Cattle and sheep are also the main reservoirs of VTEC and as with Cryptosporidium, the bacteria are excreted in large numbers onto pasture. Furthermore, ‘super-shedding’ cattle have been shown to excrete massive numbers of VTEC and this has important consequences for transmission, especially via environmental and waterborne pathways (Chase-Topping et al., 2008). VTEC have been isolated from a number of farmed and wild animals (Bardiau et al., 2010) and given the high density of deer in Scotland, it is possible that these animals are a potential reservoir of infection, especially in areas which are more rural and likely to be served by PWS.

Infection with VTEC often results in severe abdominal pain and bloody diarrhoea but in approximately 10-15% of cases, disease progresses to the haemolytic uraemic syndrome, which can result in acute renal failure and death (Tarr et al., 2005). While E. coli O157 is the best known serotype, other non-O157 strains such as E. coli O26 have become more prominent and appear to have a similar reservoir, while also having increased virulence (Pollock et al., 2011).

Risk of waterborne disease and mitigation strategies

In Scotland, most of the drinking water is surface-derived (rather than groundwater) and in global studies, low levels of oocysts have been detected in 65-97% of surface-water supplies, suggesting that most populations may be at some risk for waterborne infection (Mason et al., 2010). In 2000, an outbreak of cryptosporidiosis occurred
among Glasgow and Clyde residents who received drinking water from Loch Katrine (NHS Scotland, 2001). In order to eliminate Cryptosporidium from Loch Katrine-sourced water, enhanced filtration treatment was introduced to this part of the Glasgow supply system in September 2007. Retrospective analysis of Cryptosporidium incidence in local populations receiving drinking water, where coagulation and RGF has been introduced, highlights a demonstrable reduction in local incidence rates of cryptosporidiosis (Pollock et al., 2008).

In Scotland, the majority of drinking water supplies, especially in major urban areas such as Glasgow and Edinburgh, 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 and it is not uncommon for boil water notices to be in place for several months at a time. Furthermore, approximately 3% of the Scottish population is dependent on a PWS for their water, with a high proportion of these not being treated before consumption. It is often the case that the catchment areas surrounding PWS are frequented by farmed and/or wild animals, which harbour zoonotic pathogens such as VTEC and Cryptosporidium and after periods of heavy rain, these pathogens can leach into PWS where inadequate treatment poses a risk to susceptible consumers (Ogden et al., 2001).

A number of risk mitigation strategies can be employed for those on a PWS and these include chemical disinfection using chlorine or ultra-violet filtration, the latter of which has purported cidal activity against Cryptosporidium. Clearly, land and livestock management is crucial in preventing contamination of watercourses and the timing of slurry application to land is critical. Other strategies include removal of farmed animals from the catchment, erection of fences around the catchment and Scottish Government grants to partially fund improvements to PWS.

Waterborne outbreaks and incidents associated with drinking water

In Scotland, 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 the exposures for these cases can only be estimated through local case investigation, which may be an insensitive method. Despite this, there is robust epidemiological and microbiological evidence to suggest that cryptosporidiosis has been transmitted to consumers of municipal and private drinking water in Scotland for a number of years (Pollock et al., 2008 and Pollock et al., 2010).

In the past, Health Protection Scotland (HPS) have been asked to participate in Problem Assessment Groups (PAG) after periods of intense precipitation, where an increase in oocysts has been noted by Scottish Water. Generally, the extensive risk assessment and microbiological investigations have resulted in the decision that a boil water notice is not required, with close monitoring of the local populations through syndromic and laboratory surveillance. Since 2009, HPS has rarely been notified by Scottish Water or local health protection teams of increased oocyst counts in final drinking water and this may be due to multi-barrier water treatment approaches being introduced for most urban municipal drinking water supplies in Scotland. It is not anticipated that climate factors will adversely affect these supplies provided the systems are efficiently managed and well-optimised and liaison continues between Scottish Water, SEPA, livestock farmers and land-owners.

In contrast to municipal drinking water supplies, PWS in Scotland are a cause for concern given that 1 in 5 supplies contained high levels of coliforms, in 2010 (DWQRS, 2011). Furthermore, in 2010 an outbreak of E. coli O157 affecting 14 people was strongly associated with a PWS, where pathogen was detected in the supply. A UV
filtration system had been installed in the affected properties but the cause of the outbreak was considered to be due to a failure of the disinfection system through inadequate maintenance and poor management of the supply (DWQRS, 2011).

Although a number of treatment options are available for owners of PWS, there is evidence to suggest that appropriate disinfection is not universally adhered to. There are a number of financial and sociological reasons for this. Although Scottish Government provides grants for upgrades to existing PWS, the uptake of these has been limited. Grants of up to £800 may be awarded but the average quote for installation of UV filtration equipment may be as high as £4,000 (SGHD, 2009), which disinterests land-owners. Furthermore, while many PWS already have disinfection systems in place, the majority of these are either incorrectly installed or are not adequately maintained (DWQRS, 2011). Finally, many PWS consumers perceive that the risk of microbial contamination is low and/or that they have acquired immunity to these pathogens (SGHD, 2009). The combination of these factors highlights that consumers of PWS may be at risk from gastro-intestinal zoonoses, especially after intense and/or prolonged precipitation events.

Future projections

Given that Scottish Water has a water safety programme for all of its water supplies by the end of 2011, it is likely that municipal drinking water will largely be free of waterborne pathogens such as Cryptosporidium and VTEC. The evidence to date suggests that in Scotland, it is rural and private water supplies which are most likely to be affected. While it is not possible to attribute the source of infection to a clinical case (unless a case-control study is performed with appropriate microbiological and environmental sampling), outbreak studies and surveillance suggest that PWS have a significant role in transmission of these pathogens in Scotland (NHS Grampian 2009; Licence et al., 2002; DWQRS, 2011; Pollock et al., 2010). From these studies, a quantitative estimate of 10-15% of cases of VTEC and Cryptosporidium may be attributable to PWS.

Projecting into the 2020s and assessing the UKCP09 projections, it is unlikely that the number of cases of cryptosporidiosis or VTEC associated with drinking water should significantly change. For the 2050s and 2080s, the UKCP09 projection that Scotland may increase in temperature by approximately 2.8°C and 4.4°C respectively relative to the current day for the upper limit of the High emissions scenario, may have a bearing on pathogen survival on land and in drinking water. 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 not possible to predict 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.

Extant HPS surveillance and research

In conjunction with DWQRS, HPS has conducted research on how the implementation of enhanced physical treatment on municipal drinking water affects host immunity to Cryptosporidium. While filtration in Scotland has been shown to result in reduced incidence of cryptosporidiosis, it has also been postulated that this might paradoxically decrease herd immunity to Cryptosporidium through reduced exposure to non-viable oocysts and/or their proteins. However, it is important to stress that host immunity is multi-factorial and depends on both infectious dose and viability of the consumed oocysts, as well as the immunological status of the host at the time of ingestion and during the incubation period. It is probable that susceptibility/resistance to infection is due to key interactions in the immunological milieu (both cellular and physical) being significantly influenced by extrinsic and intrinsic factors e.g. steroidal medications for
underlying disease or endogenous stress cortisol levels. HPS intends to publish several peer-reviewed publications on these aforementioned studies.

Acknowledgements

We would like to thank Dr Kevin Pollock at Health Protection Scotland for assessing this metric.

C.6 Change in Barley Yields

Methodology

As the main production area for both winter and spring barley is in the East of Scotland, for the purposes of this analysis, this area was assumed to be representative of all the winter and spring barley growing areas in Scotland.

The analysis has, therefore, focused on the UKCP09 climate projections for the East of Scotland Administrative region and observed temperature and precipitation data (used to correlate historic barley yields and fit trend lines) were taken from the Leuchars weather station, which is at 3468E 7209N, 10 metres above mean sea level.

The yield, cultivated area and production data were provided by the Scottish Government’s Rural & Environment Science & Analytical Services (RESAS). Data were available from 1990-2010 for spring and winter crops separately. Combined crop data from earlier years were not suitable for use in this study.

Analysis

As barley has two cropping seasons, winter and spring, these were considered separately and the combined total was also compared to current production. The two crops were found to be most sensitive to different climate variables:

- Winter yield was most closely linked to total rainfall\(^ {202} \) in December and January
- Spring yield was most closely linked to mean temperature\(^ {202} \) from April to July.

The projections for winter barley indicate a potential threat to yield, being negatively correlated with total rainfall in December and January. As rainfall in these months is projected to increase for the East of Scotland, the yields of barley are therefore also projected to decrease. The minimum decrease by the 2020s is projected to be 13% from the 1990-2010 average yields for the driest scenario (p10, Medium emissions scenario). However, the decrease by the 2080s is projected to be up to 31% for the wettest scenario (p90, High emissions scenario).

The reduction in winter barley yields is balanced somewhat by an increase in yields for spring barley, owing to an increase in mean spring growing season temperatures. Significant increases in December and January rainfall are projected to occur sooner than significant increases in mean spring temperatures, however, so this compensatory effect occurs later rather than sooner. By the 2050s, a decrease in total barley yield is still more likely than an increase. By the 2080s, however, there is more likely to be an increase in yield, relative to the 1990-2010 average.

Results

Figures C6.1 and C6.2 show the response functions for winter and spring barley respectively. Figure C6.1 shows the negative correlation between winter barley yield

\(^{202}\) At Leuchars weather station
and rainfall in December and January. Figure C6.2 shows the positive correlation between spring barley and mean temperatures between April and July.

![Figure C6.1](image1.png)

**Figure C6.1**  
Response Function for (Winter Barley)  
(total rainfall in December and January)

![Figure C6.2](image2.png)

**Figure C6.2**  
Response Function for (Spring Barley)  
(mean temperature April to July)

Tables C6.1 and C6.2 show the projected percentage changes in yield for winter and spring barley respectively. Table C6.1 shows a significant reduction in yield for winter barley from the 2020s onwards, for all emissions scenarios. Table C6.2 shows that it is more likely that there would be a reduction in yield for spring barley in the short-term.
(2020s), but then there would be a slight increase in yield by the 2050s and a more significant increase by the 2080s, based on the UKCP09 climate projections.

### Table C6.1 Projected percentage change in yield (Winter Barley)

<table>
<thead>
<tr>
<th>Region</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
<th>Emission Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
<td>p10</td>
</tr>
<tr>
<td>EasternScotland</td>
<td>-12.7</td>
<td>-15.7</td>
<td>-19.2</td>
<td>-14.0</td>
</tr>
<tr>
<td>EasternScotland</td>
<td>-13.5</td>
<td>-17.9</td>
<td>-24.0</td>
<td>-14.8</td>
</tr>
</tbody>
</table>

### Table C6.2 Projected percentage change in yield (Spring Barley)

<table>
<thead>
<tr>
<th>Region</th>
<th>2020</th>
<th>2050</th>
<th>2080</th>
<th>Emission Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
<td>p10</td>
</tr>
<tr>
<td>EasternScotland</td>
<td>-16.4</td>
<td>-6.6</td>
<td>0.7</td>
<td>-10.6</td>
</tr>
<tr>
<td>EasternScotland</td>
<td>-6.3</td>
<td>5.2</td>
<td>22.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

### Impacts of Climate Change on Barley Yields in Scotland: Monetisation

This section outlines the economic impact of climate change on barley yields in Scotland. The impacts on yields are expressed in monetary terms as this is a common metric that allows the direct comparison of climate change impacts with other agricultural impacts, and also other impacts in different sectors.

This analysis is set out as follows. First, the outputs from the risk assessment are presented and discussed, including a detailing of the assumptions involved. Following this, the methodology and the unit values employed to estimate the impacts in monetary terms are outlined. Finally the monetisation results are presented.

**Outputs from the Risk Assessment**

The output from the physical risk assessment is the change in the yield of barley as a result of climate change.

