A Summary of the State of Knowledge on Climate Change Impacts for Ireland

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Background
The background to this report lies with its predecessor, the first State of Knowledge on Climate Change Impacts for Ireland (Desmond et al, 2009). That report filled a large knowledge gap by providing an authoritative synthesis of the available information on climate change impacts and adaptation. Since then we’ve had the publication of the IPCC 5th Assessment Reports (2013) and numerous national level reports on all aspects of climate change science, impacts and adaptation. In addition, we’ve begun to see the implementation of adaptation at sectoral and local levels. This new reality has created an urgent need for an updated synthesis report that accurately reflects the scientific advances made nationally in knowledge and information generation. The report represents the distillation of a large body of work, largely carried out through research activities since 2009.

Identifying Pressures
Changes in Ireland’s climate are in-line with and similar to relevant global trends. Climate change will have diverse and wide ranging impacts on our environment, society, economic sectors and natural resources. The challenge is to provide decision makers at all levels and the general public with high quality information to make informed decisions on policy development and investments that will be resilient to the impacts of climate change.

This report provides:
1) a summary of observed and projected changes in the Irish climate across a number of key parameters;
2) a synthesis of knowledge of ongoing and anticipated climate change impacts across a number of environmental and economic sectors;
3) recommendations for further steps required to support policy development and aid the implementation of adaptation nationally.

Informing Policy
The information summarised in this report will assist in the development of coherent and rational decision making at the national, sectoral and local level, namely by:

• Providing a high level synthesis of existing climate change information across a number of key parameters such as temperature, precipitation, sea level rise and extreme weather events;
• Providing a synthesizes of ongoing and anticipated climate change impacts across a large number of environmental and economic sectors;
• Providing a summary of possible adaptation options;
• Identifying knowledge gaps and suggestions on how they might be filled.

Developing solutions:
This report provides Irish decision makers with an authoritative and timely summary of the state of knowledge on climate change impacts. It will assist the development of adaptation strategies and plans at national, sectoral and local level decision making. It is part of the solution to the societal challenge of transitioning to a climate resilient Ireland.
ENVIRONMENTAL PROTECTION AGENCY
The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don’t comply.

Knowledge: We provide high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.

Advocacy: We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.

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We regulate the following activities so that they do not endanger human health or harm the environment:
- waste facilities (e.g. landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g. pharmaceutical, cement manufacturing, power plants);
- intensive agriculture (e.g. pigs, poultry);
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
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- large petrol storage facilities;
- waste water discharges;
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- Advising Government on matters relating to radiological safety and emergency response.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.
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(2014-CCRP-FS.19)

EPA Research Report

Prepared for the Environmental Protection Agency

by

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ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The programme is financed by the Irish Government. It is administered on behalf of the Department of Communications, Climate Action and Environment by the EPA, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank staff at Met Éireann, Maynooth University, the National University of Ireland Galway (NUIG), Trinity College Dublin, the Irish Centre for High End Computing (ICHEC), the MaREI Centre (Beaufort, UCC), the Office of Public Works (OPW), the Department of the Environment, Heritage and Local Government and the Department of Agriculture, Fisheries and Food. In particular, we thank Ray McGrath (Met Éireann, retired) for his reviews and for providing very useful comment and feedback throughout. Thanks are also due to colleagues in the EPA for additional comment and review. Finally, thanks go to Maria Jacob (intern with the EPA in 2015).

Cover images: Top left – climate observations, courtesy of Met Éireann, reproduced under a CC BY-SA 2.0 licence. Top right – climate change impact, courtesy of Iarnród Éireann (http://www.raiu.ie/download/pdf/structural_failure_of_a_platform_canopy_at_kent_station_.pdf). Bottom – “We need to talk about climate change”, courtesy of Barry O’Dwyer, University College Cork.

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.
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# Contents

Acknowledgements .......................................................... ii
Disclaimer .......................................................................... ii
Project Authors ............................................................... iii
List of Figures, Tables and Boxes ........................................ vii
Executive Summary ........................................................... ix

## 1 Introduction

1.1 Analyses of Climate Change in Ireland .......................... 2
1.2 Tipping Points ............................................................. 6
1.3 International Commitments: The Paris Agreement and Implications ........................................... 6
1.4 Risk and Uncertainty ....................................................... 6
1.5 Climate Change Impacts in Ireland ................................. 7
1.6 Structure of Report ......................................................... 8

## 2 Current Knowledge on Climate Change for Ireland

2.1 Atmosphere: Air Temperatures, Precipitation and Extreme Weather .................................................... 9
2.2 Terrestrial and Hydrological ........................................... 10
2.3 Oceans and Seas ............................................................ 13
2.4 Cross-cutting Areas: Flooding (River and Coastal) and Soils ............................................................... 13

## 3 Sectoral Impacts and Adaptation Options

3.1 Critical Infrastructure and the Built Environment .............. 16
3.2 Industry and Insurance .................................................. 18
3.3 Agriculture ................................................................. 19
3.4 Forestry .................................................................... 22
3.5 Terrestrial Biodiversity ................................................. 24
3.6 Peatlands and Fens ....................................................... 24
3.7 Coastal Areas .............................................................. 25
3.8 Marine and Fisheries .................................................... 26
3.9 Tourism .................................................................. 27
3.10 Water Management and Resources ............................. 28
3.11 Human Health and Well-being .................................... 28
List of Figures, Tables and Boxes

Figures

Figure 1.1. Tipping elements in context of the global mean temperature evolution 4

Tables

Table 1.1. Mean ensemble projected change (anomalies) in global mean surface temperature for the mid- and late 21st century, relative to 1986–2005 4
Table 1.2. Ensemble of RCM simulations (Nolan, 2015) 5
Table 2.1. Observed and projected changes for temperature in Ireland 9
Table 2.2. Observed and projected changes for precipitation in Ireland 10
Table 2.3. Observed and projected changes for synoptic variables for Ireland 11
Table 2.4. Observed and projected changes for soil temperature for Ireland 11
Table 2.5. Observed and projected changes for hydrological variables for Ireland 12
Table 2.6. Observed and projected changes for phenology and climate space changes for Ireland 12
Table 2.7. Observed and projected changes for maritime variables for Ireland 14
Table 2.8. Observed and projected changes for SLR in Ireland 15
Table 2.9. Observed and projected changes for cross-cutting variables 15
Table 3.1. Climate change impacts on critical infrastructure and the built environment 17
Table 3.2. Climate change impacts on industry and insurance 19
Table 3.3. Climate change impacts on agriculture 20
Table 3.4. Climate change impacts on forestry 22
Table 3.5. Climate change impacts on terrestrial biodiversity 23
Table 3.6. Climate change impacts on peatlands 25
Table 3.7. Climate change impacts on coastal areas 26
Table 3.8. Climate change impact on fisheries and marine 27
Table 3.9. Climate change impacts on tourism 28
Table 3.10. Climate change impacts on water management and resources 29
Table 3.11. Climate change impacts on human health and well-being 30
Boxes

Box 1.1.  Drivers of climate change  1
Box 1.2.  IPCC representative concentration pathways  2
Executive Summary

This report presents a summary of the state of knowledge on ongoing climate change and projected impacts for Ireland. It updates and enhances the information provided in the 2009 Summary of the State of Knowledge Report (Desmond et al., 2009). The information provided takes account of new data, analyses and knowledge that have been published since then.

The purpose of this report is to provide an accessible summary of the available information in a format that will be of use to policymakers, sectoral and local decision-makers and other stakeholders interested in or working on adaptation to climate change in Ireland. The national information is largely based on Environmental Protection Agency (EPA) funded research and linked research funded by other national bodies, including Met Éireann, the Office of Public Works (OPW) and the Marine Institute, and research carried out by third-level institutes. The material in this report should be viewed within the wider context provided by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Reports (AR5) (2013a,b, 2014a,b). The development of this report has also been supported by the “Climate Ireland” information portal. It has further been shaped by the inputs of national experts through a series of stakeholder events held in 2015.

Warming of the global climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century (IPCC, 2013). Mitigation actions are being taken to limit climate change, most notably the 2015 Paris Agreement. However, many changes and their associated impacts are “locked-in” to the Earth’s climate systems and past actions will drive changes for decades to come. There is now a clearer understanding of how the risks of climate change can be reduced and managed through mitigation and adaptation actions (IPCC, 2014).

The impacts of climate changes are evident on natural and human systems on all continents and across the oceans (IPCC, 2014). Observations show that Ireland’s climate is also changing. The observed scale and rate of change is consistent with regional and global trends across the range of essential climate variables discussed in The Status of Ireland’s Climate, 2012 (Dwyer, 2012). These changes are projected to continue and increase over the coming decades (Gleeson et al., 2013). However, the climate of the North Atlantic and the regional impact of the melting of the Greenland ice sheet may cause unique climate change issues in this region (Rahmstorf, 2015).

Climate change means not only changes in the average climate such as temperature, but also changes in the frequency and intensity of extreme weather and climate events. It is recognised that extreme events, such as severe flooding, droughts and heat-cold waves, can have important socio-economic consequences. Changes in their frequency and intensity are therefore of particular interest to policymakers and stakeholders (O’Sullivan et al., 2015; Nolan et al., 2013, 2015).

Observed and projected physical climate changes include:

- increase in average temperature (surface air temperature, sea surface temperature);
- changes in precipitation patterns;
- ongoing mean sea level rise;
- changes in the character of weather extremes such as storms, flooding, sea surges and flash floods.

In Ireland, climate change will have diverse and wide-ranging impacts on the environment, society, economic sectors and natural resources. These include managed and natural ecosystems, water resources, agriculture and food security, human health, and coastal infrastructures and zones (Coll and Sweeney, 2013).

Extreme weather events give rise to the most immediate and severe impacts for natural and managed systems (e.g. agriculture and forestry) as well as infrastructure and economic and societal disruption. Changes in the number or nature of extreme weather events are therefore of concern.
Climate change may offer some opportunities for sectors such as tourism and agriculture in the short to medium term (Sweeney et al., 2013).

Risks associated with a changing climate depend on the exposure and vulnerability of the affected system and its ability to absorb and adapt to such change. Adaptation has the potential to effectively manage and minimise adverse climate change impacts, but this potential or adaptive capacity differs between sectors and regions. Ultimately, there are constraints and limits to adaptation.

Addressing uncertainties is a key challenge for actions on adaptation. There is uncertainty about observed climate change and its past effects on natural and human systems. Projections of future climate change and associated impacts are also uncertain, which presents a great challenge at all levels of policy and decision-making. In the short to medium term, changes may be subtle in the context of the natural internal variability of the climate system. In the longer term, i.e. after 2030, uncertainty will gradually come to be dominated by uncertainty in the ambition and effectiveness of future international actions to address the drivers of climate change, i.e. to the mitigation of emissions of greenhouse gases (GHGs). The state at which the global climate systems will stabilise will be largely determined by the cumulative global emissions of carbon dioxide from fossil fuels and land use change (IPCC, 2013). This will determine the full extent of climate change and the level of adaptation that will be required.

Nationally, uncertainties exist in relation to both the rate and extent of the impacts that Ireland will experience. In the short to medium term, these uncertainties are primarily due to the inherent variability and the chaotic nature of the climate system. The chaotic nature of the weather/climate system is a fundamental source of uncertainty, which is amplified by climate change. Uncertainty is not uniform: some weather elements (e.g. precipitation, weather extremes) are inherently “noisy”, while others (e.g. temperature) are more predictable. The physical linkage of GHGs with atmospheric temperature will ensure that the projected influence of climate change on the latter will be subject to less uncertainty than that for precipitation, which may remain subject to considerable uncertainty at a regional level in the short to long term.

In this regard, it is important that any assessment of the need and level of adaptation must first consider how communities, sectors and localities currently interact with weather and a variable climate. While there is less certainty about the short-term predictability of climate change and extreme weather events, there is a consensus that both global and regional climates are changing and, thus, there are greater levels of certainty about the gradual trends we can expect for Ireland’s climate.

The report provides a summary of observed and projected changes in the Irish climate across a number of key parameters. It also synthesises knowledge of ongoing and anticipated climate change impacts across a number of environmental and economic sectors. Finally, it presents recommendations for further steps required to support policy development and aid the implementation of adaptation nationally. In order to facilitate this process, an adaptation framework is needed. This would aim to advance work within and across sectors and at a number of levels, through further development of the knowledge base, building capacity, communication of scientific knowledge and the implementation of actions. This adaptation framework would enable synergies between groups, generate understanding and learning (especially in relation to cross-cutting issues) and avoid maladaptation.