There are a number of assumptions that are important to note in the interpretation of these outputs in the context of the subsequent monetisation exercise. They include the following:

- The analysis is undertaken for a scenario of future climate change only imposed on present socio-economic conditions. Thus, it does not include the effects of future socio-economic change (land-use change, agricultural policy including reform, international agricultural development, mitigation policy for agriculture, etc.). It also does not include baseline productivity increases from technological advance, water and irrigation, new species (including Genetically Modified Organisms), etc.

- The analysis only considers the direct primary effect of a number of climate variables on yield, using simple statistical relationships. However, in practice the impact of climate on yield is likely to be much more complex. For example, the relationship between climate, crop growth and yield are complicated by a large number of climate, soil and crop management factors, the effects on pests and pathogens, extreme events and seasonal to daily change, etc.

- The analysis assumes no adaptation, including no farm-level autonomous adaptation. In practice, farm responses may reduce impacts through a

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203 An introduction to the analysis technique and methods for monetisation of impacts is given in Appendix D, Sections D.1 and D.2.
number of local responses (e.g. the use of alternative cultivars, the adoption of different species, etc.).

- The analysis does not include the raft of international drivers that are likely to affect future UK agriculture, including developments in world trade patterns, responding to changes in demand for, and supply and prices of agricultural commodities in global and regional markets. It also does not consider the effects of climate change internationally.

The change in barley yields is expressed in thousand tonnes per annum for the different future time periods (2020s, 2050s and 2080s), scenarios (Low, Medium and High) and probabilistic-like outputs for the p10, p50 and p90 probability levels. The results are presented in Table C6.3 below.

### Table C6.3: Change in barley yields under different scenarios (‘000 tonnes per annum). Baseline 1990-2010, 1,734,000 tonnes per annum.

<table>
<thead>
<tr>
<th></th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>Low</td>
<td>-205</td>
<td>-73</td>
<td>88</td>
</tr>
<tr>
<td>Medium</td>
<td>-269</td>
<td>-176</td>
<td>-65</td>
</tr>
<tr>
<td>High</td>
<td>-163</td>
<td>1</td>
<td>204</td>
</tr>
</tbody>
</table>

Note: negative numbers imply a decline in yield; positive numbers imply an increase in yield.

At first glance, Table C6.3 shows a decline in barley yields for the majority of the early time periods and scenarios considered, shown with red shading. However, the table reveals an increase in barley yields for p90 for both the 2050s and 2080s for the Low, Medium and High emissions scenarios. An increase in yields also occurs for the p50 High emissions scenario for the 2050s and p50 Medium and High emissions scenarios for the 2080s.

Increases in barley yields are most favourable in the far future under the High emissions scenario and for the p90 probability limit.

**Methodology and Unit Values**

The basic approach to the costing analysis is, for each impact category considered, to multiply relevant unit values (market prices or non-market prices) by the physical impacts identified above.

To value the above changes in barley yields, the study has adopted a partial equilibrium approach. This applies direct yield prices only (see later discussion for the caveats with this approach).

An average annual market price of barley for the UK is used. An average of the most recent 5 years is taken (2006-2010) to minimise the impact of the annual variation in prices. The price data comes from Defra (2010b)\(^{204}\), which presents annual prices of malting barley and feed barley for the UK in £ per tonne. Therefore, we calculate a weighted price of barley based on the amount of barley that is used for brewing/distilling and animal feed within the UK (i.e. for domestic use). This information is also available in the Defra report on an annual basis in thousands of tonnes. Prices of malting barley and feed barley for the most recent 5 years are presented in Table

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C6.4. The data shows that the price of malting barley is higher than the price of feed barley in all 5 years.

Table C6.4: Market price of barley in the UK (£ per tonne)

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malting barley</td>
<td>80</td>
<td>124</td>
<td>153</td>
<td>125</td>
<td>108</td>
</tr>
<tr>
<td>Feed barley</td>
<td>70</td>
<td>106</td>
<td>118</td>
<td>88</td>
<td>98</td>
</tr>
</tbody>
</table>

Source: DEFRA (2010b).

It is important to note that the average UK price of barley used in this analysis includes the subsidies in place in Europe and is therefore not representative of real world market prices. Having said that, the average world price of barley obtained from the World Bank statistics is £98.19 per tonne over the years 2006 to 2010. This is very similar to the average UK price of barley used in this analysis, i.e. £103.63 per tonne over 2006-2010. Thus, we would not expect much difference in the welfare effects calculated using the average UK price of barley rather than the average world market price of barley.

The data on the domestic use of barley for brewing/distilling and animal feed shows that a larger quantity of barley is used for the latter in all 5 years considered (see Defra (2010b) for the data). The ratio of domestic use for the purpose of a) brewing/distilling; and b) animal feed to the two uses combined is one-third and two-thirds, respectively. These ratios are used as weights to calculate the weighted annual average price of barley, estimated to be £103.63 per tonne from the price data in Table C6.4. This price is used to value the changes in barley yields in all scenarios considered in all future time periods. In doing so, we make the following assumptions:

a) The price of barley in all of the UK is the same as the price of barley in Scotland.

b) The ratio of barley used for brewing/distilling and animal feed when exported is the same as the ratio between these two uses when used domestically. By making this assumption we ensure that the total quantity of barley produced in the UK is used in the same ratio as the domestic use ratio (for the purposes of brewing/distilling and as animal feed) and thus the weighted average price between these two uses may be estimated consistently.

c) The price estimated represents the current price of barley and is not adjusted for projected price changes in future time periods.

Results and Discussion

Multiplying the unit price identified above by the change in the barley yield given in Table C6.3 leads to an estimate of the impact of climate change on barley revenues in Scotland. The results are shown in Table C6.5.

Consistent with other sectors, the indicative results below are presented in terms of constant (2010 prices) for the three time periods considered in the CCRA i.e. the 2020s, 2050s and 2080s. The results are presented in this way to facilitate direct comparison.

At this stage, the values are presented in un-discounted terms. It should be noted that the use of the values in subsequent analysis, for example in comparing the costs and

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205 World Bank data on historical world prices of barley comes from http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/PINK_DATA.xls; An average PPP exchange rate for the years 2006-2010 was used from the currency conversion tool developed by Walton and Muller (2010) to convert prices from US $ to UK £.
benefits of adaptation options to reduce these impacts, would need to work with discounted present values.

**Table C6.5: Change in barley revenues per annum due to climate change (£ million). Baseline 1990-2010.**

<table>
<thead>
<tr>
<th></th>
<th>2020s p10</th>
<th>2020s p50</th>
<th>2020s p90</th>
<th>2050s p10</th>
<th>2050s p50</th>
<th>2050s p90</th>
<th>2080s p10</th>
<th>2080s p50</th>
<th>2080s p90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>-21.2</td>
<td>-7.6</td>
<td>9.1</td>
<td>-17.9</td>
<td>-0.4</td>
<td>20.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>-27.9</td>
<td>-18.2</td>
<td>-6.8</td>
<td>-20.2</td>
<td>-5.7</td>
<td>12.5</td>
<td>-12.2</td>
<td>9.1</td>
<td>35.2</td>
</tr>
<tr>
<td>High</td>
<td>-16.9</td>
<td>0.1</td>
<td>21.1</td>
<td>-4.3</td>
<td>20.7</td>
<td>52.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: negative numbers imply a loss in revenue and positive numbers imply a gain in revenue.

The annual falls in revenue in the 2020s due to climate change are projected to be between £7m and £28m. In the 2050s, the annual change in revenue as a result of the change in barley yield is projected to be between £-21.2m and £21.1m, i.e. with similar negative to positive effects across the p10 to p90 range. A similar pattern can be found in the 2080s, though in this time period, the positive effects are higher in magnitude in all scenarios in the 2080s compared to the 2050s. The annual effects for the 2080s are projected to be between £-17.9m and £52.1m.

To put the projected changes into perspective, the current annual average value of barley production in the UK at market prices is £588.3m (Defra, 2010b). This implies that the impacts projected in the 2020s (see Table C6.5) accounts for between 1% to 5% of the total current value. The changes projected in the 2050s account for between -4% to 4% of the total current value, and the changes in the 2080s account for between -3% to 9% of total current value.

It is important to note that the above projected changes do not represent welfare changes since they are not based on the 'gross margin', i.e. the revenue minus the cost. Whilst we do not have the data for gross margins for barley, other cereals indicate they are typically 0.3 – 0.5 of the changes projected above (depending on the crop).

Whilst this exercise provides an indicative estimate of the monetised value in the UK context, it is important to stress that Scottish production cannot be seen in isolation of global food production and prices that are likely to change in future time periods. Climate change will also impact on the economics of farm management and particularly to agribusiness approaches to risk management, and so lead to autonomous changes in agricultural practices more generally. To properly assess this, effects have to be analysed in the wider context of what will be happening to the prices of agricultural commodities as a result of changes in yields worldwide. Furthermore, future prices will change significantly, as a result of global production trends, socio-economic drivers (population, food production levels, biofuel use, etc.) and from the effects of climate change on production.

### C.7 Impacts of Climate Change on Agricultural Land Classification in Scotland: Monetisation

This section looks at the economic impact of climate change on Land Capability for Agriculture (LCA) in Scotland. LCA identifies the potential to use an area of land for...
different agricultural systems or management practices in the future based upon intrinsic physical limitations of the land (e.g. climate, soils and topography) that cannot be removed or ameliorated by reasonable management. In other words, LCA identifies the changes in various classes of agricultural land in Scotland in the future based on changes in climate and other factors. This change in LCA is presented in monetary terms as this is a common metric that allows the direct comparison of climate change impacts against other agricultural impacts, as well as other impacts in different sectors.

The analysis is set out as follows. First, the outputs from the risk assessment are presented and discussed, including a detailing of the assumptions involved. Following this, the methodology and the unit values employed to estimate the impacts in monetary terms are outlined. Finally the monetisation results are presented.

Outputs from the Risk Assessment

The output from the physical risk assessment is the area of land (in km²) that falls into various LCA classes in the current time period and the area of land that is projected to fall into the various classes in the 2050s. The LCA classes refer to the LCA classification that was used to rank land on the basis of its potential productivity and cropping flexibility. This was determined by the extent to which the physical characteristics of the land (soil, climate and relief) imposed long term restrictions on its use. The LCA is a seven class system, in which some of the classes are further subdivided into divisions. Class 1 represents land that has the highest potential flexibility of agricultural use whereas Class 7 land is of very limited agricultural value. These classes have been described in the main text in Table 4.7.

In addition to the information provided in Table 4.7 the Macaulay Land Use Research Institute\textsuperscript{208}, which developed the LCA classification for Scotland, categorises land in the LCA classes: 1-3.1 as arable agricultural land; 3.2-4.2 as mixed agricultural land; 5 as improved grassland; and 6-7 as rough grazing land. Definitions of these four categories are given in Table C7.1.

Table C7.1: LCA classification definitions by category

<table>
<thead>
<tr>
<th>Class</th>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3.1</td>
<td>Arable agricultural</td>
<td>Land in these classes, often referred to as prime agricultural land, is capable of being used to produce a wide range of crops. The climate is favourable, slopes are no greater than 7 degrees and the soils are at least 45cm deep and are imperfectly drained at worst. This land is highly flexible for other uses as well, such as for biofuel crops and woodland, although current management may make other options, such as heathland restoration, difficult in the short term.</td>
</tr>
<tr>
<td>3.2-4.2</td>
<td>Mixed agricultural</td>
<td>Land in these classes is capable of being used to grow a moderate range of crops including cereals (primarily barley), forage crops and grass. Grass becomes predominant in the rotation in Class 4.2 whilst other more demanding crops such as potatoes can be grown in Class 3.2. The climate is less favourable than on prime land, slopes up to 15 degrees are included and many soils exhibit drainage limitations.</td>
</tr>
<tr>
<td>5</td>
<td>Improved grassland</td>
<td>Land in this class has the potential for use as improved grassland. A range of different limitation types, either operating singly or in combination, can restrict the land capability to this class. These limitations include climate, slope, wetness, and often a heterogeneous pattern of conditions that render even occasional cultivation unsuitable. Land which has had this potential for</td>
</tr>
</tbody>
</table>

\textsuperscript{208} See http://www.macaulay.ac.uk/explorescotland/lca.html
improvement exploited is much more productive than land which remains in its unimproved state.

| 6-7 | Rough grazing | This land has very severe limitations that prevent sward improvement by mechanical means. This land is either steep, very poorly drained, has very acid or shallow soils and occurs in wet, cool or cold climates zones. In many circumstances, these limitations operate together. The existing vegetation is assessed for its grazing quality (Class 6 is of high grazing value for example) but Class 7 land is of very limited agriculture value. Nonetheless, this ground often has a high value, for example in terms of storing carbon in its organic soils and supporting rare species and habitats. |

Source: Macaulay Land Use Research Institute website.

The current LCA and the projections of LCA in the 2050s are given in Table C7.2.

Table C7.2: Area of LCA by class in the current time period and in the 2050s and the change between the two (in km²)

<table>
<thead>
<tr>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>3₁</th>
<th>3₂</th>
<th>4₁</th>
<th>4₂</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>42</td>
<td>1092</td>
<td>3331</td>
<td>7322</td>
<td>3603</td>
<td>4484</td>
<td>13528</td>
<td>37454</td>
<td>2502</td>
<td>73358</td>
</tr>
<tr>
<td>2050s</td>
<td>690</td>
<td>8981</td>
<td>5376</td>
<td>7989</td>
<td>1625</td>
<td>1417</td>
<td>13624</td>
<td>29993</td>
<td>1516</td>
<td>71211</td>
</tr>
<tr>
<td>Change</td>
<td>648</td>
<td>7889</td>
<td>2045</td>
<td>667</td>
<td>-1978</td>
<td>-3067</td>
<td>96</td>
<td>-7461</td>
<td>-986</td>
<td>-2147</td>
</tr>
</tbody>
</table>

Note: negative values imply a decline in land area by the 2050 from the current time period.

It is important to note that the LCA projection for the 2050s was based on the Medium-High emissions scenario, i.e. UKCIP02, and not UKCP09.

Summing across all classes, the current total land capability for agriculture is 73,358 km², whereas the total projected for the 2050s is 71,211 km². This implies that there is projected to be an overall decline in land available for agricultural purposes in the 2050s of 2,147 km². However, most of the decline in the area of land available for agriculture in the 2050s is within the lower LCA classes or those with less agricultural potential. On the other hand, there is projected to be an increase in the area of land that is classed as having high agricultural potential (particularly within classes 1, 2, 3₁ and 3₂) in the 2050s. In other words, there seems to be a shift in land from lower to higher classes in the 2050s compared to the current time period, which implies a potential benefit for agriculture in Scotland in the future.

The overall decline in the land available for agricultural purposes between the two time periods suggests that perhaps socio-economic trends (e.g. population changes, urbanisation etc.) have been taken into account, along with climate changes, in making these projections for the 2050s.

Methodology and Unit Values to be Adopted

The basic approach to the costing analysis is, for each LCA category considered, to multiply relevant unit values (market prices) by the physical changes in the area of land for agriculture identified in earlier sections of this report.

The first step is to compare and match the LCA classification for Scotland with the research from the Macaulay Land Use Research Institute.

GKD Galbraith’s review of farmland values in 2010²⁰⁹ gives a breakdown of land grade and a range of values attributed to each land type. Land value prices may vary significantly across the country however, for cost analysis purposes the midpoint of the

²⁰⁹ http://www.ckdgalbraith.co.uk/land-management-review
range has been given as the approximate value. For the costing, certain land classifications have been given the same value; for example, grades 2 and 31 have a value of £5,250 as they both fit into the category of “good arable” land.

Based on the descriptions of the LCA classification, the grades considered by GKD Galbraith are matched or mapped onto the LCA classifications as shown in Table C7.2. Matching the LCA land grades that corresponded closest to the GKD Galbraith land values was quite straightforward. For example, land graded ‘1’ by GKD Galbraith is the best arable land available. This matches the description of class 1 of the LCA classification of prime land, with no or minor limitations. Where land GKD Galbraith and MaCauley classifications did not match perfectly informed judgement was used. For example, ‘hill/rough grazing’ was assigned to both LCA grades of 6 and 7 as it gave the best general valuation. Although a single cost was used for the costing analysis, the range presented in Table C7.4 implies that there may be a marked difference in land quality within individual classes. Table C7.3 presents the land prices by land class for 2010.

Table C7.3: Land classification grade and the value attributed (in £ per acre, 2010 prices)

<table>
<thead>
<tr>
<th>GKD Galbraith land classification</th>
<th>Scottish LCA equivalent</th>
<th>2010 price range</th>
<th>Assigned value for costing calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Arable</td>
<td>1</td>
<td>£6000 +</td>
<td>£6,000</td>
</tr>
<tr>
<td>Good Arable</td>
<td>2, 31</td>
<td>£4,500 - £6,000</td>
<td>£5,250</td>
</tr>
<tr>
<td>Second class Arable / Silage</td>
<td>32</td>
<td>£3,000 - £4,500</td>
<td>£3,750</td>
</tr>
<tr>
<td>Rotational grass</td>
<td>41, 42</td>
<td>£2,000 - £3,000</td>
<td>£2,500</td>
</tr>
<tr>
<td>Permanent pasture</td>
<td>5</td>
<td>£1,000 - £2,000</td>
<td>£1,500</td>
</tr>
<tr>
<td>Hill/rough grazing</td>
<td>6, 7</td>
<td>£100 - £1,000</td>
<td>£550</td>
</tr>
</tbody>
</table>

Table C7.3 shows that agricultural land prices are provided for grades 2 and 31, grades 41 and 42 and grades 6 and 7 together, and grades 1, 32 and 5 individually. For the costing, the area has been converted to be expressed in acres rather than km², as detailed in Table C7.2, due to initial cost data²¹⁰.

The monetary value of the change in LCA by the 2050s was arrived at by combining the price information in Table C7.3 with the physical changes in the land area shown in Table C7.2. Note that these values include the socio-economic effect as well as the climate change impact. Since we do not know what proportion of this total impact may be attributed to climate change alone, we present results for the climate-induced impact being of the order of 10%, 50% and 90% of the total impact.

Results and Discussion

The monetary value of the change in LCA by the 2050s as a result of socio-economic change and climate change is presented in Table C7.4. The total monetary value of the impacts across all land classes is a net increase of approximately £10.2b.

²¹⁰ One km² is equivalent to 247.11 acres, which has been used as the basis of this conversion.
### Table C7.4: Monetary value of change in LCA by 2050s due to socio-economic and climate changes (£ in 2010 prices)

<table>
<thead>
<tr>
<th>LCA Class</th>
<th>1</th>
<th>2</th>
<th>3.1</th>
<th>3.2</th>
<th>4.1</th>
<th>4.2</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>All Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total change</td>
<td>£960m</td>
<td>£10,235m</td>
<td>£2,653m</td>
<td>£618m</td>
<td>-£1,222m</td>
<td>-£1,895m</td>
<td>£36m</td>
<td>-£1,014m</td>
<td>-£134m</td>
<td>£10,237m</td>
</tr>
</tbody>
</table>

Note: negative values imply a loss in monetary value by the 2050s from the current time period.

### Table C7.5: Monetary value of change in LCA by 2050s due to percentage attributed to climate change (£ in 2010 prices)

<table>
<thead>
<tr>
<th>% attributable to climate change</th>
<th>1</th>
<th>2</th>
<th>3.1</th>
<th>3.2</th>
<th>4.1</th>
<th>4.2</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>All Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>£96m</td>
<td>£1,023m</td>
<td>£265m</td>
<td>£62m</td>
<td>-£122m</td>
<td>-£189m</td>
<td>£4m</td>
<td>-£101m</td>
<td>-£13m</td>
<td>£1,024m</td>
</tr>
<tr>
<td>50%</td>
<td>£480m</td>
<td>£5,117m</td>
<td>£1,327m</td>
<td>£309m</td>
<td>-£611m</td>
<td>-£947m</td>
<td>£18m</td>
<td>-£507m</td>
<td>-£67m</td>
<td>£5,119m</td>
</tr>
<tr>
<td>90%</td>
<td>£865m</td>
<td>£9,211m</td>
<td>£2,388</td>
<td>£556m</td>
<td>-£1,100m</td>
<td>-£1,705m</td>
<td>£32m</td>
<td>-£913m</td>
<td>-£121m</td>
<td>£9,214m</td>
</tr>
</tbody>
</table>

Note: negative values imply a loss in monetary value by the 2050s from the current time period.
This net increase is driven by the increase in prime and good arable land areas, as well as a decline in the area of lowest value land.

Table C7.5 shows the monetary value of the change in LCA by the 2050s based on when 10%, 50% and 90% of the total monetary value is attributable to climate change. The net monetary loss when 10%, 50% and 90% of the total monetary value is attributed to climate change is £1.0b, £5.1b and £9.2b respectively. The overall impact of climate change on LCA in Scotland by the 2050s is falls into the ‘Medium’ impact category.

This finding compliments the prediction of the risk assessment that notes that since large areas of land are projected to move to a higher class, that there would be an increase in landscape value, with a particular benefit to more rural areas. However, it must be borne in mind that this analysis uses a single 2010 price data set. For a more robust analysis it would be beneficial to use average land value prices from recent years.

C.8 Impacts of Climate Change on Algal/Fungal/Mould Growth in Buildings Affecting Respiratory Conditions (Asthma) in Scotland: Monetisation

This section looks at the economic impact of climate change on asthma as a result of living in damp housing in Scotland. This impact is presented in monetary terms as this is a common metric that allows the direct comparison of climate change impacts against other health impacts, as well as other impacts in different sectors.

The section is set out as follows. First, the outputs from the risk assessment are presented and discussed, including a detailing of the assumptions involved. Following this, the methodology and the unit values employed to estimate the impacts in monetary terms are outlined. Finally the monetisation results are presented.

Outputs from the Risk Assessment

The review of increased algal or fungal/mould growth in buildings affecting respiratory conditions in Scotland indicates that approximately 10% of people in Scotland who have been diagnosed with asthma by a physician, have it as a result of living in a damp property. The review also notes that at present 390,000 people have asthma in Scotland. This implies that approximately 39,000 people in Scotland have physician diagnosed asthma as a result of living in a damp property. The review does not indicate weather or how the incidence of asthma due to damp living conditions is likely to change in the future as a result of climate change.

There are a number of assumptions that are important to note in the interpretation of these outputs in the context of the subsequent monetisation exercise. They include the following:

- Apart from future population growth that is taken into account, the analysis is undertaken for a scenario of future climate change imposed on present socio-economic conditions. Thus, it does not include the effects of future socio-economic change such as economic growth or cultural change resulting in better building standards and correspondingly lower fungal/mould growth in buildings etc.
- The analysis assumes no adaptation, including no household-level autonomous adaptation. However, in reality, the Scottish Government aims to remove substandard housing by 2015 under the Housing (Scotland) Act
2006, with the aim of eradicating fuel poverty by 2016, reducing damp homes and the effect on respiratory conditions.

**Methodology and Unit Values to be adopted**

The basic approach to the costing analysis is, for each impact category considered, to multiply relevant unit values (market prices) by the physical impacts identified in earlier sections of this report. For health impacts, there are no market prices, but the same approach can be adopted by deriving appropriate non-market values.

To do this, the monetisation of health risks identifies the components that comprise changes in welfare, which are summed to give the total welfare change, i.e. the total effect on society. For health, three components are needed to estimate this:

i. Resource costs, i.e. medical costs paid by the health service in a given country or covered by insurance, and any other personal out-of-pocket expenses made by the individual (or family).

ii. Opportunity costs, i.e. the cost in terms of lost productivity (work time loss (or performing at less than full capacity)) and the opportunity cost of leisure (leisure time loss) including non-paid work.

iii. Dis-utility, i.e. other social and economic costs including any restrictions on or reduced enjoyment of desired leisure activities, discomfort or inconvenience (pain or suffering), anxiety about the future, and concern and inconvenience to family members and others.