Advancing the knowledge base

- Development and sustained support of observation systems for essential climate variables and analysis of trends and changes.
- Improvement of climate projections and near-time climate forecasting, e.g. periods from years to decades as well as mid- and end of century information.
- Support for the development of analysis of fundamental physical processes that drive the rate and extent of climate change, e.g. ocean systems and precipitation.
- Greater understanding of slow-onset climate change and abrupt changes.

Further development of sectoral risk and vulnerability assessments

- A national-level climate change risk assessment is required to set out priority climate risks for Ireland.
and provide analysis of the implications of cross-sectoral and cumulative risks and external climate impacts (e.g. on human migration, markets, supply chain management). In time, it would be expected that this high-level national assessment will be supported by sectoral and locally specific vulnerability/sensitivity analysis.

- Possible opportunities for Ireland should be identified (e.g. agriculture, tourism, industry).
- Any new approaches to climate risk management should ideally be placed within an adaptive risk management framework.

**Development of adaptation options, including costs and benefits**

- A full range of adaptation options must be included in decision-making, with particular attention focusing on green approaches (e.g. green infrastructure).
- The costs of current and future climate change impacts and adaptation must be established for a range of key sectors. This must be based on a consistent framework applicable across all sectors and relevant to different types of impact to ensure comparability and consistency in the use of climatic and socio-economic projections. The role of the insurance industry must be established, particularly in response to extreme weather events.
- Development of cross-sectoral comparative metrics and indicators to enable high-level assessment of the scale and urgency of adaptation requirement.
- Tools for the assessment of the effects on other sectors, up- or downstream effects and in supply chains, macroeconomic (general equilibrium) effects, changes in behaviour as a result of changes in risk exposure (moral hazard risk) of adaptation measures.
- Information must be made available on sources of funding/finance for adaptation actions.

**Development and implementation of effective governance structures**

- Further and deeper horizontal and vertical co-ordination of adaptation efforts as the implementation of adaptation progresses.
- The participation of multiple stakeholders, including the business and local communities, must be explored with a view to ratcheting up adaptation action at all levels of decision-making.
1 Introduction

Warming of the climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Observations show that global average temperatures have increased by 0.85°C (in the range 0.65–1.06°C) since 1850 (IPCC, 2013a). The atmosphere and ocean have warmed, the amount of snow and ice has diminished, the sea level has risen and the concentrations of greenhouse gases (GHGs) in the atmosphere have increased (IPCC, 2013a). Since the 1950s, many of the observed changes have been unprecedented over periods of decades to millennia. The impacts are observed on natural and human systems on all continents and across the oceans. Evidence of climate change impacts is clearest in natural systems (IPCC, 2014a).

Projections of future global and regional climate change under all Intergovernmental Panel on Climate Change (IPCC) representative concentration pathways (RCPs) scenarios demonstrate that continued emissions of GHGs will cause further warming and changes in the components of the climate system.

Changes in Ireland’s climate are in line with and similar to relevant global trends. Temperatures have increased by 0.8°C since 1900: an average of 0.07°C per decade over that period (Dwyer, 2012). As a result of the slow response time (inertia) of the climate system, changes are projected to continue and increase over the coming decades. Even if GHG emissions could be stopped immediately, some impacts, such as sea level rise (SLR), are projected to continue up to and beyond the end of this century.

Climate change will have diverse and wide-ranging impacts on Ireland’s environment, society, economic sectors and natural resources. These include managed and natural ecosystems, water resources, agriculture and food security, human health, and coastal infrastructures and zones (Coll and Sweeney, 2013; Coll et al., 2014).

Box 1.1. Drivers of climate change

Natural and anthropogenic substances and processes that alter the Earth’s energy budget are drivers of climate change. According to the IPCC (2013a), it is extremely likely that more than half of the observed increase in global average temperature from 1951 to 2010 was caused by an anthropogenic increase in GHG concentrations and other anthropogenic forcings.

The attribution of specific extreme events to anthropogenic climate change, i.e. establishing a robust causal link, is very challenging. However, there has been significant progress in this area in recent years, especially in terms of the analysis of the change in probability of a specific type of event due to the influence of climate change.

Case study

In the summer of 2003, anthropogenic climate change increased the risk of heat-related mortality in central Paris by ~70% and by ~20% in London, which experienced lower levels of extreme heat. Out of the estimated ~315 and ~735 summer deaths attributed to the heatwave event in Greater London and central Paris, respectively, 64 (±3) deaths were attributable to anthropogenic climate change in London and 506 (±51) in Paris (Mitchell et al., 2016).

This type of analysis has yet to be undertaken in a systematic manner for extreme events in Ireland. However, Storm Desmond, 4–6 December 2015, was analysed by van Oldenborgh et al. (2015), who found that the similar extreme rainfall events across the UK were about 40% more likely to occur as a result of climate change.
1.1 Analyses of Climate Change in Ireland

1.1.1 Observed climate change

Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Systematic instrumental observations of the weather covering large geographical regions did not appear until the mid-19th century. Paleoclimate reconstructions extend some records back hundreds to millions of years. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean and the land surface.

The availability of high-quality climate observations is a critical starting point from which an understanding of past and emerging trends in the current climate can be developed. They are also essential to help build robust projections of future climate (Dwyer, 2012).

Met Éireann holds an important archive of meteorological data for Ireland. Some records extend back more than 100 years. These data are subject to ongoing development and analyses and are reported to international databases. McElwain and Sweeney (2007) and Gleeson et al. (2013) have provided analyses of these records in line with international standards, e.g. the data are referenced to the standard 30-year average. Other sources of data and analysis include the Office of Public Works (OPW), the Marine Institute and the Environmental Protection Agency (EPA).

Ireland has important long-term records of flora and fauna. These are reported to international databases, e.g. European Phenology Network (http://www.pik-potsdam.de/~rachimow/epn/html/frameok.html). Analyses of flora and fauna show that natural systems in Ireland are reacting to climate change. These patterns of change are similar to those that are occurring at regional and global levels as reported by the IPCC (2014a).

Paleoclimate analysis and other archives provide information on climate conditions in Ireland over periods outside the historical records. These data provide important information on climate variability and the stability of key factors that determine Ireland’s climate such as the meridional overturning circulation (MOC) associated with the Gulf Stream. Projections of the long-term stability of the MOC remain highly uncertain; however, it is notable that many model projections show a cool region developing in the North Atlantic. This feature has already shown signs of emergence in the observation data (Rahmstorf, 2015).

1.1.2 Projected climate change

Global climate models (GCMs) provide projections of future climate conditions based on different atmospheric GHG concentrations or, more broadly, different levels of radiative forcing of the climate system. The IPCC AR5 WG1 report (2013) provided the most recent systematic analysis of outputs from a range of GCMs. These models simulate changes based on a set of scenarios of anthropogenic forcings.

Box 1.2. IPCC representative concentration pathways

One of the more intractable sources of uncertainty in providing projections of climate change is the fundamental uncertainty in future emissions of GHGs. Emissions of GHGs will depend on future economic development, the rate of adoption of renewable technologies and other socio-economic factors, which are difficult to predict.

To address this, climate model projections are driven by scenarios of natural and anthropogenic forcings, the standard set for the IPCC AR5 reports being the RCPs. The RCPs describe four possible climate futures, all of which are considered possible depending on how much GHG is emitted in the years to come. The four RCPs – RCP2.6, RCP4.5, RCP6 and RCP8.5 – are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0 and +8.5 W/m², respectively). Figure 1.1 presents the radiative forcing of the RCPs for the period 2000–2100. For this reason, climate scientists are very careful in their use of language, and make it very clear that the outputs of climate models are projections of climate change, which are based on these scenarios, and are not predictions or forecasts of climate change.
Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth–atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report, radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre (W/m²) (IPCC, 2007).

The numbers in the RCPs refer to the radiative forcings, expressed in W/m², for possible climates in the year 2100, relative to the pre-industrial era. Total radiative forcing is determined by both positive (warming) forcing from GHGs and negative (cooling) forcing from aerosols. The dominant factor is the positive forcing from carbon dioxide (CO₂). As the radiative forcing increases, the global temperature at the surface rises.

### RCP primary characteristics

#### RCP2.6 – low emissions
Radiative forcing reaches 3.1 W/m² before it returns to 2.6 W/m² by 2100. In order to reach such forcing levels, ambitious GHG emissions reductions would be required over time.

This future is consistent with: Rapid decline in the use of fossil fuels; Low energy intensity; Use of croplands increase due to bio-energy production; More intensive animal husbandry; Methane emissions reduced by 40%; Global CO₂ emissions stable at today’s levels up to 2020, then decline and become negative by 2100; Atmospheric CO₂ concentrations peak around 2050, followed by a modest decline to around 400 ppm by 2100. (Bjørnæs, 2010)

#### RCP4.5 – intermediate emissions
Radiative forcing is stabilised shortly after 2100, but consistent with a future with relatively ambitious emissions reductions.

This future is consistent with: Lower energy intensity; Effective reforestation programmes; Decreasing use of croplands and grasslands due to yield increases and dietary changes; Effective climate policies; Stable methane emissions; CO₂ emissions increase only slightly before decline commences around 2040. (Bjørnæs, 2010)

#### RCP6 – intermediate emissions
Radiative forcing is stabilised shortly after 2100, which is consistent with the application of a range of technologies and strategies for reducing GHG emissions.

This future is consistent with: Heavy reliance on fossil fuels; Intermediate energy intensity; Increasing use of croplands and declining use of grasslands; Stable methane emissions; CO₂ emissions peak in 2060 at 75% above today’s levels, then decline to 25% above today. (Bjørnæs, 2010)

#### RCP8.5 – high emissions
This RCP is consistent with a future with no policy changes to reduce emissions. It is characterised by increasing GHG emissions that lead to high GHG concentrations over time.

This future is consistent with: Continued growth in CO₂ emissions; Rapid increase in methane emissions; Increased use of croplands and grassland which is driven by an increase in population; Low rate of alternative technology development; No implementation of climate policies. (Bjørnæs, 2010)
A new set of scenarios developed by the IPCC (2013a), the RCPs, were used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme (IPCC, 2013a). The RCPs define four possible scenarios for global GHG concentrations until 2100 (Box 1.2). It is worth noting that only those global emissions trajectories consistent with RCP2.6 project global warming within the range identified as a target under the Paris Agreement (2015). Given the challenges implicit in achieving the goals of the Paris Agreement, it is important that decision-makers consider the range of projections under each of the RCPs and measure
the vulnerabilities and risks according to their own circumstances.

GCMs currently provide analysis at horizontal resolutions typically in the range 100–300 km, although some models have been run at finer resolutions. This provides insight into the broader regional characteristics of potential climate change. However, since climate fields such as precipitation and wind speed are closely correlated to the local topography, this resolution may be inadequate for the simulation of the detail and pattern of climate change on the scale of a region the size of Ireland.

To overcome this limitation, the regional climate model (RCM) method dynamically downscales the coarse information provided by the global models and provides high-resolution information on a sub-domain covering Ireland.

Recently, RCMs were run at high spatial resolution, a maximum of 4 km, thus allowing for a better evaluation of the potential local effects of climate change. Since RCMs have a better representation of coastlines and general topography, the resulting model output is more useful for focused climate change impact studies (Nolan, 2015).

To address the issue of uncertainty, a multi-model ensemble approach was employed (Table 1.2). Specifically, the future climate of Ireland was simulated using three different RCMs, driven by four GCMs. To account for the uncertainty in future emissions, a number of Special Reports on Emission Scenarios (SRESs)1 (B1, A1B, A2) and RCP (4.5, 8.5) emission scenarios were used to simulate the future climate. Through the ensemble approach, the uncertainty in the RCM projections can be partially quantified, thus providing a measure of confidence in the predictions. However, it should be noted that any schematic bias inherent in the GCMs will be transposed to the outputs of the RCMs. Therefore, it is very important to compare both parent GCM and daughter RCM outputs with observation data to appreciate the potential limitations of projections.