The welfare changes represented by components (i) and (ii) can be proxied using market prices for these items. This needs to be added to a measure of the affected individual's loss of utility, reflected in a valuation of the willingness-to-pay/accept (WTP/WTA), to avoid/compensate for the loss of welfare associated with, for example, an illness. It is the estimates of element (iii) that rely on the use of non-market valuation techniques and consequently have a greater degree of uncertainty attached.

There is a long tradition of the valuation of health endpoints in the UK for use in cost-benefit analysis. Currently, guidance is given in documents produced by the Department of Transport, Department of Health and Defra. It is highlighted, however, that values that currently exist may not express accurately the willingness-to-pay (WTP) that individuals might express, e.g. to avoid an increase in mortality risks from climate change. More specifically, existing values are derived often in the context of the work-place (wage-risk studies) that estimate the willingness to accept (WTA) a higher wage rate in accordance with a greater risk of accidental death. Alternatively, attention has been given to the valuation of fatal transport accidents, the frequency of which might be expected to change with for e.g. the introduction of new transport infrastructure.

Both the transport and workplace examples of contexts differ from the climate change context and so may be expected to result in different WTP values. The principal differences are:

- The length of life-time lost on average through the impact. Whereas the impact of premature death in the road or work context can be expected to be on an individual of average age within the population and therefore result in the loss of about 35 years of life, the loss from climate related risks may be very different, for example if it occurs in the elderly population.

- Size of the risk change. The annual risk change associated with climate change may be lower than the risk valued in the transport accident context.
• Context specificity. The nature of the risk is perceived to be different according to the degree to which exposure to the risk is voluntary, the extent to which the potential impact is perceived to be controllable, and the size of the impact (in terms of number of deaths resulting). For example, premature death as a result of a road accident may be perceived to be more voluntary to a death that results from climate change.

Baseline analysis (total reported incidence)

The first step in the monetisation of these potential health impacts in Scotland is to establish a baseline. Information on the current number of deaths and hospital admissions that asthma is responsible for in Scotland is readily available from various government sources. According to WHO’s International Classification of Diseases, (ICD-10211), asthma is coded J45-J46. The national health statistics for the UK contain annual data on the number of deaths and hospital admissions according to ICD codes. Data on deaths due to asthma (ICD J45-J46) in Scotland are obtained from the General Register Office for Scotland212. According to the latest available information, the numbers of deaths due to asthma in Scotland were 112, 103, 93 and 91 in the years 2007, 2008, 2009 and 2010 respectively. This limited data shows a gradual decline in the number of deaths due to asthma in Scotland since 2008. Information on hospital admissions due to asthma (ICD J45-J46) in Scotland is obtained from the United Kingdom Health Statistics, 2010213. The number of hospital admissions due to asthma in Scotland was 7,199 in 2008/2009.

The output from the risk assessment (see above) gives us the total number of people in Scotland who currently have asthma, i.e. 390,000 people. Subtracting from this total, the number of deaths and hospital admissions in 2008/2009, i.e. 98 deaths in 2008/2009214 and 7,199 hospital admissions in 2008/2009, gives the number of people in Scotland with ‘minor to moderate asthma symptoms’, i.e. in the region of 383,000 people. It should be noted that by calculating individuals with minor to moderate asthma symptoms in this way we are making a strong assumption about cases of deaths, hospital admissions and individuals with minor to moderate asthma symptoms as being mutually exclusive of one another. In other words we assume that every single case was either recorded as a death or a hospital admission or failing both as having, what we have termed, minor to moderate asthma symptoms. This implies that no single individual with asthma could, for example, have minor to moderate asthma symptoms and also be admitted to hospital in a given year, which is entirely plausible. Therefore, it is important to bear in mind that we might be overestimating the impacts to some degree at least.

The second step is to calculate the number of cases of deaths and hospital admissions due to asthma and the number of cases with minor to moderate asthma symptoms that may be attributed to damp housing conditions. Given that the risk assessment review states that 10% of the total cases of asthma may be attributed to damp housing conditions, this information is used to calculate the various health outcomes, as shown in Table C8.1 below.

211 See http://www.who.int/classifications/icd/en/
212 See http://www.gro-scotland.gov.uk/index.html
214 This was calculated as the average of the number of deaths due to asthma in the years 2008 and 2009, i.e. (103+93)/2, in order to retain consistency with the data available for HAs.
Table C8.1: Numbers of deaths, hospital admissions and minor to moderate symptoms due to asthma attributable to damp housing in Scotland in 2008/2009

<table>
<thead>
<tr>
<th></th>
<th>Deaths</th>
<th>Hospital Admissions</th>
<th>Minor to Moderate Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of cases</td>
<td>98*</td>
<td>7,199</td>
<td>382,703</td>
</tr>
<tr>
<td>10% of cases</td>
<td>10</td>
<td>720</td>
<td>38,270</td>
</tr>
</tbody>
</table>

* This was calculated as the average of the number of deaths due to asthma in the years 2008 and 2009, i.e. \(\frac{(183+109)}{2}\), in order to retain consistency with the data available for Hospital admissions.

Note: this reports the total baseline incidence due to damp housing conditions, not the current level attributable to current climate.

The third step is to find suitable unit values to monetise these health outcomes. For hospital admissions, previous economic analysis in UK Government, by the Interdepartmental Group on Costs and Benefits (IGCB, 2007) has assessed the economic costs of hospital admissions in the context of air quality regulation, providing a daily value. This provides a resource cost of £266 (2010 prices) per patient-day of a hospital admission due to respiratory illness, which is used here. The IGCB study also reports opportunity costs (i.e. costs of absenteeism from work resulting in loss of work output) of a hospital admission of £68 (2010 prices) per patient-day, which is also used here. Note that IGCB recommends using a value of £0 for the opportunity cost of a hospital admission due to respiratory illness since they note that the loss in work output due to air pollution induced morbidity will be negligible as the elderly and seriously ill will be most affected, of which the vast majority are expected to be above retirement age anyway. However, given that the data on the number of hospital admissions due to asthma includes children as well as adults, we thought a value of £68 per patient-day would be more appropriate especially if children were admitted to hospital and parents could not attend work in order to look after them. Finally the disutility costs associated with a hospital admission due to respiratory illness come from two studies namely Pearce et al., (1998) and Chilton et al., (2004) that are reviewed in the IGCB report. Pearce et al.’s study yields an average value per person of avoiding one day in hospital of £70, whereas Chilton et al.’s study yields a figure of £530 (2004 prices). Thus we take the central value of these two studies of £300 (in 2004 prices) which when converted to 2010 prices is £328 per patient-day.

The next step is to estimate the average length of stay (days) in hospital for asthma. The United Kingdom Health Statistics, 2010, reports the average length of stay in hospital by the underlying cause (according to the ICD-10 diagnostic categories). For Scotland, the average length of stay due to asthma (ICD J45-J46) was 3 days in 2008/2009.

In order to value the number of deaths resulting from asthma, the relevant monetary metric is considered to be the Value of Statistical Life (VSL). The VSL value that is currently quoted in Defra guidance is £1.49m (Defra, 2008b). Though this value is presented in the context of flooding, we assume that it can be transferred to the present context without the need for adjustment (see earlier discussion).

In order to arrive at estimates of the resource cost and opportunity cost for cases with minor to moderate asthma symptoms, asthma statistics relating to costs and incidence were used from the Asthma UK report (2004). Note that we are calculating costs for cases with minor to moderate asthma symptoms as the respective costs associated with the average asthma patient. The Asthma UK report suggests that in 2003-2004: i) asthma cost the NHS £889m per year; ii) work days lost costs due to asthma amounted to £1,200m per year; and iii) there were 5.2 million people with asthma in the UK that year. Based on this information we calculated the resource cost per average asthma
patient per year as £170 (i/iii) and the opportunity cost per average asthma patient per year as £230 (ii/iii). Converting these to 2010 prices gives a resource cost and opportunity cost per patient per year of £200 and £271 respectively for cases with minor to moderate asthma symptoms in the UK, which is assumed to be unchanged for Scotland.

Finally the disutility cost for cases with minor to moderate asthma symptoms was obtained from the monetary valuation of morbidity health-points section of the ExternE report (European Commission, 2005). Here, the willingness to pay to avoid one ‘symptom day’ of respiratory illness or one day with mildly, red watering, itchy eyes and runny nose is reported to have been valued at 38 euros per day (2004 prices). We take this as the most appropriate disutility cost for cases with minor to moderate asthma symptoms. Converting into pound sterling and 2010 prices, this is £34 per day. Given that this cost is represented on a daily basis, we would need to know the average number of days per year that an individual shows minor to moderate asthma symptoms. There is no real way of knowing this information, thus, based on an informed judgement, we assume this to be 5 days/year. Given that this number is based on an informed judgement rather than fact, monetary results will be presented with and without this cost component in order to make comparisons between the two.

The fourth step brings the individual components together. This uses the physical information on the number of deaths, hospital admissions and cases with minor to moderate asthma symptoms detailed in Table C8.1 and the respective unit values as discussed above.

The final step is to adjust these estimates for future population changes in Scotland in the 2020s, 2050s and 2080s. In order to do this, the principal population projections for Scotland presented in Table C8.2 are adopted.

Table C8.2: Current and future population projections for Scotland, in thousands

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>5,168</td>
<td>5,470</td>
<td>5,569</td>
<td>5,517</td>
</tr>
</tbody>
</table>

The monetary estimates are simply adjusted in proportion to the population projections in the future time periods. This assumes that the incidence of respiratory diseases in the population is similar across sex and age-groups in both the current time period and the future time periods.

Baseline analysis (climate related incidence)

Traditionally in an impact assessment framework, a climate response function would be derived that links current climate or extremes to the current disease burden. These are usually derived from epidemiological studies that provide associations between, e.g. daily temperature and daily hospital admissions.

In the case above, this function would provide a link on how current levels of asthma vary with temperature or humidity.

Unfortunately there are no such studies to base this analysis upon, and it has not been considered in the main CCRA, or quantitatively in the review. There is therefore no information on how the current baseline levels (above) vary with climate change – which in turn make future projections extremely speculative.

This is highlighted as a research gap. There is a need to investigate if there are any correlations between various climatic factors (e.g. daily temperature, seasonal
temperature, humidity, extreme precipitation) and mortality, hospital admissions or other mild to moderate symptoms of asthma.

In the absence of this information, it is assumed that current climate has some effect on the incidence level of asthma from damp building conditions, but that it will not be responsible for all – indeed even very much – of the current reported baseline levels above.

**Analysis of the impacts of future climate change**

Following on from above, traditionally in an impact assessment framework, the climate response function derived from current incidence would be applied to future changes in climate or extremes to estimate the future asthma burden. Again, this is consistent with the approach used for other health outcomes in the CCRA health assessment. However, there is no information on the current level of climate risks, and thus it is not possible to identify the potential increase in the future with climate change.

This makes it extremely difficult to scope out the potential monetary costs of climate change on asthma in Scotland. In the absence of this quantitative information, an indicative assessment of the monetary impacts for an additional 10% increase in the total asthma burden arising from damp housing conditions in future time periods has been used. Note that this implicitly assumes that baseline incidence is positively associated with some climate variables, and that these will increase with future climate change. It is stressed that this is extremely uncertain, but this provides a possible bounding of the scale of the impact.

**Results and Discussion**

Table C8.3 presents the current monetary value of current annual deaths, hospital admissions and cases of minor to moderate symptoms due to asthma that is attributable to damp housing conditions in Scotland. The physical health impacts data in Table C8.1 and the unit values above were applied to estimate these values.

**Table C8.3: Monetary value of total baseline current annual deaths, hospital admissions and minor to moderate symptoms due to asthma attributable to damp housing in Scotland (£, in 2010 prices)**

<table>
<thead>
<tr>
<th>% cases attributable to damp buildings</th>
<th>Deaths</th>
<th>Hospital Admissions</th>
<th>Minor to Moderate Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>14,602,000</td>
<td>1,429,721</td>
<td>23,268,342</td>
</tr>
</tbody>
</table>

Note: this reports the total baseline value due to damp building conditions, not the current value attributable to current climate.

The total monetary value of asthma attributable to damp building conditions in Scotland is approximately £39.3m assuming 10% of total cases are attributable to damp building conditions. If the disutility cost component for minor to moderate asthma symptoms is not included in the total monetary value (due to the assumption made on the number of days per year that individuals show such symptoms) it would amount to £32.8m. Note that these are total current values and do not separate out the current contribution of climate or extreme weather to these numbers. In practice, the level of the current asthma burden that could be attributed to current climate would be much lower.

Table C8.4 presents the values after adjustments are made for population changes in future time periods. Consistent with other sectors, the indicative results below are presented in terms of constant (2010 prices) for the three time periods considered in the CCRA, i.e. the 2020s, 2050s and 2080s. The results are presented in this way to facilitate direct comparison.
At this stage, we present the values in un-discounted terms. It should be noted that the use of the values in subsequent analysis, for example in comparing the costs and benefits of adaptation options to reduce these impacts, would need to work with discounted present values.

As expected, an increase in population in future time periods from the current time period implies that the total monetary value of baseline health impacts also increases in proportion to the change in population (again, it is stressed that these reflect the total incidence due to damp housing conditions, not the climate related incidence). When 10% of total cases are attributable to damp housing conditions the total monetary estimate increases from £39.3m in 2008/2009 to £42m in the 2080s, which is a 6.75% increase.

**Table C8.4: Total monetary value of total baseline health impacts attributable to damp housing in Scotland after adjusting for population changes in future time periods (£, in 2010 prices)**

<table>
<thead>
<tr>
<th>% cases attributable to damp buildings</th>
<th>Time Period</th>
<th>2008/2009</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td></td>
<td>39,300,064</td>
<td>41,596,623</td>
<td>42,349,469</td>
<td>41,954,035</td>
</tr>
</tbody>
</table>

Note: this reports the total baseline value due to damp building conditions, not the current value attributable to current climate.

The figures presented above must be taken with some caution since the recent trends in deaths due to asthma show that these have been falling gradually over the last couple of years. It also does not include future legislative, public health or behavioural change that reduces baseline incidence.

Table C8.5 provides an indicative estimate of the monetary value of health impacts that might be attributable to future climate change. When 10% of the total monetary value is attributable to climate change, the climate change-attributable health costs across the three future time periods are valued at £4.16 million to £4.23 million (assuming 10% of current cases are due to damp building conditions). It is stressed that there is no basis for the level of this increase, i.e. the climate related current attribution or the future level of change from climate change, and thus these results can be regarded as illustrative only.

**Table C8.5: Illustrative monetary value of health impacts attributable to climate change on damp housing incidence of asthma in Scotland (£, in 2010 prices)**

<table>
<thead>
<tr>
<th>% cases attributable to damp buildings</th>
<th>Time Period</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td></td>
<td>4,159,662</td>
<td>4,234,947</td>
<td>4,195,403</td>
</tr>
</tbody>
</table>

Notes: Values assume 10% of total monetary value is attributable to climate change. Values are adjusted for population changes in the future time periods.

These estimates are very indicative, and use a simple multiplier to estimate the possible importance of increases in the current total baseline incidence due to damp building conditions (not the current level attributable to current climate) with future climate change.

Based on the monetary ranking given in Section 4.1, the health impacts of climate change estimated above for Scotland would fall into the Low category.
Appendix D  Projected Human Welfare Value without Adaptation

A monetisation exercise has been carried out as part of the CCRA to provide an indicative cost per year of potential economic, environmental and social consequences that may have an effect on human welfare.

D.1 Introduction

Climate change adaptation decisions that are designed to reduce climate change risks inevitably involve making trade-offs concerning the use of scarce economic resources. To the extent that economic efficiency is an important criterion in informing such decision-making, it is useful to express climate change risks in monetary terms, so that they can be:

- Assessed and compared directly (using £ as a common metric) and
- Compared against the costs of reducing such risks by adaptation.

For the CCRA, a monetisation exercise has been undertaken to allow an initial comparison of the relative significance of different risks within and between sectors. Since money is a metric with which people are familiar, it may also serve as an effective way of communicating the possible extent of climate change risks in Scotland and help raise awareness.

It is important to note, however, that this exercise focuses on the effect on overall human welfare for Scotland (described in more detail in the section below). The intrinsic value of elements of the natural environment is not captured, nor is the variation in social vulnerability within Scotland considered. Therefore, the indicative ‘value rankings’ determined by this exercise do not always represent all factors that make a particular risk significant. In other words, the value rankings provided here should be considered as partial representations of the overall significance of these metrics, and additional non-quantified dimensions of these consequences need to be considered. These other dimensions are discussed and taken into consideration in the overall categorisation of risks provided in the main body of this report.

D.2 Method

Where possible, an attempt has been made to express the size of individual risks (as described in this report) in monetary terms as a cost per year. The aim is to express the risk in terms of its effects on human welfare, as measured by the preferences of individuals in the affected population. The total value to society of any risk is taken to be the sum of the values of the different individuals affected. This distinguishes this system of values from one based on ‘expert’ preferences, or on the preferences of political leaders.

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

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

However, due to the availability of data, it has sometimes been necessary to use alternative approaches (e.g. repair or adaptation costs) to provide indicative estimates.
A variety of methods have been used to determine these costs. In broad terms, these methods can be categorised according to whether they are based on:

- Market prices (MP),
- Non-market values (NMV) or
- Informed judgement (IJ)

Informed judgement has been used where there is no quantitative evidence and is based on extrapolation and/or interpretation of existing data.

In general terms, these three categories of method have differing degrees of uncertainty attached to them, with market prices being the most certain and informed judgement being the least certain. It is important to stress that the confidence and uncertainty of risks differs. Therefore, care must be taken in directly comparing the results. A further caveat is that whilst an attempt has been made to use the best monetary valuation data available, the matching-up of physical and monetary data is to be understood as an approximation only.

In general, the approach adopted for Scotland is consistent with that taken in the UK level sector reports and a detailed description of the data considered in the valuation of each risk is provided in these reports. Details of the monetary valuation approach applied to the CCRA as a whole can be found in the CCRA Method Report (Defra, 2010a).

However, in cases where a specific valuation approach was adopted for Scotland, a description of the chosen method is outlined in the sections below. In each case, a justification is given for the approach taken.

Valuations have generally been scaled from the UK analysis to the Scotland context, but account is also taken of differences between the Scotland context and the UK as a whole. Where potential climate change consequences have been quantified at the Scotland scale these have been applied.

### Understanding the Valuation Rankings

Valuations are based on projections for the Medium emissions scenario, central estimate (p50) for the 2050s with no socio-economic changes.

Valuations are ranked as Low (L), Medium (M) or High (H), based on a logarithmic scale of increasing value.

A negative ranking signifies a cost (or financial loss); a positive ranking signifies a saving (or financial benefit).

In general, the following ranges are applied: Low - less than £10 million per year; Medium – between £10 and £100 million per year; High - over £100 million per year. However, there are exceptions; for example, if a large proportion of a business that is vital for the sustainability of a region is affected then this would result in a High ranking even if the total cost was less than £100 million per year.

It is important to note that the valuation exercise has only been undertaken for those risks that have been identified as being sufficiently important to assess as part of this first risk assessment for Scotland. Furthermore, it has not been possible to provide monetary valuation for some risks. Therefore, the sum of the valuations does not provide the total cost in human welfare terms of projected climate change. The valuation exercise only provides a means of identifying the relative significance of these selected risks.
D.3 Climate change impacts on the natural environment (terrestrial)

Methods

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based. The results for the Biodiversity and Ecosystem Services Sector risks are based on informed judgement. Given the generally indirect ways in which these impact on human welfare, these estimates are highly uncertain, and this is emphasised by the use of question marks in the valuation column of the summary table below. As a consequence of this uncertainty, and in the absence of better empirical evidence, it is considered inappropriate to scale these results. This conclusion is supported by the fact that location-specific components are likely to be less significant in the welfare valuation of these risks.

A more in-depth assessment of monetisation of the Biodiversity and Ecosystem Services risks, based upon the UK National Ecosystem Assessment, can be found in the Biodiversity and Ecosystem Services Sector Report.

Discussion

Table D.1 draws together all the monetary estimates by use of a cost ranking. There is low confidence in the monetisation surrounding the risks relating to the terrestrial natural environment.

Table D.1 Monetary valuation of climate change impacts on the natural environment (terrestrial) – Medium emissions scenario (p50; 2050s); no population change

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species unable to track changing climate space</td>
<td>BD5</td>
<td>-M?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Changes in species migration patterns</td>
<td>BD9</td>
<td>-M?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Changes in soil organic carbon</td>
<td>BD8</td>
<td>-M?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Risks of diseases to biodiversity</td>
<td>BD4</td>
<td>-M?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Generalist species more able to adapt than specialists</td>
<td>BD11</td>
<td>-L?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Risk of pests to biodiversity</td>
<td>BD3</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Risks to species and habitats due to drier soils</td>
<td>BD1</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Loss of services through loss of keystone species</td>
<td>BD46</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Asynchrony between species breeding cycle and food supply</td>
<td>BD23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>
Wildfires due to warmer and drier conditions BD12 -L? L Informed judgement Based on informed judgement in UK Sector report

Changed recharge and groundwater levels WA13 - - - Not assessed

Impact of outdoor leisure, sport and tourism GNr5 - - - Not assessed

Agricultural intensification BD21 AG26 AG27 - - - Not assessed

Environmental effects of climate mitigation measures BD6 -L L Informed judgement Based on informed judgement in UK Sector report

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

### D4 Climate change impacts on the natural environment (freshwater)

**Methods**

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based.

**Discussion**

The cost rankings given in Table D.2 are based on informed judgement and therefore have high uncertainty attached. Changes in raw water quality are suggested to constitute the highest ranked cost. Changing migration patterns imply that there are likely to be a mix of species that gain and lose as a result of climate change, and an accompanying array of associated welfare effects that are location-specific. These welfare impacts are initially likely to be in the form of amenity effects, but in parallel with longer lasting changes in regulating and supporting systems. The uncertainty is, however, very high.

**Table D.2 Monetary evaluation of climate change impacts on the natural environment (freshwater) – Medium emissions scenario (p50; 2050s); no population change**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased societal water demand</td>
<td>BD15</td>
<td>-M to -H</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Lower summer river flows (Q95)</td>
<td>WA2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ecosystem risks due to low flows and increased water demand</td>
<td>BD14</td>
<td>-M to -H</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Biodiversity risks due to warmer rivers and lakes</td>
<td>BD10</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Impact</td>
<td>Metric</td>
<td>Valuation Ranking</td>
<td>Confidence Ranking</td>
<td>Estimation Method</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>--------</td>
<td>------------------</td>
<td>--------------------</td>
<td>------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Raw water quality</td>
<td>WA9</td>
<td>-H</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Warmer and drier conditions</td>
<td>WA1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Water quality and pollution risks</td>
<td>BD13</td>
<td>-M to -H</td>
<td>L</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Asynchrony between species breeding cycle and food supply</td>
<td>BD23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

D.5 Climate change impacts on the natural environment (coastal)

Methods
The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based.

Discussion
The cost rankings given in Table D.3 are based on informed judgement and therefore have high uncertainty attached.

Table D.3 Monetary evaluation of climate change impacts on the natural environment (coastal) – Medium emissions scenario (p50; 2050s); no population change

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks to species and habitats due to coastal evolution</td>
<td>BD2</td>
<td>-M to -H</td>
<td>M</td>
<td>Informed judgement</td>
<td>Based on informed judgement in UK Sector report</td>
</tr>
<tr>
<td>Changes in species migration patterns</td>
<td>BD9</td>
<td>-M?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment based on results in UK Sector report. Ranking given here only relates to a small number of indicator species. Total effects likely to be much greater</td>
</tr>
<tr>
<td>Major coastal flood / reconfiguration (includes coastal erosion)</td>
<td>BD20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Water quality and pollution risks</td>
<td>BD13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Physical effects of extreme events (flooding) on shallow marine habitats</td>
<td>MA39</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Priority habitats lost due to coastal erosion</td>
<td>FL14b</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>
## D.6 Climate change impacts on the natural environment (marine)

### Methods

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based.