### Table 1.2. Ensemble of RCM simulations (Nolan, 2015)

<table>
<thead>
<tr>
<th>RCM</th>
<th>GCM</th>
<th>Scenario (number of simulations)</th>
<th>Period</th>
<th>Grid spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>CLM3</td>
<td>ECHAM5</td>
<td>Historical (2)</td>
<td>1961–2000</td>
</tr>
<tr>
<td></td>
<td>CLM3</td>
<td>ECHAM5</td>
<td>A1B (2), B1 (1)</td>
<td>2021–2060</td>
</tr>
<tr>
<td>Group 2</td>
<td>CLM4</td>
<td>ECHAM5</td>
<td>Historical (2)</td>
<td>1961–2000</td>
</tr>
<tr>
<td></td>
<td>CLM4</td>
<td>ECHAM5</td>
<td>A1B (2)</td>
<td>2021–2060</td>
</tr>
<tr>
<td>Group 3</td>
<td>CLM4</td>
<td>CGCM3.1</td>
<td>Historical (1)</td>
<td>1961–2000</td>
</tr>
<tr>
<td></td>
<td>CLM4</td>
<td>CGCM3.1</td>
<td>A1B (1), A2 (1)</td>
<td>2021–2060</td>
</tr>
<tr>
<td>Group 4</td>
<td>CLM4</td>
<td>HadGEM2-ES</td>
<td>Historical (1)</td>
<td>1961–2000</td>
</tr>
<tr>
<td></td>
<td>CLM4</td>
<td>HadGEM2-ES</td>
<td>RCP4.5 (1), RCP8.5 (1)</td>
<td>2021–2060</td>
</tr>
<tr>
<td>Group 5</td>
<td>CLM4</td>
<td>EC-Earth</td>
<td>Historical (3)</td>
<td>1981–2009</td>
</tr>
<tr>
<td></td>
<td>CLM4</td>
<td>EC-Earth</td>
<td>RCP4.5 (3), RCP8.5 (3)</td>
<td>2021–2060</td>
</tr>
<tr>
<td>Group 6</td>
<td>WRF</td>
<td>EC-Earth</td>
<td>Historical (3)</td>
<td>1981–2009</td>
</tr>
<tr>
<td></td>
<td>WRF</td>
<td>EC-Earth</td>
<td>RCP4.5 (3), RCP8.5 (3)</td>
<td>2021–2060</td>
</tr>
</tbody>
</table>

1 The SRES is a report by the IPCC that was published in 2000. The GHGs emissions scenarios described in the report have been used to make projections of possible future climate change. The SRESs were used in the IPCC Third Assessment Report (2001) and in the IPCC Fourth Assessment Report (2007).
1.2 Tipping Points

Climate scenarios reveal slow evolutions of, among others, temperature and precipitation, which follow the rising GHG concentrations with a certain delay. In addition to these slow evolutions, climate change may also lead to more abrupt changes. This possibility is referred to as a tipping point within the climate system. The precise levels of climate change sufficient to trigger tipping points remain uncertain, but the risk associated with crossing multiple tipping points in the Earth system or interlinked human and natural systems increases with rising temperature (IPCC, 2014a). For example, the major ice sheets in Greenland and Antarctica are vulnerable to a class of tipping point event whereby the threshold for inevitable loss of ice can be crossed, but the onset is slow, with impacts accumulating over a few centuries.

Figure 1.1 roughly divides the temperature space into four qualitatively distinct domains. The first one embraces the range between the Last Glacial Maximum and the Holocene Climate Optimum in which the pre-industrial human enterprise was born (purple line). The second domain covers temperature ranges between 1°C and 3°C and thus includes the Paris range. From Figure 1.1, it is immediately apparent that, even if global warming is limited to below 2°C, some important tipping elements may already be harmed or transformed. In fact, the tipping point for marine ice sheet instability in the Amundsen Basin of West Antarctica may well have been crossed already, and the risk of crossing further tipping points will increase with future warming. Progressing into the third domain with global warming reaching 3–5°C would seriously harm most tipping elements. For warming levels beyond this range (spanning the fourth domain), the world as we know it would be bound to disappear.

Traditionally, tipping points are estimated as having a low probability of occurrence, but a great impact on society. Policy-relevant climate issues that could be linked to potential future tipping elements in the climate systems include:

- loss of mass of the Greenland and West Antarctic ice sheets;
- loss of Arctic sea ice and the Alpine glaciers – the most vulnerable sensitive elements for global warming;
- changes in the Atlantic thermohaline circulation (THC).

The THC is part of a large-scale ocean circulation that contributes to milder winters in northern Europe when compared with regions at a similar latitude in North America and northern Asia. A change in the THC is caused by changes in the salinity of the North Atlantic Ocean. That is why this sensitive element is linked only indirectly to global warming, through melting of the Greenland ice sheet and changes in (Arctic) precipitation. The probability of collapse of this circulation is estimated to be low, even for high temperatures. However, changes in the intensity of the THC may have significant impact regionally without actually crossing the tipping point for collapse (Lenton et al., 2007).

1.3 International Commitments: The Paris Agreement and Implications

The Paris Agreement commits 196 countries to the mitigation goal of limiting global temperature rise to well below 2°C. According to the IPCC AR5 report, to achieve this 2°C objective, global GHG emissions must be reduced by 40–70% by 2050 compared with 2010 and be zero or below in 2100. This would be broadly consistent with RCP2.6.

Current commitments to reduce emissions, however, even if fully implemented, will lead to an estimated 2.7°C rise, consistent with RCP4.5.

Global emissions would need to peak soon and then decline rapidly for the Paris Agreement goals to be feasible. Even in this scenario, the uncertain sensitivity of the climate to GHGs means that there would remain at least a small chance of warming of 4°C or more by 2100. It is therefore prudent to prepare for further warming while pursuing more ambitious emission reductions as part of the global effort.

The Paris Agreement is clear that, if mitigation actions succeed in limiting the rise in global temperature, less adaptation will be needed to deal with the consequences of climate change.

1.4 Risk and Uncertainty

The IPCC AR5 WG1 Report 2013 outlines developments and progress in GCMs. However, uncertainties remain. These uncertainties increase at regional and local levels where spatial, geographical and/or local factors can dominate climate conditions. The IPCC has developed methods to assess and
convey such uncertainties, e.g. through describing confidence levels. The robustness of trends and projections in the main climate variables are expressed here using this confidence level terminology, which is in line with the definitions set out in the IPCC AR5 reports. However, note that for the most part the statements of confidence in this report are based on polling expert judgement, rather than on the more analytical approach possible for IPCC global assessment. This is due to variability in Ireland’s climate and a current lack of RCM model outputs to tease out more robust statistical descriptions of uncertainty. For an in-depth discussion of this terminology we refer the reader to Stainforth et al. (2007).

The implications of uncertainties and how they can be addressed in the development and implementation of adaptation actions varies according to the sector, issue or location being considered. Guidance on how to manage uncertainty in decision-making is beyond the scope of this report, but reference material includes Willows and Connell (2003) and Walker et al. (2013). In the short to medium term, uncertainties are primarily due to scientific uncertainties such as inherent variability and the chaotic nature of some of the phenomena being considered, e.g. rainfall and wind regimes. In the longer term, i.e. after 2030, the dominant uncertainty is primarily the ambition and effectiveness of future international actions to address the drivers of climate change, i.e. to reduce emissions of GHGs. This will eventually determine the full extent of climate change and the level of adaptation that will be required.

However, uncertainties should not be taken as an excuse for inaction in addressing climate change. There is overall agreement on the robustness of trends and projections of key climate variables and associated impacts such as temperature and SLR at global and continental scale. However, many uncertainties will remain, especially with regard to precipitation and extreme climate events at a regional and local level, where the information is needed most. Climate change uncertainty adds to the variety of other decision criteria that decision-makers have to deal with in their day-to-day activities. However, climate information, including its associated uncertainty, can still be very informative. Many methodologies exist to take potential climate change impacts into account in policy development and investment decisions that recognise uncertainties but do not require precise and accurate quantification (robust decision-making). Rather than a barrier to action, uncertainty can be treated as a motivation towards a precautionary approach.

Watkins and Hunt (2012) made a case for a strategy of decision-making under uncertainty that allows public and private organisations and households to learn as they go. This can be achieved by introducing the principles of robust adaptation into an adaptive risk management framework. Central to the approach are the following policy criteria:

- reversible;
- provide margins of safety, e.g. in the design of infrastructure;
- prioritise soft strategies without high sunk costs or fixed engineering;
- reduce the decision time horizon of investments;
- reduce long-term commitments.

The development of actions on adaptation also requires appropriate approaches, such as vulnerability assessment and risk management, to address uncertainties. Iterative risk management is a useful framework for decision-making in complex situations characterised by large potential consequences, persistent uncertainties, long timeframes, potential for learning, and multiple climatic and non-climatic influences changing over time (IPCC, 2014a).

1.5 Climate Change Impacts in Ireland

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014a). Climate change is expected to create new risks for natural and human systems and amplify existing risks in countries at all levels of development (IPCC, 2014a). Ireland is already observing the impacts of climate change on natural and human systems.
The combination of warming temperatures and melting ice sheets and glaciers is causing the global sea level to rise, which presents a growing threat to vital coastal ecosystems and millions of people around the world who live in coastal regions. This threat includes both the gradual upwards creep in sea level and periodic, catastrophic ocean surges associated with land-falling cyclones. Ireland, as an island with soft coastlines, is already observing the impacts of SLR (Dwyer, 2012).

A warmer atmosphere has a greater capacity to hold water vapour. Consequently, climate models project that global warming will tend to cause wet regions to get wetter and dry regions to get drier. According to the IPCC (SRES Report, 2012), there is medium confidence that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions. Ireland’s geographic location makes it particularly difficult to present projection outputs with high confidence. The North Atlantic moderates our climate, and ocean areas near Greenland show signs of local cooling, which, if sustained, may impact on Irish weather and climate in unexpected ways, notwithstanding the wider regional and global warming trends (Rahmstorf, 2015). Therefore, although this report represents best available knowledge, which points to continued warming patterns of climate change, there is a chance that regional cooling may increase the climatic contrast between continental Europe and the Atlantic, with Ireland positioned at a highly variable and volatile interface.

1.6 Structure of Report

This report presents a summary of the current state of knowledge on climate change and expected impacts for Ireland. It will be of use to policymakers, sectoral and local decision-makers and stakeholders interested in or working on adaptation to climate change.

This report is not intended as a national risk assessment, as it does not undertake sectoral or local-level climate sensitivity/vulnerability assessment or determine specific risks and opportunities for Ireland. Rather, the report provides an overview of key climate hazards for those entrusted with developing their own sectoral or local climate risk assessments. We understand these as “Tier 1” risks, which should provide the basis for initial climate risk screening when developing adaptation strategies and progressing actions that enhance climate resilience, implementation and investment.

The information in Chapter 2 on observations and projections is largely based on work carried out by Met Éireann, Maynooth University, University College Dublin, University College Cork, the Irish Centre for High End Computation (ICHEC) and material from the IPCC AR5 WG1 Report (2013b). This element of the report has also been supplemented by expert opinion elicited through workshops and written submissions. The report focuses on data and information on key climatic parameters of the atmosphere, terrestrial, hydrological and ocean domains.

Information in Chapter 3 on sectoral impacts is drawn from IPCC AR5 WG2 Report (2014b) and Irish-based research. Synthesised material is also drawn from Ireland’s climate information platform: Climate Ireland (http://www.climateireland.ie/#/). Headline impacts are outlined for a number of sectors, including: critical infrastructure and built environment, industry and insurance, agriculture, forestry, peatlands, biodiversity and ecosystems, marine and fisheries, tourism, water management and resources, and human health. In this way, the report structure is similar to the earlier report from 2009. We also present a set of possible adaptation options for managing climate risks. This is not an exhaustive list, but rather outlines the possible range of management responses available in different situations and for differing timelines. In reality, the value of each of these options will need to be assessed according to criteria such as efficacy, cost and timelines using an approach such as multi-criteria analysis.

Finally, we present recommendations for further steps, which are required to support the development of policy and the implementation of adaptation in Ireland.
2 Current Knowledge on Climate Change for Ireland

A summary of observed and projected climate change across key domains of atmosphere, terrestrial and hydrology, and oceans is presented. The “scientific confidence” in the validity of these findings is described according to five qualifiers: very low, low, medium, high and very high.³

2.1 Atmosphere: Air Temperatures, Precipitation and Extreme Weather

See Tables 2.1–2.3.

Air temperature: Surface air temperature is a key climate variable. Temperatures in Ireland increased by about 0.8°C over the period 1900–2011. The decadal trend is 0.07°C averaged over the period 1900–2011. The standard measurement of temperature in the atmosphere is taken at synoptic and climatic stations across Ireland. The analysis is based on up to 100 years of records (and over 100 years for certain stations).

Precipitation: The localised nature and temporal variability of precipitation makes it less amenable to statistical analyses. In Europe the number of very wet days has increased over the last 50 years (Dwyer, 2012).

Table 2.1. Observed and projected changes for temperature in Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Mean annual surface air temperature has increased by approximately 0.8°C over the last 110 years (Dwyer, 2012)</td>
<td>High</td>
<td>National: projections for mid-century indicate an increase of 1–1.6°C in mean annual temperatures, with the largest increases seen in the east of the country (Gleeson et al., 2013; Nolan, 2015)</td>
<td>Medium/high</td>
</tr>
<tr>
<td>All seasons are warmer; summer and winter minimum temperatures have tended to be higher than the 1961–1990 average, in particular over the last 20 years (Walsh and Dwyer, 2012)</td>
<td>High</td>
<td>All seasons are projected to be significantly warmer (0.9–1.7°C) by mid-century (Nolan, 2015)</td>
<td>Medium/high</td>
<td></td>
</tr>
<tr>
<td>The changes also show regional variation. Warming is more pronounced at the extremes (i.e. hot or cold days) and in winter night-time temperatures (Nolan et al., 2013)</td>
<td>High</td>
<td>Warming is enhanced for the extremes (i.e. hot or cold days), with highest daytime temperatures projected to rise by up to 2.6°C in summer and lowest night-time temperatures to rise by up to 3°C in winter (Nolan, 2015)</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Heatwaves: the number of warm days has increased (Walsh and Dwyer, 2012)</td>
<td>High</td>
<td>Increased frequency of heatwaves</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Cold snaps/frost days/ nights: the number of frost days has decreased (Walsh and Dwyer, 2012)</td>
<td>High</td>
<td>National (mid-century): averaged over the whole country, the number of frost days (days when the minimum temperature is below 0°C) is projected to decrease by over 50%. Similarly, the number of ice days (days when the maximum temperature is below 0°C) is projected to decrease by typically 75%. The projected decrease in the number of ice days is greatest in the north (Nolan, 2015)</td>
<td>Medium</td>
<td></td>
</tr>
</tbody>
</table>

³ Confidence in the validity of a finding synthesises the evaluation of evidence and agreement. Scientific confidence in projection refers to the likelihood, or probability, of some well-defined outcome having occurred or occurring in the future (IPCC, 2013a).
In the Irish context precipitation refers almost exclusively to rainfall, although snow and hail are included in the definition. Precipitation is measured at synoptic and climatic stations across Ireland.

**Extreme weather and climate events:** This refers to the occurrence of an intense or atypical weather or observation of a climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. Generally, both extreme weather events and extreme climate events are referred to collectively as “climate extremes” (IPCC, 2012). Events can include storms (speed and direction are two key measurements used to characterise wind and provide information on the strength and frequency of weather systems), flooding (pluvial, fluvial or coastal, with coastal flooding linked to storm surge and/or wave action), sea surges, and hot and cold days. Studies have shown that the intensity and frequency of extreme events are changing and will change further as a result of climate change (IPCC, 2013a). The character and severity of impacts from climate extremes depends not only on the extremes themselves, but also on exposure and vulnerability to these extremes (IPCC, 2012).

### 2.2 Terrestrial and Hydrological

See Tables 2.4–2.6.

**Soil temperature** is measured throughout Ireland by Met Éireann, Teagasc and other bodies. In general, measurements are made in the surface layers of the soil most pertinent to microbial activity and plant growth and development.

**Ground and surface water runoff and fresh water temperatures:** Information regarding surface and groundwater is based on the National Water Quality Monitoring Network, which comprises EPA, OPW and local authority facilities.

**Phenology** is the study of the timing of recurring natural events (both terrestrial and marine) and includes leaf unfolding, bird migration and the

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Increase in average annual national rainfall of approximately 60 mm or 5% in the period 1981–2010, compared with the 30-year period 1961–1990 (Walsh and Dwyer, 2012)</td>
<td>Medium</td>
<td>Results show significant projected decreases in mean annual, spring and summer precipitation amounts by mid-century. The projected decreases are largest for summer, with reductions ranging from 0% to 20% (Nolan, 2015)</td>
<td>Low/medium</td>
</tr>
<tr>
<td>In general, the larger increases in rainfall are recorded in the western half of the country (Walsh and Dwyer, 2012)</td>
<td>Medium (low confidence for local detail and very low confidence for extremes)</td>
<td>The number of extended dry periods (defined as a time period of at least 5 consecutive days for which the daily precipitation is less than 1 mm) is also expected to increase substantially (5–35%) by mid-century over the full year and during autumn and summer (Nolan, 2015)</td>
<td>Low/medium</td>
<td></td>
</tr>
<tr>
<td>An analysis of seasonal rainfall over the same period shows small increases in all seasons over recent decades; however, the spatial distribution and intensity vary (Walsh and Dwyer, 2012)</td>
<td>National (mid-century): the expected decreases in precipitation are largest for summer with values ranging from 10% to 20%. The expected increases in dry periods are also largest for summer with projected values of ~35% (Nolan, 2015)</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less snow days</td>
<td>High</td>
<td>Less snow throughout</td>
<td>Medium/high</td>
<td></td>
</tr>
<tr>
<td>Drier summers</td>
<td>Medium (2007 and 2008 were anomalous but did not reverse trend)</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.3. Observed and projected changes for synoptic variables for Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme weather and climate events</td>
<td>Storms: summer storm tracks over Europe are dominated by internal variability over the past millennium (Gagen et al., 2016). A review of storminess over the North Atlantic (Feser et al., 2015) suggests that most long-term studies show merely decadal variability for the last 100–150 years; there is no evidence of a sustained long-term trend</td>
<td>Low confidence</td>
<td>Slightly fewer storms, but more intense ones. The tracks of intense storms are projected to extend further south (Nolan, 2015) However, uncertainty on details remains high (Matthews et al., 2016)</td>
<td>Low/medium</td>
</tr>
<tr>
<td></td>
<td><strong>Flooding</strong>: for the period 1954–2008 summer mean flows are dominated by increasing trends, while there is a tendency for increases in winter mean flows for longer record stations (Dwyer and Murphy, 2012)</td>
<td>Medium/high</td>
<td>Using impact models, a robust signal of increasing seasonality in hydrological regimes is evident, with increases in winter and spring stream flows and a decrease in summer stream flow likely. A 20% increase in the amount of water flowing through rivers is expected for the majority of catchments by mid- to late century, while for summer decreases of over 40% (those with little groundwater storage in particular) have been simulated for the end of the century (Murphy and Charlton, 2007; Steele-Dunne, 2014)</td>
<td>Medium</td>
</tr>
<tr>
<td>Large-scale circulation</td>
<td>Atmospheric: no discernible change in large-scale circulation patterns affecting Ireland</td>
<td>Medium</td>
<td>Atmospheric: possible greater frequency of blocking high-pressure systems; increased risk of prolonged heatwave events. While some studies link declining Arctic Sea ice with cold continental air outbreaks, across Europe the implications for the future climate are less clear (Vihma, 2014)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Ocean: no coherent trends observed, significant interannual variability impacts on large-scale hydrographic conditions and climate</td>
<td></td>
<td>Ocean: THC may slow during the 21st century</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 2.4. Observed and projected changes for soil temperature for Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil temperature</td>
<td>The changes are consistent with the observed changes in air temperature</td>
<td>Medium</td>
<td>Consistent with air temperature: warmer in the south-east</td>
<td>Medium</td>
</tr>
<tr>
<td>Ecosystem carbon</td>
<td>It is difficult to estimate the impact of climate change on carbon pools, as management practices, such as soil drainage and peat extraction, have a much larger impact on carbon loss. However, there has been a significant net uptake of carbon to biomass, in recent years, primarily as the result of an active afforestation programme</td>
<td>Medium</td>
<td>In general, longer growing seasons and wetter conditions would encourage the uptake of carbon to ecosystems. However, prolonged dry periods can have an adverse impact on carbon pools (Bahn, 2013; Khalil, 2013)</td>
<td>High</td>
</tr>
</tbody>
</table>
### Table 2.5. Observed and projected changes for hydrological variables for Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water (rivers and lakes) and runoff</td>
<td>Rivers: analysis of long records of annual mean flows shows a tendency for increasing flows</td>
<td>Low or very low for extremes</td>
<td>Intensification of the hydrological cycle, leading to both increased incidences of high- and low-flow periods (Coll et al., 2014)</td>
<td>High confidence on intensification based on physical reasoning</td>
</tr>
<tr>
<td></td>
<td>Summer mean river flows are dominated by increasing trends, while there is a tendency for increases in winter mean flows for longer record stations (Dwyer and Murphy, 2012)</td>
<td>Medium</td>
<td>Increased flow to rivers in winter and less in summer</td>
<td>Medium confidence</td>
</tr>
<tr>
<td></td>
<td>Lakes: no systematic analysis of lake levels has been carried out to date (Dwyer, 2012)</td>
<td>N/A</td>
<td>More intense rainfall patterns may lead to higher volumes of runoff at peak times, increasing the risk of flooding</td>
<td>Medium confidence</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Groundwater: no systematic analysis of national groundwater levels has been carried out to date (Dwyer, 2012)</td>
<td>N/A</td>
<td>SLR may lead to salination of groundwater systems in coastal areas (Williams, 2007)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>However, regional analysis of long-term groundwater level trends in the SERBD was undertaken to investigate if any impacts of climate change were evident in groundwater levels. The analysis showed no consistent change in the timing of groundwater level minima or maxima in the SERBD (Tedd et al., 2011)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface freshwater temperatures</td>
<td>Probably consistent with air and soil temperatures</td>
<td>Low/medium</td>
<td>Consistent with air and soil temperatures</td>
<td>Low/medium</td>
</tr>
</tbody>
</table>

N/A, not available; SERBD, South Eastern River Basin District.

### Table 2.6. Observed and projected changes for phenology and climate space changes for Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenology</td>
<td>Terrestrial: longer growing season; earlier spring</td>
<td>High/medium</td>
<td>Longer growing season; earlier spring</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Trees and plants: evidence of change in timing of phenological phases such as bud burst, leaf unfolding, flowering, fruiting, leaf colouring and leaf fall in some trees and plants (Donnelly et al., 2013)</td>
<td>High/medium</td>
<td>Projections suggest that bud burst of birch will continue to advance at least until 2100, but the rate of advance will vary across the country with the north-east showing the greatest advance (Caffarra et al., 2013a)</td>
<td>High/medium</td>
</tr>
<tr>
<td></td>
<td>Birds: change in the timing of arrival and departure of a wide range of birds, including land and seabirds and winter and summer migrants, to Ireland has been observed (Stirnemann et al., 2013). These changes generally resulted in earlier arrival and departure in spring, which in turn was correlated with rising spring temperature</td>
<td>High/medium</td>
<td>Further change linked to temperature change</td>
<td>High</td>
</tr>
</tbody>
</table>
occurrence of algal blooms. Many natural events of this kind are strongly influenced by weather and hence climate.

2.3 Oceans and Seas

See Tables 2.7 and 2.8.

**Sea temperatures**: Globally, ocean temperatures have increased by about 0.8°C up to 2015, relative to the period 1971–2000. Increasing and thermal expansion of water is currently the main driver of the observed SLR. Observations of ocean temperatures are largely based on surface measurements from satellite observation systems and observations from research vessels and ships of opportunity.

**Sea chemistry (pH and salinity)**: Globally, evidence is emerging that sea chemistry is changing in response to higher concentrations of CO₂ in the atmosphere and climate change. Marine biological systems have been shown to be very sensitive to changes in water chemistry. In Ireland, significant work has been done on the impacts of changes in chemistry on natural systems and growth.

**SLR**: Measurements in Ireland are based on the analysis of tide gauge systems. Isostatic uplift, i.e. geological rebound following deglaciation after the last Ice Age, distorts the signal, but has been accounted for in the analysis of SLR around Ireland.

These sources are now complemented with data from satellite altimetry.

**Waves and surges**: Ocean waves are driven by local winds. Surges are the apparent rise in sea level as a result of distant storms at sea. Waves and surges impact on a wide variety of human activities, including coastal infrastructure, shipping, settlement and coastal erosion.

2.4 Cross-cutting Areas: Flooding (River and Coastal) and Soils

See Table 2.9.

**Flooding**: The pattern of human settlement in Ireland has been concentrated on urban development along the rivers and coasts with more than 50% of Ireland’s population currently coastal in distribution, mainly in urban environments from small seaside towns to the main urban centres. Many areas of importance are already vulnerable to flooding. Many climate variables, such as precipitation and storms, and other parameters such as urban fabric and land use, increase this risk.