### Discussion

The welfare costs of Harmful Algal Blooms (HABs) and Jellyfish are not known, but informed judgement based on studies of the costs of HABs suggests that these costs may be relatively low in the Scottish case. Based on data to 1998, ECOHARM (2001) identify an annual impact on the UK of HABs on mussel aquaculture of between €2.54 (£2.20) and €5.28 (£4.57) million. This does not account for climate change, but it may give an indication of the potential scale of the costs.

Other impacts include effects on recreational users and tourists. The ECOHARM (2001) study uses a contingent valuation survey to elicit preferences and showing impacts of between €215 (£186) and €1,524 (£1,318) million for the whole of Europe. Clearly the impact on the Scottish case would be a small fraction of this. The ECOHARM (2001) study does not consider the impact of climate change explicitly – so these costs may be likely to increase in future.

Increases in disease from pathogens and disease hosts are not likely to have significant impacts in the Scottish, or even the UK case. This is because of existing controls – which mean that the impacts are rather limited.

For ocean acidification costs, the results of the UK sector study were adjusted for the values of shellfish catch in Scotland as compared to that in England and Wales. This gives us cost estimates as shown in Table D.4 below.

### Table D.4 Mid-point annual costs of ocean acidification – with no socioeconomic change - Scotland (£m)

<table>
<thead>
<tr>
<th>Year</th>
<th>Shellfish</th>
<th>Mollusc</th>
<th>Aquaculture</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020s</td>
<td>2.18</td>
<td>0.60</td>
<td>0.20</td>
<td>2.98</td>
</tr>
<tr>
<td>2050s</td>
<td>11.66</td>
<td>3.08</td>
<td>0.99</td>
<td>15.68</td>
</tr>
<tr>
<td>2080s</td>
<td>25.11</td>
<td>6.60</td>
<td>2.18</td>
<td>33.84</td>
</tr>
</tbody>
</table>

---

215 A current day exchange rate of 0.865 pounds to the euro has been assumed for all currency conversions

The complexity of the valuation of the shift in fish species cannot be understated. This is because in some cases, for example plaice and cod, the shift moves the catch closer to Scotland’s ports, whereas in other cases, for example haddock, the catch is moved further away. The analysis also highlights the potential for species shift across international boundaries, with associated implications for fishing quotas.

In the Marine and Fisheries Sector Report, expert judgement was used to suggest that the overall cost would be low, less than £9 million per annum. Plaice and cod seem to be shifting towards Scotland’s ports\textsuperscript{217}, whereas sole and Haddock are generally moving further away. It seems appropriate to suggest that the costs for Scotland would also be low – and indeed they could be negative (i.e. benefits).

For the case of invasive species, the sector analysis considered the case of the eradication of the Carpet Sea Squirt from marinas in the UK, suggesting that the costs could rise to £72 million for the whole of the UK by the 2080s. Given that 9% of berths are in Scotland\textsuperscript{218}, this suggests costs of up to £6.5 million for Scotland by the 2080s. This does not consider increases in numbers of berths, which is likely as incomes increase and so demand for recreational boating increases.

Based on the above, we can summarise the likely impacts of climate change on the marine sector in Scotland as shown below. The uncertainties differ significantly. For HABs and jellyfish, the gaps in modelling of potential future increases in event frequency mean that these estimates should be considered highly uncertain. For increases in the spread of invasive species the uncertainty is suggested to be low – but this is only true for the cost of the carpet sea squirt. Further work is needed on a number of these areas to come to more robust estimates of the likely consequences.

**Table D.5 Monetary valuation of climate change impacts on the natural environment (marine); Medium emissions scenario (p50; 2050s); no population change**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in fish catch latitude/centre of gravity</td>
<td>MA4</td>
<td>+L</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Species migration</td>
<td>MAr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Distribution of marine alien/invasive species</td>
<td>MA6</td>
<td>-L</td>
<td>L</td>
<td>Market Prices/ Informed judgement</td>
<td>Carpet sea squirt only used in valuation. Valuation ranking includes 8 other species identified in CCRA.</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Increased ocean acidification</td>
<td>MA3</td>
<td>-M</td>
<td>L</td>
<td>Market prices</td>
<td>Considers shellfish, aquaculture and molluscs.</td>
</tr>
<tr>
<td>Damage to cultured aquatic species</td>
<td>MA30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Loss of service through loss of keystone species</td>
<td>BD46</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

\textsuperscript{217} Based on a visual inspection of coordinates on Google maps.

\textsuperscript{218} Based on http://www.insights.org.uk/articleitem.aspx?title=Marinas:%20The%20Tourism%20Aspect%20of%20Leisure%20Boating#Market size and value
<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of Harmful Algal Blooms due to changes in ocean stratification</td>
<td>MA1</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Plankton blooms</td>
<td>MA23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Impact of outdoor leisure, sport and tourism</td>
<td>GNr5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

## D.7 Climate change impacts on agriculture

**Methods**

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based.

**Discussion**

In terms of estimation, the clearest estimates are given for crops. Here the impact on sugar beet, wheat and potatoes was estimated in the Agriculture Sector Report however, as no sugar beet is grown in Scotland, specific analysis was undertaken for barley yields. The impacts on potatoes were negligible when CO₂ fertilisation was taken into account and benefits for wheat can be estimated for Scotland. The results are shown in Table D.6. Summing these means we can expect a high level of benefit for this impact. The impact identifying the effect of changes in mean temperature on livestock stress factors in the UK was negligible – but these estimates do not include extreme events (e.g. heatwaves) where mortality may be significant. The impact in Scotland is likely to be negligible.

For flooding, scaling for the extent of agricultural land in Scotland we can surmise there would be a low to medium cost involved. This draws on the results of the sector analysis – which applied the estimated costs of one flood event to value future flood risks to agriculture.

For pests and diseases, the Agriculture Sector Report examined two crop impacts, but the results suggested little or no impact of climate, probably due to the use of pesticides in response to increased pest prevalence. It has therefore not been possible to value this metric.

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220 Based on the area harvested in 2010 (source: [http://www.scotland.gov.uk/Publications/2010/12/17150639/5](http://www.scotland.gov.uk/Publications/2010/12/17150639/5). The change for harvest as suggested for Western Scotland in the sector report was applied to Scotland as no regional data on wheat production in Scotland was available.
Table D.6 Impact on Gross Margins for Wheat per annum in Scotland due to climate change in the 2020s, 2050s and 2080s, compared to 1961-1990 climate. (£m per year, 2010 prices, with adjustments to prices and land use, but no discounting)

<table>
<thead>
<tr>
<th>Emission scenario</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>Low</td>
<td>11.3</td>
<td>21.0</td>
<td>32.3</td>
</tr>
<tr>
<td>Medium</td>
<td>6.9</td>
<td>13.9</td>
<td>21.9</td>
</tr>
<tr>
<td>High</td>
<td>14.7</td>
<td>26.2</td>
<td>40.0</td>
</tr>
</tbody>
</table>

Table D.7 gives a summary of the expected scale of damages to agriculture in Scotland from climate change. It can be seen that significant benefits are expected in terms of crops, but the uncertainties in modelling of the physical impacts should be borne in mind.

Table D.7 Monetary valuation of climate change impacts on agriculture – Medium emissions scenario (p50; 2050s); no population change

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop yield</td>
<td>AG1</td>
<td>+M</td>
<td>M</td>
<td>Market prices</td>
<td>Consider impact on wheat production and potatoes (no sugarbeet grown in Scotland)</td>
</tr>
<tr>
<td>Agricultural land classification and crop suitability</td>
<td>AG25</td>
<td>+M</td>
<td>M</td>
<td>Market prices</td>
<td>Based on 2010 farmland values.</td>
</tr>
<tr>
<td>Agricultural land classification and crop suitability</td>
<td>AG51</td>
<td>+M</td>
<td>M</td>
<td>Market prices</td>
<td></td>
</tr>
<tr>
<td>Changes in grassland productivity</td>
<td>AG10</td>
<td>+M</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Waterlogging effects</td>
<td>AG21</td>
<td>-L / +L</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Changes in global trading patterns</td>
<td>GNr4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Human food supply from domestic agriculture</td>
<td>AG66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Flood risk to high quality agricultural land</td>
<td>AG2</td>
<td>-L to M</td>
<td>M</td>
<td>Informed judgement</td>
<td>Approximation</td>
</tr>
<tr>
<td>Public water supply-demand deficits</td>
<td>WA5</td>
<td>-L</td>
<td>L</td>
<td>Market prices</td>
<td>Supply costs used. These equate to adaptation costs and are used to proxy welfare costs, only.</td>
</tr>
<tr>
<td>Agricultural land lost due to coastal erosion</td>
<td>FL14a</td>
<td>-M</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drier soils (due to warmer and drier summer conditions)</td>
<td>AG4</td>
<td>NQ</td>
<td>-</td>
<td>-</td>
<td>Not possible to value</td>
</tr>
<tr>
<td>Livestock pests and diseases</td>
<td>AG44</td>
<td>NQ</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Climate Change Risk Assessment For Scotland
<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in milk production due to heat stress</td>
<td>AG7a</td>
<td>-L</td>
<td>M</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Livestock heat stress factors</td>
<td>AG8</td>
<td>Negligible</td>
<td>-</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AG15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of particular landscapes and associated rural communities, previously managed by livestock keepers</td>
<td>AG65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Biodiversity/wildlife changes</td>
<td>AG26</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td></td>
<td>AG27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk of crop pests and diseases</td>
<td>AG3</td>
<td>NQ</td>
<td>-</td>
<td>-</td>
<td>No impact identified in sector report – likely because of increased use of pesticides</td>
</tr>
<tr>
<td>Increase in greenhouse gas emissions</td>
<td>AG17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td></td>
<td>AG59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breeding habits/ reproductive behaviour of species</td>
<td>AG30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td></td>
<td>AG57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AG58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil erosion and leaching</td>
<td>AG19</td>
<td>NQ</td>
<td>-</td>
<td>-</td>
<td>Not quantified in sector study</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

**D.8 Climate change impacts on forestry**

**Methods**

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based.

**Discussion**

To estimate the damage costs due to Red Band Needle Blight, the UK estimates were scaled by the area of pine forests. The damage costs in the sector study reflect a range of values for ecosystem services in forests assuming a 10% damage to services caused by the impacts of the pathogens. There are issues with this scaling as it assumes an even coverage of impact across the UK. The annual costs for Scotland may be up to £7.8 million by the 2080s.
Table D.8 Estimated change in damage costs due to Red Band Needle Blight in Scotland by emissions scenario (£million/year, 2010 prices, no uplift or discounting) with future climate change (2020s, 2050s, 2080s) assuming current forest stock (no future socio-economic scenarios)

<table>
<thead>
<tr>
<th>UKCP09 scenario</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>Low</td>
<td>0-0.2</td>
<td>3-8</td>
<td>8</td>
</tr>
<tr>
<td>Medium</td>
<td>0-0.2</td>
<td>0.2-1</td>
<td>3.4-8</td>
</tr>
<tr>
<td>High</td>
<td>0.2-1</td>
<td>3-8</td>
<td>8</td>
</tr>
</tbody>
</table>

For the costs of green spruce aphid, the sector study is used with scaling for the relative size of spruce forest in Scotland. This gives estimates of the costs as shown in Table D.9. It should be noted that these are based on market prices – as the effects on other services were felt to be limited.