**Soil**: The condition and ecosystem function of soils is influenced by a wide variety of parameters including climate, land use and land management. Analysis of this cross-cutting issue requires development.
### Table 2.7. Observed and projected changes for maritime variables for Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific Confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea surface temperature</td>
<td>Increases in Irish coastal water temperatures since 1980s. There has been an observed 0.85°C rise in Irish coastal sea since 1950, with 2007 being the warmest year in Irish coastal records. The rate at which warming has occurred since 1994 (0.6°C per decade) is unprecedented in the 158-year observational record, the warmest years on record being 2005, 2006 and 2007 (Nolan et al., 2010). An increase of 1.02°C above the long-term mean (1982–2010) in inshore waters to the north of Ireland was recorded in 2015 (Larsen et al., 2016). Between 1982 and 2015, satellite composite data (Casal et al., 2017) from all waters surrounding Ireland show an overall increase of 0.26°C per decade (p-value ≤ 0.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Increased intensity of storms, ongoing increase in mean sea temperature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sea chemistry (pH and salinity) | Increased seawater acidity observed in both surface waters and Labrador Sea Water (intermediate water mass) between 1990 and 2010 (McGrath et al., 2012); salinity changes vary with region. Atlantic waters freshened from 1960 to 1990 and are now becoming more saline. Associated changes in water mass formation/circulation. No distinct salinity trends exist in deeper waters on the Irish continental shelf (i.e. water depths of c. 200 m). Surface salinity anomalies on the Irish shelf also show variability from year to year, with evidence of freshening in coastal waters associated with increased winter rainfall (Nolan et al., 2010). |
|                                | High for acidity, low for salinity                                                | With increasing CO₂ in the atmosphere, the acidity is projected to increase; salinity changes vary with region. Changes in rainfall will affect coastal salinities, implications for coastal dynamics, water column stability, water quality, etc. |
|                                | High for acidity, low for salinity                                                | High for acidity, low for salinity |

| Sea phenology | The growth season in coastal waters has expanded for some phytoplankton species, primarily diatoms. Warm water zooplankton species have shifted northwards in their distribution, with a decline of cold water species evident. In warm years, jellyfish and comb jellies are more evident with an increase since 1997 (Nolan et al., 2010). Many, but not all, warm water species, including sprat, anchovy, pilchard and blue-mouth, have increased in abundance to the north of Ireland and in the Celtic Sea. The survival of salmon at sea has declined since the 1970s and the recruitment success of the European eel has dropped significantly since the 1980s (Nolan et al., 2010). |
|                | Medium/high                                                                        | Changes will continue in the phenology of biological events and this will have a serious impact on the structure and function of marine ecosystems |
|                |                                                                                   | Low |
## Table 2.8. Observed and projected changes for SLR in Ireland

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Scientific confidence</th>
<th>Projected changes</th>
<th>Scientific confidence projection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLR &lt; 1 m</strong></td>
<td>Since the early 1990s (1993) a SLR of c. 3.5cm per decade (currently c. 3.4 mm/year) has been observed. Earlier tide gauge records pre-1990 show SLRs of 1–2 mm/year for Ireland’s coasts. This forms a clear indication of the expected acceleration in SLR from warming of a coupled atmosphere–ocean system (Devoy, 2008)</td>
<td>Medium</td>
<td>Rise of c. 55–60 cm to 2100 [based on IPCC RCPs 2.6–4.5 and other medium-scale climate warming scenarios, namely Dunne et al. (2008) and Lowe et al. (2009)]. Predicted changes in mean sea level will be the primary driver in magnifying the impacts of changing storm surge and wave patterns in coastal areas</td>
<td>Medium/high</td>
</tr>
<tr>
<td></td>
<td>Regional SLR, allowing for isostatic components, of c. 25 cm (Dublin/east coast of Ireland), c. 44 cm (Sligo/central western coasts) and c. 40 cm (south-west Ireland) by c. 2080–2100 (Devoy, 2008)</td>
<td></td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td><strong>SLR &gt; 1 m</strong></td>
<td>SLR will continue beyond 2100, but with large uncertainty as to ultimate stabilised levels (Hansen, 2015)</td>
<td></td>
<td></td>
<td>Low/medium</td>
</tr>
<tr>
<td><strong>Waves and surges</strong></td>
<td>Observational records and reanalyses indicate an increase in significant wave heights of about 20 cm per decade since the 1950s in the North Atlantic (IPCC, 2013a)</td>
<td>Medium</td>
<td>Expected changes in wave heights are uncertain, but recent high-resolution simulations focused on Ireland (Gallagher et al., 2016) suggest a 15% decrease in mean and extreme significant wave heights by the end of the century (Gallagher et al., 2016)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Expected surge levels (i.e. temporary sea surface heights above the “background” sea level) for most non-estuary coasts for the 20- to 30-year return period surge events are likely to increase by ≤9 mm/year up to 2100 (c. 9 cm rise) (Lowe et al., 2009)</td>
<td></td>
<td>Increase in number of high-magnitude storms, generating bigger associated surges (&gt; 1 m) by 2031–2060 (Devoy, 2008)</td>
<td>Medium</td>
</tr>
</tbody>
</table>

## Table 2.9. Observed and projected changes for cross-cutting variables

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Observed changes</th>
<th>Projected changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>River flooding</td>
<td>Linked to precipitation patterns</td>
<td>Increased risk of river flooding</td>
</tr>
<tr>
<td>Coastal flooding</td>
<td>Linked to storm patterns and SLR</td>
<td>Increased risk of coastal flooding, particularly as a result of the impacts of SLR and surge/storminess with coupled surge events. Losses in coastal wetlands: &gt; c. 20% losses for medium-based change scenarios</td>
</tr>
<tr>
<td>Soil: inundation of poorly drained land</td>
<td>Linked to precipitation patterns</td>
<td>Increased duration of standing water on poorly drained lands in winter. Greater drying of turloughs and rain-fed lakes in summer</td>
</tr>
<tr>
<td>Soil: inundation of poorly drained land</td>
<td>N/A</td>
<td>Increased soil moisture may lead to enhanced N₂O emissions (Dong-Gill, 2013)</td>
</tr>
</tbody>
</table>

N/A, not available.
3 Sectoral Impacts and Adaptation Options

The information in this chapter is intended as a supplement for sectoral decision-makers tasked with developing climate change adaptation strategies and plans. The sectors chosen for this analysis have not been prioritised, but are generally understood as important to the Irish economy and society and are potentially vulnerable to climate change impacts.

The information provided is structured according to changes in key climate variables (as set out in Chapter 2), projected sectoral impacts and potential adaptation options as set out in the academic literature. Expert opinion is used to fill information gaps. The list is not exhaustive, as it is beyond the scope of this report to provide high-level detail. Where large knowledge gaps exist, these are identified as areas for future research, action or monitoring.

Some of these adaptation options will need to be considered in the short term and others will become more relevant as climate change progresses. All will need to be costed and investigated for their effectiveness as the adaptation process progresses and is co-ordinated at both sectoral and strategic level. This is beyond the scope of this analysis.

Given the considerable uncertainties that attach to projected changes, particularly as regards precipitation and extreme weather, it will be important that adaptation choices are robust, i.e. that they are relatively insensitive to uncertainty and aim to strengthen resilience at national, local and sectoral levels. Adaptation options, particularly soft and institutional measures, need to be flexible in order to respond to short-, medium- and long-term changes as they emerge. There are interdependencies between the impact of adaptation options in different sectors and their economic, social and environmental impacts and their resilience and capacity to recover from external shocks.

Consequently, there is much opportunity for the adoption of win–win policy measures, for example measures that can protect against climate change impacts such as flooding, but that also deliver other benefits for human health, protection of livelihoods, biodiversity, etc.

Ideally, adaptation should be co-ordinated between sectors and planned within an “adaptive risk management framework” that is responsive to new information and stakeholder feedback and becomes more detailed and quantified over time. Tables 3.1–3.11 provide numerous examples of individual adaptation options, but there is much scope for adaptation to be delivered through the use of “decision pathways”, whereby ultimate goals are identified, but the route to adaptation is flexible to the emerging evidence on climate change with relevant pre-planned intermediate adaptation options being triggered as new climate thresholds are realised.

3.1 Critical Infrastructure and the Built Environment

Critical infrastructure represents those national infrastructure assets that are essential for the functioning of the country and the delivery/maintenance of vital societal functions. It includes energy, transport, communication networks, water services and health services. Ireland’s critical infrastructure could be at risk from projected changes in climate and, in particular, increasing temperatures, SLR, changing rainfall patterns and the increased occurrence of extreme weather events.

The built environment refers to the residential and commercial building infrastructure. Climate change is expected to have profound impacts on the built environment (Revi et al., 2014) as a result of changes in temperature, precipitation patterns, extreme events and SLR. Governments are key to crafting and co-ordinating building sector responses and can identify and encourage synergies between adapting buildings to climate change and mitigating their GHG emissions, recognising the potential for multiple benefits (Chalmers, 2014).

3.1.1 Conclusions

There is a general lack of information available on the vulnerability of Ireland’s critical infrastructure to climate change. In particular, little is known about the status of infrastructure that is owned or managed by
### Table 3.1. Climate change impacts on critical infrastructure and the built environment

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climatic variables</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport: road, rail, sea,</td>
<td>Temperature increases in summer and more intense heatwaves</td>
<td>Thermal expansion of roads and rail lines (EC, 2013), leading to degradation and disintegration</td>
<td>Assess vulnerability of infrastructure and design climate-resilient infrastructure (IAE, 2009)</td>
</tr>
<tr>
<td>aviation, ports</td>
<td></td>
<td>Impacts of heat on passenger comfort (especially for rail)</td>
<td>Improved carriage and vehicle design</td>
</tr>
<tr>
<td></td>
<td>Decrease in cold snaps and frost and ice days and nights</td>
<td>May reduce minor accidents and reduce personal and motor insurance costs</td>
<td>Improved communication of travel conditions and timely advice (Collins et al., 2011)</td>
</tr>
<tr>
<td>SLR</td>
<td>Infrastructure located on low-lying coastal areas (e.g. rail lines on east coast, ports infrastructure on the east and south coasts, Shannon Airport)</td>
<td></td>
<td>New infrastructure managed and controlled to avoid areas susceptible to coastal flooding and erosion (IAE, 2009)</td>
</tr>
<tr>
<td></td>
<td>Damage to infrastructure (all) and service disruption</td>
<td></td>
<td>New infrastructure designed to cope with changing weather patterns and extreme events</td>
</tr>
<tr>
<td>Extreme events (flooding, winds)</td>
<td>Possible impact on road and rail embankment and verge stability</td>
<td></td>
<td>Improved design, monitoring and maintenance</td>
</tr>
<tr>
<td></td>
<td>Changing patterns of siltation for ports</td>
<td></td>
<td>Improved design, monitoring and maintenance</td>
</tr>
<tr>
<td>Energy: supply and grid</td>
<td>Temperatures increase</td>
<td>More energy demands are possible for cooling (DECLG, 2012a)</td>
<td>Review of current and future energy demands (IAE, 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water cooling of power stations, including cooling water availability (DECLG, 2012a)</td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>Infrastructure, power stations, storage facilities located on the coast that are vulnerable. Potential damage to offshore wave and tidal energy generation systems</td>
<td></td>
<td>Avoid development in high-risk areas such as flood plains, unless justifiable (National Directorate for Fire and Emergency Management, 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Enhance design criteria; update disaster preparedness (Revi et al., 2014)</td>
</tr>
<tr>
<td>Extreme events</td>
<td>Potential damage to power generation and infrastructure</td>
<td></td>
<td>Enhance design criteria; update disaster preparedness (Lyons et al., 2013; Revi et al., 2014)</td>
</tr>
<tr>
<td>General wind characteristics</td>
<td>Wind generation will deliver at least 35% of electricity demand by 2020 and even more by 2030: Changes in wind regimes in Ireland will have a significant effect on electricity generation</td>
<td></td>
<td>Effective grid management; investment in diverse renewable energy generation and storage</td>
</tr>
</tbody>
</table>
the state. This is a knowledge gap that needs to be addressed. Some information exists on the impacts of climate change on the built environment, but not enough is known about specific vulnerabilities or the roll-out of policy/actions in this area. In addition, this is an area that has large potential for emissions mitigation actions. As yet, we know little of how the twin objectives of adaptation and mitigation might be achieved with a view to achieving synergies and avoiding maladaptation in this sector.