Table D.9 Estimated change in damage costs due to Green Spruce Aphid in Scotland by emissions scenario (£million/year, 2010 prices, no uplift or discounting) with future climate change (2020s, 2050s, 2080s) assuming current forest stock (no socio-economic change)

<table>
<thead>
<tr>
<th>£million / year</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>Low</td>
<td>0-1</td>
<td>0-1</td>
<td>1-5</td>
</tr>
<tr>
<td>Medium</td>
<td>0-1</td>
<td>0-1</td>
<td>1-5</td>
</tr>
<tr>
<td>High</td>
<td>0-1</td>
<td>1-5</td>
<td>1-5</td>
</tr>
</tbody>
</table>

The impact of yield loss due to drought was valued, as in the sector study, on the basis of market prices for soft and hard wood. This leads to estimated costs for the central estimate as shown in Table D.10 of between £0.7 and £3.1 million per year depending on the scenario considered.

Table D.10 Value of forest yield loss due to drought – Scotland – under different emissions scenarios (no socioeconomic change - £million/annum)

<table>
<thead>
<tr>
<th>£million / year</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p10</td>
<td>p50</td>
<td>p90</td>
</tr>
<tr>
<td>Low</td>
<td>0.3</td>
<td>1.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Medium</td>
<td>-0.1</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>High</td>
<td>0.7</td>
<td>1.8</td>
<td>3</td>
</tr>
</tbody>
</table>

The output from the physical risk assessment is the baseline yield and projected potential production of different species of hardwood and softwood trees in the public forest estate. The changes in yield are based on the UKCIP02 projections and are from the baseline period of 1961-1990.

The output from the physical risk assessment is the baseline yield and projected potential production of different species of hardwood and softwood trees in the public forest estate. The changes in yield are based on the UKCIP02 projections and are
from the baseline period of 1961-1990. This information is given in Table D.11 for hardwood species and in Tables D.12 for the softwood species.
Table D.11 Baseline potential production and change in 2050s and 2080s from baseline due to climate change - hardwood trees in the UK (in m³ per year)

<table>
<thead>
<tr>
<th>Region</th>
<th>Ash</th>
<th>Beech</th>
<th>Pedunculate oak</th>
<th>Silver birch</th>
<th>Sycamore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>2050s</td>
<td>2080s</td>
<td>Baseline</td>
<td>2050s</td>
</tr>
<tr>
<td>Scotland – all</td>
<td>1,676</td>
<td>320</td>
<td>630</td>
<td>3,372</td>
<td>217</td>
</tr>
<tr>
<td>Scotland – conservancies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Scotland</td>
<td>124</td>
<td>32</td>
<td>49</td>
<td>256</td>
<td>28</td>
</tr>
<tr>
<td>Grampian</td>
<td>62</td>
<td>19</td>
<td>39</td>
<td>460</td>
<td>90</td>
</tr>
<tr>
<td>Highland</td>
<td>178</td>
<td>23</td>
<td>57</td>
<td>212</td>
<td>-6</td>
</tr>
<tr>
<td>Perth and Argyll</td>
<td>894</td>
<td>190</td>
<td>349</td>
<td>1,630</td>
<td>8</td>
</tr>
<tr>
<td>South Scotland</td>
<td>367</td>
<td>58</td>
<td>120</td>
<td>821</td>
<td>67</td>
</tr>
</tbody>
</table>

Table D.12 Baseline potential production and change in 2050s and 2080s from baseline due to climate change - softwood/coniferous trees in the UK (in m³ per year)

<table>
<thead>
<tr>
<th>Region</th>
<th>Corsican pine</th>
<th>Douglas fir</th>
<th>European larch</th>
<th>Japanese larch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>2050s</td>
<td>2080s</td>
<td>Baseline</td>
</tr>
<tr>
<td>Scotland - all</td>
<td>12,150</td>
<td>2,652</td>
<td>5,031</td>
<td>43,708</td>
</tr>
<tr>
<td>Scotland - conservancies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Scotland</td>
<td>127</td>
<td>69</td>
<td>99</td>
<td>309</td>
</tr>
<tr>
<td>Grampian</td>
<td>7,218</td>
<td>3,162</td>
<td>4,790</td>
<td>8,322</td>
</tr>
<tr>
<td>Highland</td>
<td>385</td>
<td>6</td>
<td>95</td>
<td>10,747</td>
</tr>
<tr>
<td>Perth and Argyll</td>
<td>3,160</td>
<td>-210</td>
<td>209</td>
<td>11,993</td>
</tr>
<tr>
<td>South Scotland</td>
<td>1,175</td>
<td>121</td>
<td>215</td>
<td>10,658</td>
</tr>
</tbody>
</table>
An overview of the scale of costs associated with climate change in Scotland is given in Table D.13. Of those impacts that could be valued, the costs are low. Timing of impacts and associated costs are also very uncertain, particularly the costs of red band needle blight and the impacts of drought.

**Table D.13 Monetary valuation of climate change impacts on Forestry – Medium emissions scenario (p50; 2050s); no population change**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow and frost damage</td>
<td>FO7, FO14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Increase of potential yield of Sitka spruce in Scotland</td>
<td>FO4b</td>
<td>+L</td>
<td>M</td>
<td>Market price</td>
<td></td>
</tr>
<tr>
<td>Forest extent affected by pests and diseases</td>
<td>FO1</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement / non-market value/ market price</td>
<td>Considers red band needle blight and green spruce aphid. UK estimates applied on basis of relative forest areas.</td>
</tr>
<tr>
<td>Wildfires due to warmer and drier conditions</td>
<td>BD12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not quantified in UK level analysis.</td>
</tr>
<tr>
<td>Loss of forest productivity due to drought</td>
<td>FO2</td>
<td>-L</td>
<td>L</td>
<td>Market price</td>
<td></td>
</tr>
<tr>
<td>Windthrow and storm damage</td>
<td>FO3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Winter hardening</td>
<td>FO20, FO26</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

**D.9 Climate change impacts on business and services**

**Methods**

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based. The cost rankings of the remaining risks are based on informed judgement, based on the UK level assessment.

**Discussion**

Risk metrics BU4 and FL7 both address the exposure to insurance companies as a result of flooding to commercial buildings. These have not been estimated in the physical risk assessment for Scotland. However, scaling on the basis of commercial activity in Scotland relative to England, and assuming the same flood risk, the total expected annual damages attributed to this risk in Scotland is estimated to be £35m, £65m and £90m for the 2020s, 2050s and 2080s, respectively under the Medium emissions scenario. Additional business interruption cost in Scotland are estimated to be £1m, £2m and £3m for the 2020s, 2050s and 2080s, respectively under the Medium emissions scenario.
On the basis of these results it is estimated that the combined domestic and commercial claims in Scotland could double by the 2020s (Medium p50 emissions scenario), increase by almost three-fold in the 2050s and increase between three and four times by the 2080s. This equates to an additional average annual total claim for flood related damage of the order of £20m, £40m and £50 million in the 2020s, 2050s and 2080s, respectively.

However, the Business, Industry and Services Sector Report notes that the overall impact to 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.

Table D.14 highlights that on the basis of the risks considered, flood risk is likely to be the most significant to business, most particularly in relation to the implications for insurers. It should be highlighted, however, that impacts on the insurance sector, together with the high cost ranking for business failure to mainstream climate change, should not be seen as welfare impacts. Rather, they indicate sectors of business vulnerability to climate change and serve to indicate the need for adaptation action.

**Table D.14 Monetary valuation of climate change impacts on Business and Services – Medium emissions scenario (p50; 2050s); no population change**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>An expansion of tourist destinations in Scotland</td>
<td>BU8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Key workers unable to get to work due to extreme events or infrastructure failure</td>
<td>GNr6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Customer demands (opportunities)</td>
<td>GNr3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Flooding of non-residential property</td>
<td>FL7 FL24 FL27</td>
<td>-H</td>
<td>H</td>
<td>Market prices/informed judgement</td>
<td>Scaled from results in UK Sector report. Repair costs used, equating to adaptation costs.</td>
</tr>
<tr>
<td>Insurance industry exposure to UK flood risks</td>
<td>BU7</td>
<td>-H?</td>
<td>H</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment</td>
</tr>
<tr>
<td>Ability to obtain flood insurance for residential properties</td>
<td>FL13</td>
<td>-</td>
<td>L</td>
<td>Market prices</td>
<td>Scaled from results in UK Sector report.</td>
</tr>
<tr>
<td>Emergency response to events (fires)</td>
<td>GNr2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Mortgage provision threatened due to increased flood risk</td>
<td>BU6</td>
<td>-M</td>
<td>H</td>
<td>Market prices</td>
<td>Scaled from results in UK Sector report. Double counting with FL6. Should not be interpreted as welfare impact</td>
</tr>
<tr>
<td>Monetary losses due to tourist assets at</td>
<td>BU2</td>
<td>-L</td>
<td>M</td>
<td>Market prices/</td>
<td>Scaled from results in UK Sector report. Risk assessment</td>
</tr>
<tr>
<td>Impact</td>
<td>Metric</td>
<td>Valuation Ranking</td>
<td>Confidence Ranking</td>
<td>Estimation Method</td>
<td>Notes</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>--------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>risk from flooding</td>
<td></td>
<td></td>
<td>informed</td>
<td>judgement</td>
<td>not likely to have considered all assets. Therefore likely to be lower bound of true welfare costs.</td>
</tr>
<tr>
<td>Risk of restrictions in water abstraction for industry</td>
<td>BU3</td>
<td>-L</td>
<td>M</td>
<td>Non-value markets/ informed judgement</td>
<td>Scaled from results in UK Sector report. Double-counting with WA8b</td>
</tr>
<tr>
<td>Emergency response to events (floods)</td>
<td>GNr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Loss of natural resource that attracts tourists leading to loss of revenue and requirement to shift assets</td>
<td>BU29</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Cultural heritage at flood/erosion risk</td>
<td>BE4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Risks of business disruption due to flooding</td>
<td>BU4</td>
<td>-M</td>
<td>H</td>
<td>Market prices/ informed judgement</td>
<td></td>
</tr>
<tr>
<td>Energy demand for cooling</td>
<td>EN2</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Impacts on game angling or course fishing</td>
<td>BUr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Underestimation of decommissioning liabilities and end of life costs</td>
<td>BUr2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Climate risks to investment funds</td>
<td>BU1</td>
<td>-H?</td>
<td>L</td>
<td>Informed judgement</td>
<td>Scaled from results in UK Sector report. Likely to be double-counting with risks in other sectors such as floods, agriculture, transport and health. Should not be interpreted as welfare impact</td>
</tr>
<tr>
<td>Cost of international emergency aid</td>
<td>GNr8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>BU5</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment.</td>
</tr>
<tr>
<td>A decrease in output for businesses due to supply chain disruption</td>
<td>BU9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain
D.10 Climate change impacts on infrastructure

Methods

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based. The risk metric, BE9, is estimated using market prices and the cost rankings of the remaining risks are based on informed judgement.

Discussion

There are a number of risk metrics concerned with damage to transport infrastructure resulting from the projected increases in frequencies of extreme weather events under climate change. On the basis of the UK level Transport Sector Report, it is possible to identify cost rankings for these risks for Scotland. For TR1 the outcome of the assessment shows that cost of disruption from floods is expected to be low in economic terms in the 2050s (£1 – 9 million per year) for the Medium emissions scenario p50 projections. For TR2, (erosion and landslides), the cost ranking is low in the 2050s but may increase to a medium cost for the Medium and High emissions scenarios projections for the p90 level in the 2080s (though zero for the p10 projection).

The risk metric relating to reduction in heating demand (BE9) is based on market prices and generates a low negative cost (i.e. benefit) ranking in the 2020s and a medium ranking in the 2050s and 2080s. On the other hand, the risk metric relating to increases in cooling demand (EN2) is judged to generate a corresponding positive cost ranking. Infrastructure damage due to extreme weather events, (EN1) relies on informed judgement, in the absence of a quantitative physical risk assessment. The risks of outages as a result of substations at risk of flooding (EN1) are judged to be low in the 2050s and possibly medium in the 2080s. The risk to power stations is judged to warrant a low cost ranking in the 2020s and 2050s, and a low/medium in the 2080s, though this is highly uncertain.