3.2  Industry and Insurance

The impact of climate change on economic development and growth potentially affects all economic sectors (Arent et al., 2014); this includes direct impacts and secondary impacts due to market links and supply chains. Climate change will also affect insurance systems. More frequent and/or intensive weather disasters as projected for some regions/hazards will increase losses and loss variability in various regions and will challenge insurance systems to offer affordable coverage (Arent et al., 2014).

While not all business sectors will be equally impacted, climate change will impact on Irish businesses through changing markets, impacts on premises and processes, and increased vulnerability of supply chains, which may have implications for investments, insurance costs and stakeholder reputation (Forfás, 2010).

Industries, such as pharmaceuticals, software, information and communication technology (ICT), food and refrigeration, could be impacted directly under future climate conditions from shortage of water in the summer and extreme precipitation in winter. In addition, the supporting infrastructure (transport, communications, energy) that such industries depend on could also be impacted, leading to indirect impacts on industry such as loss of productivity and disruption of supply chains (McDermott, 2016).

3.2.1  Conclusions

There is a general lack of information available on the vulnerability of Ireland’s industry and business to climate change. This is a knowledge gap that needs
to be addressed in collaboration with industry itself. It is also worth noting that there may be opportunities for some segments of industry such as those in the climate services sectors, data centres, water infrastructure management, but these remain to be quantified.

### 3.3 Agriculture

Agriculture is one of Ireland’s most important indigenous sectors and accounts for approximately 64% of the total land area of Ireland. Approximately 80% of the agricultural area is devoted to grass (silage, hay and pasture), 11% is devoted to rough grazing and the remainder is allocated to crop production. Beef and milk production currently account for around 58% of agricultural output.

According to the agricultural accounts from the Statistical Yearbook of Ireland 2014 (2014a), livestock, milk and crops (in million euros) were worth €3,158.7, €2,073.5 and €1,963.2, respectively, and roughly 90,000 people were employed in agriculture during 2013.

The effects of climate change on crop and food production are already evident in several regions of the world, with negative impacts more common than positive (Cameron, 2014). For Ireland and northern Europe more generally, the impacts of climate change are not expected to be as severe as those projected for areas in the southern parts of Europe, where the

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climate variables</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>Extreme events</td>
<td>Food, drinks and construction industries impacted (Forfás, 2010)</td>
<td>Planning authorities to evaluate need for further legislative restrictions on new builds in risk areas (Forfás, 2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced productivity due to compromised supporting infrastructures such as road, rail and communications (Environment, Community and Local Government, 2012a)</td>
<td>Climate change incorporated into long-term planning, design, investment and maintenance of all actors in the transport sector (Forfás, 2014)</td>
</tr>
<tr>
<td></td>
<td>Temperature increases</td>
<td>Impacts on ICT due to cooling requirements (Forfás, 2010)</td>
<td>The establishment of district cooling should be actively considered (Forfás, 2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ICT/pharmaceuticals: rising ambient air temperatures, variations in water quality and availability of cooling water can have effects on chemical processes (Forfás, 2010)</td>
<td>Changes in long-term planning, standards and building regulations, use of new building materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heatwaves could damage industrial plants and materials; storms may damage larger industrial infrastructure and mobile machinery</td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>Extreme events</td>
<td>Financial services impacted by domestic and global extreme events</td>
<td>Need a knowledge base of the potential insurance implications of climate change for business</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insurance sector sensitive to weather and climate risks and to limits in capacity of global financial markets to absorb risk, in particular reinsurance capacity (Forfás, 2010)</td>
<td>Irish Insurance Federation could develop risk assessments for business insurance (Forfás, 2010; Surminski, 2015)</td>
</tr>
<tr>
<td></td>
<td>Changes in precipitation patterns</td>
<td>Impacts on water resources; significant for pharmaceuticals, ICT, food and drinks (Forfás, 2010)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased risk of industrial contamination of water systems due to flooding</td>
<td>Enhanced protection systems mandated under operating licences</td>
</tr>
<tr>
<td>Sector</td>
<td>Changes in climate variables</td>
<td>Impacts</td>
<td>Adaptation options</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------</td>
<td>---------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Dairy</td>
<td>Temperature increases</td>
<td>Extension of growing season by over 35 days per year (Nolan, 2015)</td>
<td>Adoption of earlier planting and harvesting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended grazing season (Hennessy, 2010)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>All-year growth in coastal and sheltered areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible increase in viruses and diseases, e.g. foot-and-mouth disease, bluetongue viruses in cattle and sheep and aphids in winter crops (Flood, 2013)</td>
<td>Introduce and/or increase vaccination and disease control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended viability of disease vectors throughout the year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Changes in precipitation patterns</td>
<td>Changes in soil moisture (increases and decreases) will impact on plant/crop growth</td>
<td>Modification of animals’ diets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impacts on soil carbon stores and sequestration potential</td>
<td>Increased need to cultivate drought- and heat-resistant crops</td>
</tr>
<tr>
<td></td>
<td>Extreme events (heatwaves): mid-century projections indicate the warmest 5% of daily maximum summer temperatures are projected to increase by up to 2.6°C (Nolan, 2015)</td>
<td>More frequent and intense heatwaves may put water stress on both animals and plants (Flood, 2013)</td>
<td>Protection from the elements. Improved availability of water and shade</td>
</tr>
<tr>
<td></td>
<td>CO₂ concentration</td>
<td>Improved net biomass production (possible lower nutrient value). There remains significant uncertainty as to the regional impact on crops and grass</td>
<td>Ongoing review of plant species</td>
</tr>
<tr>
<td>Tillage</td>
<td>Temperature increase</td>
<td>Increased Irish agricultural production, as global agriculture is under stress (Schulte and Lanigan, 2011)</td>
<td>Protection from the elements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Projections for future crop and grass production showed a decrease of up to 9% in cereal crops, an increase in maize of up to 43–97% and an increase in grass production of up to 49–56% (Shrestha et al., 2015)</td>
<td>Adoption of earlier planting and harvesting</td>
</tr>
<tr>
<td></td>
<td>Changes in precipitation patterns</td>
<td>Nutrient leaching, soil erosion and pollution may result (higher risk from winter precipitation?)</td>
<td>Increased drainage to compensate for winter precipitation. Possible negative impact of carbon stocks in soils</td>
</tr>
<tr>
<td></td>
<td>Heavy rainfall</td>
<td>Water stress in summers</td>
<td>Recognise and account for the variability of soils and their capacity to deliver on different soil functions and ensure that land is managed in such a way that the total suite of soil functions is maximised (Schulte et al., 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impeded land access due to heavy winter precipitation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water contamination during flooding/heavy rainfall (Flood, 2013)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drier summers with episodic heavy rainfall events</td>
<td>May cause enhanced N₂O emission events (Leahy, 2004)</td>
<td>Nutrient management plans should include options to respond to meteorological conditions (Abdalla, 2010)</td>
</tr>
<tr>
<td></td>
<td>Extreme events (cold events, wet winters and springs)</td>
<td>Impact of multiple extreme climate events (e.g. fodder crisis of 2013)</td>
<td>Modification of fodder crops for animal diet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction in cold snaps and frost days will impact pest die-off and subsequent plant health (Flood, 2013)</td>
<td>Protection from the elements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maladaptation to reduction in frequency of cold events (e.g. poor response to snow events in 2011 and 2012)</td>
<td>Reduced need to cultivate frost-resistant crops</td>
</tr>
</tbody>
</table>
As the overall expected decrease in precipitation and water availability is far greater (EEA, 2012). Nonetheless, all aspects of agriculture in Ireland will be affected by climate change, and the main impacts of climate change will probably result from changes in air and soil temperature, precipitation patterns and extreme events. In addition, the impact of multiple events or a sequence of events may combine to produce “perfect storm” scenarios, which will challenge resilience to otherwise typical weather patterns.

In general, grass-based dairy systems have the capacity to adapt to projected climate change (Fitzgerald, 2009); however, there are specific challenges that will need to be addressed. Increasing the resilience of grass-based systems may constrain the level of intensification (Courtney, 2013).

Given the importance of food and other crops, a large volume of international, regional and national research has been undertaken to understand the potential response of key crops to environmental changes including climate change and increased CO₂ concentration.

### 3.3.1 Conclusions

More information is needed on the impacts of climate change on agricultural land, water stress, soil quality, crops, pests, pathogens and invasive species. Some

---

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climate variables</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td>CO₂ concentration: observed decrease in nutrient and protein in C3 and to a lesser extent in C4 crops in high CO₂ growing conditions (Myers et al., 2014)</td>
<td>Enhanced net biomass production (possible lower nutrient value)</td>
<td></td>
</tr>
<tr>
<td>Horticulture</td>
<td>Temperature increases (air and soil)</td>
<td>Changes in the risk of pests and diseases (Flood, 2013) High temperatures and water stress may turn carbon sinks into carbon sources (Schulte and Lanigan, 2011)</td>
<td>Pest control</td>
</tr>
<tr>
<td>Changes in precipitation patterns</td>
<td>Large volume of research links to nutrient leaching</td>
<td>Water harvesting (investment in local storage) in the winter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less rainfall in the summer and increased winter rainfall increase nitrate leaching and impact water quality (IPCC, 2014b)</td>
<td>Implementing water management strategies (Flood, 2013)</td>
<td></td>
</tr>
<tr>
<td>Aridity is projected to increase by 40%–120% from 2020 to 2080, Possible increase in irrigation requirement (Flood, 2013)</td>
<td>Adjusting herd size in certain regions</td>
<td>Growing crops such as maize instead of potatoes Implication for the total abatement of extended grazing (Schulte and Lanigan, 2011)</td>
<td></td>
</tr>
<tr>
<td>Extreme events (storms, cold events, heatwaves)</td>
<td>Increase in water demand for spray irrigation of 15% in 2020 up to 45% in 2080 under the medium-emission scenario and 36% in 2020 up to 58% in 2080 under the high-emission scenario (Flood, 2013)</td>
<td>Explore potential to exploit the variability of soil and capacity to deliver on different soil functions (Schulte et al., 2014)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Impact of multiple extreme climate events (e.g. fodder crisis of 2013) Reduction in cold snaps and frost days will impact pest die-off and subsequent plant health (Flood, 2013)</td>
<td>Some crop and fruit species may need to be adapted to avoid adverse impact of lack of frost, which triggers phenological phases (Donnelly, 2013)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More frequent and intense heatwaves may put water stress on both animals and plants (Flood, 2013) Lowland livestock may benefit from less exposure to harsh conditions</td>
<td>May increase the need for irrigation in certain parts of the country</td>
<td></td>
</tr>
</tbody>
</table>
impacts, such as invasive species and pathogens, are already on monitoring schedules, which should be continued within the context of a changing climate.

3.4 Forestry

The 731,650 hectares of forest in Ireland in 2012 represents 10.5% of the total land area of Ireland. Since 1990, approximately 300,000 hectares of land has been afforested under various national forest programmes. The national net uptake of these forests – the forest sink – is currently in the region of 4.8 million tonnes of CO₂ equivalent per annum. Depending on carbon sequestration accounting rules, carbon uptake in forests planted since 1990 is forecast to reach an average of 4.4 million tonnes of CO₂ equivalent per annum in the decade from 2021 to 2030.

The number of people employed in forestry in 2013 was just under 12,000 (O’Driscoll, 2014). According to the Forest Service’s *Ireland’s Forests – Annual Statistics* (2014), the direct economic activity value of forestry in Ireland is €386.9 million. Processing adds an additional €1.389 billion to the direct output value of the sector.

The management of forestry is a long-term process and forests in Ireland are generally worked on rotation periods (between planting and final harvest) of 40–50 years. Within this timeframe, climate change is projected to have a significant impact and, as a result, introducing and/or adapting management practices that strengthen the ability of forests to withstand the impacts of climate change will be critical (Ray et al., 2009).