Table D.15 summarises the results for infrastructure. It shows that there are clearly significant welfare impacts associated with energy provision, both positive and negative. There also significant benefits associated with the decrease in sea ice, thereby allowing shipping routes to change, with potentially greater use of Scottish port infrastructure. However, the uncertainty associated with these rankings, and the absence of socio-economic change, suggests that the full range of results, as indicated, need to be considered in planning adaptation.

For sea ice, the impacts are complex and confounded by potential losses of efficiency in container transport. However, it may be that there are significant benefits to Scottish ports from the opening of trade routes through the Arctic – because of the potential of increased traffic around the Scottish coast. Our informed judgement is that this impact will be low to medium for Scotland.
<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening of Arctic shipping routes due to ice melt</td>
<td>MA5b</td>
<td>+L to +M</td>
<td>L</td>
<td>Informed judgement</td>
<td>Complicated by losses in container shipping efficiency</td>
</tr>
<tr>
<td>Reduction in energy demand for heating</td>
<td>BE9</td>
<td>+M</td>
<td>H</td>
<td>Market prices</td>
<td>Climate change only (current socio-economics), for current stock. Not including existing policy, thus probable over-estimate. No rebound effects included, which may reduce benefits significantly.</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>BU5</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment.</td>
</tr>
<tr>
<td>Energy infrastructure at significant risk of flooding</td>
<td>EN1</td>
<td>-L to -M</td>
<td>L</td>
<td>Informed judgement</td>
<td>Assumes no autonomous (private sector) adaptation.</td>
</tr>
<tr>
<td>Sub-stations at significant risk of flooding</td>
<td>FL11b</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Included in Energy (EN1).</td>
</tr>
<tr>
<td>Roads and railways at significant risk of flooding</td>
<td>FL8a/b</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Links with transport and overlaps with TR1. Double-counting if summed.</td>
</tr>
<tr>
<td>Power stations at significant risk of flooding</td>
<td>FL11a ENr2</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td>Included in Energy (EN1).</td>
</tr>
<tr>
<td>Combined Sewer Overflow spill frequency</td>
<td>WA10</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment. Scaled from results in UK Sector report</td>
</tr>
<tr>
<td>Coastal erosion</td>
<td>TRr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Energy demand for cooling</td>
<td>EN2</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Low impacts due existing winter peak capacity in the UK (thus within summer reserve margin). Does not include potential issues of summer maintenance regime, or summer peak (extremes)</td>
</tr>
<tr>
<td>Scouring of road and rail bridges</td>
<td>TR6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Risk of restrictions in water abstractions for energy generation</td>
<td>EN4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Impact</td>
<td>Metric</td>
<td>Valuation Ranking</td>
<td>Confidence Ranking</td>
<td>Estimation Method</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>--------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>-------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Energy transmission efficiency capacity losses due to heat - over ground</td>
<td>EN10</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Adaptation cost (cost of upgrading)</td>
</tr>
<tr>
<td>Disruption to road traffic due to flooding</td>
<td>TR1</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Road sector only. Qualitative risk assessment.</td>
</tr>
<tr>
<td>Landslide risks on the road network</td>
<td>TR2</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Road sector only. Qualitative risk assessment.</td>
</tr>
<tr>
<td>Demand by water suppliers</td>
<td>EN5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Change in household water demand</td>
<td>WA4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>The welfare impact derives from the supply-demand imbalance captured in WA5</td>
</tr>
<tr>
<td>Loss of productivity due to ICT disruption</td>
<td>BU5</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment.</td>
</tr>
<tr>
<td>Electricity turbine efficiency</td>
<td>EN6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Gas pipe compressor rating</td>
<td>EN7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Power station cooling process</td>
<td>EN8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

### D.11 Climate change impacts on buildings and the urban environment

**Methods**

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based. The risk metric FL6, is estimated using market prices and non-market values; the cost rankings of the remaining risks are based on informed judgement.

**Discussion**

No quantitative analysis has been undertaken for Scotland for the property related flood risk (FL6). However, if we crudely scale according to population, against the total for England, it is estimated that the Expected Annual Damages (EADs) attributable to climate change alone, for the Medium p50 emissions scenario will be of the order of hundreds of millions of pounds per annum by the 2050s.

The flood risks are thought likely to have less uncertainty attached compared to the cost rankings for the other risk metrics, since they are based on quantitative modelling.
Table D.16 Monetary valuation of climate change impacts on the Built Environment – Medium emissions scenario (p50; 2050s); no population change

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowmelt flooding</td>
<td>FL41</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Property at risk of flooding</td>
<td>BE10 BE11 BE12 BE15 BE18 FL6 FL24</td>
<td>-H</td>
<td>H</td>
<td>Market price</td>
<td>Scaled from results in UK Sector report. Repair costs used, equating to adaptation costs.</td>
</tr>
<tr>
<td>Effectiveness of green space for cooling</td>
<td>BE5</td>
<td>-L</td>
<td>L</td>
<td>Informed judgement</td>
<td>Qualitative risk assessment</td>
</tr>
<tr>
<td>Increase in damp, mould and insect pests in buildings</td>
<td>BE31</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Rainwater penetration</td>
<td>BE13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>BE32</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Immigration to EU countries (including UK) and northwards migration within EU space; UK citizens living abroad may return to UK, leading to increased demand for water, food, energy, health services etc.</td>
<td>GNr7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

Note: - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain

D.12 Climate change impacts on health and wellbeing

Methods

The methods adopted to derive monetary total valuations for individual risks are consistent with those on which the UK level results are based. All risk metrics are estimated using market prices and non-market values apart from the risks of human illness due to marine pathogens (MA2a), for which the cost estimate is based on informed judgement.

Discussion

The monetary totals for climate-induced flood related deaths (HE3) are presented in Table D.17 for Scotland. Current levels of flood defences are assumed in the risk assessment. The welfare impacts of these fatalities increase further into the future, and across the emission scenarios from low to high. It is notable that the range of uncertainty expressed by the results across the probability distribution function (p10 - p90) within a given emission scenario is substantial – the latter being a factor of about four greater than the former in the 2020s.
Table D.17 Monetary value of annual additional flood related deaths due to extreme event flooding and storms, future climate change with current population (£m, 2010 prices) Scotland

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline in winter mortality due to higher temperatures</td>
<td>HE5</td>
<td>+M</td>
<td>L</td>
<td>Non-market Value</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Decline in winter morbidity due to higher temperatures</td>
<td>HE6</td>
<td>+M</td>
<td>L</td>
<td>Non-Market Value/Market Prices</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Fuel poverty</td>
<td>ENr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Cannot be assessed</td>
</tr>
<tr>
<td>Effects of floods/storms on mental health</td>
<td>HE10</td>
<td>-L</td>
<td>L</td>
<td>Non-market value/market prices</td>
<td>Adaptation costs equate to medical treatment costs</td>
</tr>
<tr>
<td>Vulnerable people at significant risk of flooding</td>
<td>FL2</td>
<td>-M</td>
<td>H</td>
<td>-</td>
<td>Incorporated in FL6 in Built Environment, above. Not assessed separately.</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>HE3</td>
<td>-M</td>
<td>L</td>
<td>Welfare impact cost non-market value</td>
<td>Assumes current flood protection levels</td>
</tr>
</tbody>
</table>

Table D.18 shows the valuation of additional flood related injuries due to extreme event flooding and storms (HE7), assuming current population. The table shows that the climate sensitivity changes the size of the results by up to a factor of 5 within and across emission scenarios.

Table D.18 Monetary valuation of additional flood related injuries due to extreme event flooding and storms (current population) – (£m, annual, 2010 prices) Scotland

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline in winter mortality due to higher temperatures</td>
<td>HE5</td>
<td>+M</td>
<td>L</td>
<td>Non-market Value</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Decline in winter morbidity due to higher temperatures</td>
<td>HE6</td>
<td>+M</td>
<td>L</td>
<td>Non-Market Value/Market Prices</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Fuel poverty</td>
<td>ENr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Cannot be assessed</td>
</tr>
<tr>
<td>Effects of floods/storms on mental health</td>
<td>HE10</td>
<td>-L</td>
<td>L</td>
<td>Non-market value/market prices</td>
<td>Adaptation costs equate to medical treatment costs</td>
</tr>
<tr>
<td>Vulnerable people at significant risk of flooding</td>
<td>FL2</td>
<td>-M</td>
<td>H</td>
<td>-</td>
<td>Incorporated in FL6 in Built Environment, above. Not assessed separately.</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>HE3</td>
<td>-M</td>
<td>L</td>
<td>Welfare impact cost non-market value</td>
<td>Assumes current flood protection levels</td>
</tr>
</tbody>
</table>

HE10 - the mental health risks associated with climate change-induced flooding and storms – also attracts a low cost ranking, based on a scaling from the UK totals.

Table D.19 Monetary valuation of climate change impacts on the Health and Wellbeing – Medium emissions scenario (p50; 2050s); no population change

<table>
<thead>
<tr>
<th>Impact</th>
<th>Metric</th>
<th>Valuation Ranking</th>
<th>Confidence Ranking</th>
<th>Estimation Method</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline in winter mortality due to higher temperatures</td>
<td>HE5</td>
<td>+M</td>
<td>L</td>
<td>Non-market Value</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Decline in winter morbidity due to higher temperatures</td>
<td>HE6</td>
<td>+M</td>
<td>L</td>
<td>Non-Market Value/Market Prices</td>
<td>Assume no acclimatisation</td>
</tr>
<tr>
<td>Fuel poverty</td>
<td>ENr1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Cannot be assessed</td>
</tr>
<tr>
<td>Effects of floods/storms on mental health</td>
<td>HE10</td>
<td>-L</td>
<td>L</td>
<td>Non-market value/market prices</td>
<td>Adaptation costs equate to medical treatment costs</td>
</tr>
<tr>
<td>Vulnerable people at significant risk of flooding</td>
<td>FL2</td>
<td>-M</td>
<td>H</td>
<td>-</td>
<td>Incorporated in FL6 in Built Environment, above. Not assessed separately.</td>
</tr>
<tr>
<td>Decline in marine water quality due to sewer overflows</td>
<td>MA2a</td>
<td>-M</td>
<td>L</td>
<td>Informed judgement</td>
<td></td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) mortality</td>
<td>HE3</td>
<td>-M</td>
<td>L</td>
<td>Welfare impact cost non-market value</td>
<td>Assumes current flood protection levels</td>
</tr>
<tr>
<td>Impact</td>
<td>Metric</td>
<td>Valuation Ranking</td>
<td>Confidence Ranking</td>
<td>Estimation Method</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>-------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Number of people at significant risk of flooding</td>
<td>FL1</td>
<td>-M</td>
<td>H</td>
<td>-</td>
<td>Incorporated in FL6 in Built Environment, above. Not assessed separately.</td>
</tr>
<tr>
<td>Summer mortality due to higher temperatures</td>
<td>HE1</td>
<td>-L</td>
<td>M</td>
<td>Non-Market Value</td>
<td>Assume no acclimatisation. Does not include urban heat island and heatwave impacts. Does not include benefits of cooling associated with rising energy costs</td>
</tr>
<tr>
<td>Summer morbidity due to higher temperatures</td>
<td>HE2</td>
<td>-L</td>
<td>L</td>
<td>Non-Market Value/Market Prices</td>
<td>Assume no acclimatisation. Does not include urban heat island and heatwave impacts. Adaptation costs (treatment)</td>
</tr>
<tr>
<td>Extreme weather event (flooding and storms) injuries</td>
<td>HE7</td>
<td>-M</td>
<td>L</td>
<td>Non-market value/ market prices</td>
<td>Adaptation costs equate to medical treatment costs</td>
</tr>
<tr>
<td>Increased algal or fungal/mould growth in buildings affecting respiratory conditions</td>
<td>HE19</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Incidents of human illness due to hosts and pathogens</td>
<td>MA2b</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Increase in prevalence of certain vector-borne diseases (ticks and lyme disease)</td>
<td>HE11 HE17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
<tr>
<td>Food borne diseases</td>
<td>HE15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

**Note:** - signifies a predominantly negative impact or loss; + signifies a predominantly positive impact or gain