The long planning period associated with forest management means it may be appropriate to consider

**Table 3.4. Climate change impacts on forestry**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climate variables</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestry</td>
<td>Temperature</td>
<td>Exotic pests and pathogens introduced to Ireland (Schulte and Lanigan, 2011). Root and butt rot fungi such as <em>Fomes</em> may be a greater threat in warmer climates (Black et al., 2010). Over 50% of the species investigated showed significant changes to the timing of leaf unfolding and leaf fall (Black et al., 2010)</td>
<td>Pest control</td>
</tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Improved monitoring and enforcement systems for pest control, e.g. the response to <em>Chalara fraxinea</em>, which causes ash dieback</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Diversity in national forest; employ currently unrepresented species (Hendrick et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>CO₂ concentrations</td>
<td>Timber quality may be affected by rapid growth as a result of increased CO₂ emissions (Environment, Community and Local Government, 2012a)</td>
<td>Diversification of biomass market to create competitive income streams for multiple grades of biomass product</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td>Reduced summer rainfall may lead to loss of productivity (Schulte and Lanigan, 2011); however, there is also evidence of forest growth being limited by current access to water (Saunders et al., 2014)</td>
<td>Consider alternatives to drought-sensitive species (Wheelan, 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soil moisture in general could become an increasingly relevant issue for this sector</td>
<td>Matching the location of forest species to locations will allow appropriate land use (Schulte and Lanigan, 2011)</td>
</tr>
<tr>
<td></td>
<td>Extreme events (storms, extended dry periods)</td>
<td>Reduction in cold snaps will allow certain tree species such as oak and ash (Forestry Focus, n.d.) to grow better but will be detrimental to those requiring frost</td>
<td>Matching the location of forest species to locations will allow appropriate land use (Schulte and Lanigan, 2011)</td>
</tr>
<tr>
<td></td>
<td>Extended dry periods are expected to increase by 7–28% annually under the medium–low scenario (Nolan, 2015)</td>
<td>Frequent strong winds may affect timber supply (Schulte et al., 2011), in particular blowdown in exposed sites</td>
<td>Increased occurrence of droughts can affect tree growth and survival</td>
</tr>
</tbody>
</table>

22
a wider range of potential climate scenarios when looking to address climate change impacts on the forestry sector. Forest managers must plan with the expectation that both weather events (storms, cold snaps, heatwaves) and at least one 20-year event will impact on their stand in the management cycle.

3.4.1 Conclusions

While a good evidence base exists for the forestry sector, a watching brief and good monitoring regimes will have to be kept on the impacts of new invasive species, pests and pathogens, changes in soil moisture regimes and forest blowdown in exposed sites.

Table 3.5. Climate change impacts on terrestrial biodiversity

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climate variables</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial biodiversity</td>
<td>Temperature increases</td>
<td>Species will move to higher latitudes and altitudes (Coll et al., 2013)</td>
<td>Creation of green infrastructure and maintenance and promotion of connectivity of wider landscapes to ensure that species can reach new climate spaces (Coll et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>Change in phenology of native species (Gleeson et al., 2013)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Rate of climate change may exceed the adaptive capacity of some species (IPCC, 2014b)</td>
<td></td>
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<tr>
<td></td>
<td>Degraded raised bogs are predicted to have substantial losses in the southern edge of the distribution (Coll et al., 2013)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Changes in precipitation patterns</td>
<td>Flora and fauna will respond differently to changes in precipitation; in general, temperate climate species will be adversely impacted by more intense hydrological cycles</td>
<td></td>
</tr>
<tr>
<td>Extreme events</td>
<td>Destruction of species or habitats (Department of Arts, Heritage and the Gaeltacht, 2011)</td>
<td>Creation of farmland habitats to support named species (Finn et al., 2010)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Department of Arts, Heritage and the Gaeltacht, 2011)</td>
<td>Strategic national policies to maintain healthy ecosystems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Department of Arts, Heritage and the Gaeltacht, 2011)</td>
<td>Establish more diverse agro-forestry systems</td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>Destruction of coastal habitats (Coll et al., 2013)</td>
<td>Coastal defences deployment for key infrastructures and sites of high nature or heritage value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SLR combines with storm surges to accelerate erosion of vulnerable coastal and estuarine habitats and ecosystems</td>
<td>Managed retreat (abandonment)</td>
<td></td>
</tr>
<tr>
<td>Cumulative effects</td>
<td>Threatened habitats will be further endangered (Department of Arts, Heritage and the Gaeltacht, 2011)</td>
<td>Strategic national policies to maintain healthy ecosystems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The terrestrial habitats most vulnerable to climate change are:</td>
<td>Establish more diverse agro-forestry systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• upland habitats (siliceous and calcareous scree, siliceous and calcareous rocky slopes, alpine and subalpine heath);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• peatlands (raised bog, blanket bog);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• coastal habitats [fixed dunes – combined with additional threat of SLR to coastal habitats (Coll et al., 2013)]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Endangered native species (Department of Arts, Heritage and the Gaeltacht, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Invasive species (Maguire et al., 2011), expansion in range of foothold species (Maguire et al., 2011)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.5 Terrestrial Biodiversity

The impacts of climate change are being observed across all continents and oceans (IPCC, 2013b). Nationally, impacts are being felt on freshwater resources, natural carbon stores, marine ecosystems, wildlife and habitats, and biodiversity.

In addition to its intrinsic value, biodiversity provides a wide range of ecosystem services that are essential for using the Earth’s resources sustainably that include:

- provisioning services: harvestable products such as food, drinking water and raw materials;
- regulatory services: water treatment or slowing the passage of water;
- cultural services: services directly involving people, e.g. recreation;
- habitat or supporting services: services needed to maintain others, e.g. pollination, that include genetic diversity and maintenance of life cycles (EEA, 2010).

The ecosystems services in Ireland are estimated to be worth €2.6 billion per annum (Bullock et al. 2008). Throughout Europe, including Ireland, the rate of habitat degradation and ensuing biodiversity loss is accelerating (EEA, 2010) and it is in this context that the threats and opportunities posed by climate change must be considered.

3.5.1 Conclusions

Some information is available nationally on terrestrial habitats and biodiversity. Observed impacts should be monitored with a view to conducting further research in the context of a changing climate. More information is required on the impacts of climate change on ecosystem services and on the role that biodiversity and habitats play in both mitigating and adapting to climate change. For example, protecting biodiversity can help limit GHG concentrations because forest, peatlands and other habitats are major stores of carbon. Moreover, healthy ecosystems, e.g. coastal wetlands, can be employed to buffer against coastal erosion. Therefore, ecosystem approaches should be an integral part of the overall mitigation and adaptation effort.

3.6 Peatlands and Fens

Peat is the remains of plant and animal constituents that accumulated under more or less water-saturated conditions owing to incomplete decomposition (Rydin and Jeglum, 2006). Soil scientists in Ireland have defined peat as consisting of at least 30% (dry mass) dead organic material. Peatlands are ecosystems with a surface layer of peat at least 30 cm (on drained land) or 45 cm (on undrained land) thick, but it is often much thicker (Renou-Wilson et al., 2011). Peat soils cover an estimated 20% of the national land area, storing ~75% of the national soil carbon. Much of this area has been extensively modified by humans over centuries and currently more than 40% of the peatlands do not have the original hydrophytic vegetation, which has been replaced by trees or grass or removed altogether for peat extraction for energy or domestic use (Wilson et al., 2013).

Undisturbed peatlands provide important global and regional ecosystem services: carbon storage, water storage and biodiversity, as well as spiritual, cultural and educational services. The societal benefits of Irish peatlands are based on ecosystem functions that are inherent to peatlands and are tightly interlinked. These functions can be substantially influenced by human activities, as well as by climate change and climate extremes, thereby directly influencing the benefits that this natural resource can provide.

Many peatlands, and particularly raised bogs, may be adversely impacted given that the habitats are already in decline and their resilience may be weakened by ecosystem fragmentation and historical degradation. The variation in the summer water table is the most significant factor for these bogs, which are most probably degraded around the edges. Large variations in water table in the summer time have been reported already in restored sites in the Midlands. Their small geographical “range” also puts them at risk, given the climate change predictions in Ireland.

There are strong co-benefits with respect to mitigation of GHG emissions associated with appropriate management of peatlands and fens, as a result of the high potential losses of stored carbon to the atmosphere.
3.6.1 Conclusions

The potential impact of climate change on Ireland’s peatlands and fens remain highly uncertain. This derives from the combined uncertainty in the projection of climate change itself and, specifically, the uncertainty in precipitation, which is a main driver of ecosystem response, and lack of knowledge on the current vulnerability status of much of Ireland’s wetlands, peatlands and fens.

3.7 Coastal Areas

Coastal flooding and erosion pose serious threats to Ireland’s economy, society and natural environment and this is particularly the case as Ireland’s major cities (Dublin, Cork, Limerick and Galway) are located on the coast. Coastal flooding occurs when high tides, surges and wave-overtopping combine to inundate coastal areas. Coastal erosion, which is intimately linked with coastal flooding, occurs when the sea progressively encroaches on the land.

Climate change will impact on and offer opportunities to all sectors operating in coastal areas and these include agriculture, biodiversity, marine and fisheries, critical infrastructure and tourism. Engineering solutions to emerging climate impacts may not always be desirable or practicable. Soft solutions, such as planned retreat, may be the preferred option.

Table 3.6. Climate change impacts on peatlands

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climatic variable</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peatlands</td>
<td>Temperature</td>
<td>Northern species such as Saxifraga nivalis will probably lose a significant part of their distribution as a result of temperature increase (Malone and O’Connell, 2009)</td>
<td>Fully protect all the remaining raised bog habitats that are near intact or degraded but still capable of natural regeneration (Renou-Wilson et al., 2011) Maintenance and conservation of wetlands (IPCC, 2013b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changing vegetation patterns (Renou-Wilson et al., 2011)</td>
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<td></td>
<td></td>
<td>Possible extension of bog species including mosses and bog myrtle (Malone and O’Connell, 2009)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inability to adapt quickly may threaten many species in peatlands (Malone and O’Connell, 2009)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Invasive species out-compete native vegetation leading to destabilisation of ecosystems (Malone and O’Connell, 2009)</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>Areas most affected will be those that have the most changes in both precipitation and temperature such as the basin peat of the Midlands (Renou-Wilson et al., 2011)</td>
<td></td>
<td>Reducing the vulnerability of peatlands by a substantial programme of drainage, blocking and wetting or re-wetting (Renou-Wilson et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>Projections indicate an increase in the number of very wet days (&gt;30mm) of ~24% under the high-emission scenario by mid-century (Nolan, 2015)</td>
<td>A severe diminution of Irish peatland cover by 2075 (Renou-Wilson et al., 2011)</td>
<td>Maintenance and conservation of wetlands (IPCC, 2013b)</td>
</tr>
<tr>
<td></td>
<td>Increased precipitation could lead to more optimal conditions for carbon sequestration, but intense rainfall could enhance peatland erosion in susceptible areas (Renou-Wilson et al., 2011)</td>
<td></td>
<td>Restoration of peatlands (Renou-Wilson et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>Long periods of low precipitation may increase the risk of bog fires, especially in drained and degraded peatlands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peatland and fen</td>
<td>Combined climate factors</td>
<td>Projected loss of climate space at the southern edge of the distribution is indicated for degraded raised bogs (Coll et al., 2014)</td>
<td>Uncertain</td>
</tr>
<tr>
<td></td>
<td>The projected available climate space for active blanket bog is regionally sensitive to loss, notably for lower lying areas in the south and west (Coll et al., 2014)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.7.1 Conclusions

Some good information exists for this sector; however, more information is required regarding SLR at the national level. More information is required on the vulnerability of low-lying coastal urban centres and critical infrastructure to the impacts of climate change. Integrated Coastal Zone Management is required and needs to be implemented to coherently meet the challenges posed by climate change.

3.8 Marine and Fisheries

The marine and fisheries sector is a very important industry in Ireland. The seafood industry, according to the Irish Sea Fisheries Board, is worth €700 million. In 2013, the fisheries sector supported just under 11,000 jobs and the value of fish landed by Irish vessels in home ports in the same year was €212 million (DAFM, 2015).

Ireland’s marine sector and its infrastructure will be at risk from climate change through increasing sea level, coastal flooding and erosion and through physico-chemical changes to the marine environment.

Ireland’s marine ecosystems (i.e. offshore, inshore and coastal) are home to a rich and diverse range of species and habitats and our oceans are a national asset supporting an important and diverse marine economy. In addition, our marine resources also provide non-commercial benefits, such as amenity and biodiversity, as well as important ecosystem services, such as carbon sequestration and nutrient dispersal.

A changing climate has wide-ranging implications for Ireland’s marine environment and these changes are already having, and will continue to have, significant impacts on both the fisheries and aquaculture industries as the effects of climate change are further realised. Understanding the effects of climate change on marine ecosystems remains a challenge, but the
three major effects of climate change identified for Ireland’s marine sector are increased sea surface temperatures, oxygen depletion and acidification.

### 3.8.1 Conclusions

There is a general lack of information on the vulnerability of Irish marine and fisheries sectors to the impact of climate change. As a number of other sectors interact here (e.g. coastal, critical infrastructure), it is important that a cross-sectoral risk-based assessment of this economically relevant sector is undertaken.

### 3.9 Tourism

The tourism industry is an economically valuable sector to many countries, including Ireland. The country’s rich historical and cultural heritage sites, developed coastal areas and relatively unspoilt environment draws a lot of tourists to Ireland. The Department of Transport, Tourism and Sport estimated that in 2013 the revenue from tourism was €5.7 billion. While a lot of the infrastructure and facilities are potentially threatened by a changing climate, there are many opportunities within Irish tourism too, especially as other countries become too warm. There is also
the possibility of extending the tourist season into the shoulder periods of April/May and October, which would be a major boost to the industry and the Irish economy in general (Salmon, 2013).

3.9.1 Conclusions

Climate change will impact on tourism in Ireland in a number of both positive and negative ways. While some work has been undertaken, more information is needed in relation to the vulnerability of built heritage and coastal heritage sites, which should at least be put on a watching brief.

3.10 Water Management and Resources

Water management and resources are a part of Ireland’s critical infrastructure. Water services cost over €1.2 billion to run in 2010, of which operational costs amounted to some €715 million, with capital expenditure of €500 million (DECLG, 2012b). The potential impacts of climate change on both water sources and infrastructure are recognised in Irish Water’s Draft Water Services Strategic Plan (2015).

For Ireland, climate change will serve to exacerbate existing risks for water management and the projected areas of concern relate primarily to water supply, quality and flood risk. Climate projections indicate that water resources will become depleted in terms of both water supply and quality and this is against a background of increasing demand due to, among other things, increased irrigation requirements (Steel-Dunne, et al, 2014).

3.10.1 Conclusions

There is a general lack of knowledge on the vulnerability of national water resources and infrastructure to a changing climate. This multi-faceted problem must be able to account for high and low flows, an ageing water infrastructure and increased demand due to population increases.

3.11 Human Health and Well-being

Human health is intricately linked to climate and weather. Globally, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming. Throughout the 21st century, climate change is expected to lead to increases in ill health in many regions (IPCC, 2014a).

In Europe, the impacts of climate change on human health and well-being include flooding, extreme temperatures, air pollution, vector-borne disease and water- and food-borne diseases. These impacts are projected to change in the future; for example, where precipitation or extreme flooding is projected to increase in Europe, the risk of campylobacteriosis and cryptosporidiosis could increase (EEA, 2012).

Climate change is likely to alter risks to public health and well-being in Ireland. The key climate change-related exposures of importance to human health...

Table 3.9. Climate change impacts on tourism

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climatic variable</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tourism</td>
<td>Temperature</td>
<td>Lengthening of the tourist season (Forfás, 2010; Salmon, 2013)</td>
<td>Respite tourist opportunities [heat refugees from severe heat in other parts of Europe (e.g. the 2015 heatwaves)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversification of tourist activities, particularly water-based sport (Forfás, 2010)</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td>There may be greater demand for winter breaks abroad</td>
<td>Product diversification and innovation (Kelly and Stack, 2009)</td>
</tr>
<tr>
<td>Extreme weather</td>
<td></td>
<td>Prolonged heatwaves and droughts may put stress on water supply and tourism products (Forfás, 2010)</td>
<td>Consider the heritage officer model to address local climate change (Desmond and Shine, 2012)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Storm surges, floods and increased wave heights may damage tourist and heritage sites depending on location (Forfás, 2010)</td>
<td>ICZM can provide a co-ordinated way of coastal management (Kelly and Stack, 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Develop tourism infrastructure that is sustainable and climate proof (Kelly and Stack, 2009)</td>
</tr>
</tbody>
</table>

ICZM, Integrated Coastal Zone Management.
are likely to be increases in heatwave-related health impacts, decreases in cold-related health impacts, increases in flood-related health impacts, changes in patterns of food-borne disease, an increase in the burden of water-borne disease and an increase in the frequency of respiratory diseases due to changes in pollen and pollutant distributions (temporal and spatial) (Cullen, 2008; Pascal, 2013).

3.11.1 Conclusions

There is a general lack of information on a number of topics in this area including impacts on air quality, vector-borne pathogens, food-borne diseases, well-being and mental stress. This is a knowledge gap that needs to be addressed.
### Table 3.11. Climate change impacts on human health and well-being

<table>
<thead>
<tr>
<th>Sector</th>
<th>Changes in climatic variable</th>
<th>Impacts</th>
<th>Adaptation options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
<td>Temperature</td>
<td>A 1°C increase above 15°C in the mean temperature was associated with a 1.5% and 1.6% increase in total mortality in rural and urban areas, respectively (Pascal, 2011)</td>
<td>Co-ordinate the approach of the health sector in assessing and preparing for climate change impacts (Desmond and Shine, 2012) Public education on appropriate actions during warm weather There is little national research on this topic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rising temperatures in summer are likely to increase heat-related mortalities and morbidity (DECLG, 2012) Higher temperatures pose risks to health from changes in air quality (UK CCRA, 2016)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature: coldest night-time temperatures are projected to increase by 1.4°C in the south-west of Ireland and by up to 3.1°C in the north under the high-emission scenario</td>
<td>While cold-related mortalities may decrease on account of increasing winter temperatures (DECLG, 2012), there is a risk of loss of societal learning/knowledge as to the appropriate responses to cold weather</td>
<td>Public awareness and educational programmes</td>
</tr>
<tr>
<td></td>
<td>Temperature: warmer conditions (also combined with wetter conditions)</td>
<td>Food-borne diseases are likely to increase (DECLG, 2012) as a result of enhanced environmental conditions for bacterial growth and viral survival and inadequate food safety practices</td>
<td>Public education on diseases and ways to prevent and combat them should be given Reviewing and monitoring food safety standards (Elliot, 2014) There is very little national-level knowledge or research in this potentially emerging area</td>
</tr>
<tr>
<td></td>
<td>Phenology: pollen and other biogenic allergens</td>
<td>Budburst for birch has been observed to have advanced approximately 26 days over the period 1954–2000 (Fitter and Fitter, 2002). The projected budburst for birch is that it will take place earlier by 2100, which has implications for the birch allergy season (Caffarra et al., 2013b)</td>
<td>Public education on warning systems and education on ways to prevent and alleviate symptoms</td>
</tr>
<tr>
<td></td>
<td>Precipitation: the number of very wet days could increase annually by 24% under the high-emission scenario (Nolan, 2015)</td>
<td>Increase in rainfall and flooding may cause more water-borne disease from contamination of drinking water and inadequate cleaning practices (DECLG, 2012)</td>
<td>Practical advice and assistance should be provided to those affected, particularly to those most vulnerable, including those living in homeless shelters Evaluate the microbiological quality of water used for washing and irrigation (Elliot, 2014)</td>
</tr>
<tr>
<td></td>
<td>Extreme weather</td>
<td>Heatwave events and warmer, drier summers are likely to invite more people to sunbathe, probably leading to more cases of skin cancer (DECLG, 2012)</td>
<td>Education with respect to appropriate behaviour and prevention measures should be taken, particularly with respect to identified vulnerable groups and facilities</td>
</tr>
<tr>
<td></td>
<td>Extended dry periods are likely to increase by 12–40% during mid-century summer months, under both the medium- to low- and high-emission scenarios (Nolan, 2015)</td>
<td>Flooding may also give rise to increased cases of infectious diseases (DECLG, 2012)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy precipitation: the annual number of very wet days (&gt;30 mm) is projected to increase by ~24% under the high-emission scenario by mid-century (Nolan, 2015)</td>
<td>Some potential to affect mental health (Berry et al., 2010)</td>
<td>The public should be warned and advice about safety should be provided</td>
</tr>
</tbody>
</table>
4 Conclusions and Recommendations

4.1 Conclusions

This report provides a summary of the current state of knowledge of the impacts of current and future climate change in Ireland across a number of key environmental, economic and social sectors. It represents the distillation of a large body of work largely carried out through research activities since 2009.

Sufficient information exists at the national, sectoral and local levels to support the development of policy and begin the process of implementing adaptation actions. We have a clearer understanding of climate change impacts and their consequences across a number of key socio-economic sectors to enable an informed process of decision-making to be undertaken on climate change in Ireland. However, a number of important knowledge gaps remain in areas such as coastal and marine, critical infrastructure, emergency planning and human health, which need to be addressed in the near future to provide a fuller picture of climate change impacts for Ireland. A watching brief is required in other areas.

The evidence base continues to be developed through various national and European research programmes. These initiatives are filling key outstanding knowledge gaps in support of policy and implementation. Through collaborations with international research groups, capacity is developing nationally, which is allowing research of the highest calibre to emerge. However, the support for climate change research must be ongoing and sustainable.

Processes have been put in place to support decision-making, such as the development of local authority guidelines and the roll-out of a national climate information platform (Climate Ireland). In addition, capacity building is ongoing through the availability of adaptation training programmes, seminars and workshops to aid decision-making at a sectoral and local level.

Uncertainties remain in relation to both the rate and the extent of climate change impacts that Ireland will experience. These will eventually determine the extent of damage that will occur and/or the level of adaptation that is required to avoid the worst impacts. Rather than being a barrier to actions, these uncertainties should promote consideration of possible risks and the use of appropriate management tools that are designed to deal with risk. Deferred actions may be more costly in the longer term.

Appropriate steps to assess risks and identify response options are therefore required. We regard this “Tier 1” assessment as an essential first step in scoping priority climate sensitivities and hazards across a number of sectors. This then needs to be supplemented by detailed vulnerability and risk analysis at a sectoral and local level that take account of sensitivities, adaptive capacity and resilience to climate change. Based on these assessments, decision-makers should be equipped to understand their exposure to climate change and take the necessary adaptation actions.

4.2 Recommendations

Adaptation actions will be required to avoid the adverse impacts of climate change and take advantage of any opportunities that may arise. In order to facilitate this process, an adaptation framework is needed. This would aim to advance work within and across sectors at a number of levels, through advancing the knowledge base, building capacity, communication of scientific knowledge and the implementation of actions. This adaptation framework would enable synergies between groups, generate understanding and learning (especially in relation to cross-cutting issues) and avoid duplication of efforts. The framework would encompass:

- advancement of the knowledge base and capacity building;
- development of sectoral risk and vulnerability assessment;
- development and assessment of adaptation options (including costs and benefits);
- development and implementation of effective governance structures.
4.2.1 Advancing the knowledge base

Development of the scientific knowledge base on climate change is ongoing at a national and international level. Most recent advances are those supported by the EU Horizon 2020 research programme and research calls under the Joint Programming Initiative Climate. The activities supported under these instruments range from research in fundamental sciences and climate services to socio-economic analysis of impacts. Key elements of this process for Ireland include:

- development and sustained support of observation systems of essential climate variables and analysis of trends and changes;
- improvement of climate projections and near-time climate forecasting, e.g. periods from years to decades as well as mid- and end of century information;
- support for the development of analysis of systems’ fundamental processes that drive the rate and extent of climate change, e.g. oceans systems and precipitation;
- greater understanding of slow-onset climate change and changes in weather extremes (e.g. precipitation and storms).

Future requirements

Improved structures and processes are required to build capacity and advance information exchanges, especially with practitioners and sectoral experts. This would improve targeting of analyses and identification of gaps in knowledge and the co-development of climate services between the research community, practitioners and end users. In synthesising the material for this report, a number of knowledge gaps are now evident, which need to be addressed for a clearer understanding of the full impacts of climate change for Ireland.

The aims would include:

- filling the outstanding knowledge gaps in relation to climate impacts to the marine and coastal environment, agriculture and food security, human health, critical infrastructure and emergency planning;
- analysis of current and emerging vulnerabilities and the identification of key areas for adaptation actions;
- development of vulnerability and process indicators to track progress on implementation of adaptation actions;
- improved understanding of resilience and adaptive capacity;
- sustainability of the shared information platform (Climate Ireland) for the research community, practitioners, policymakers and general public;
- building capacity among the planning and policy-making community, through provision of outreach material, training and guidance tools.

4.2.2 Development of sectoral risk and vulnerability assessment

The development of appropriate climate change risk and vulnerability assessments and techniques is required to underpin adaptation decision-making. In developing a common approach across levels of governance, it should be possible to progress common objectives, avoid maladaptation, recognise and deal with cross-sectoral and cumulative issues and enable monitoring and reporting to national and international processes.

Future requirements

- A national-level climate change risk assessment is required to set out priority climate risks for Ireland and to provide an analysis of the implications of cross-sectoral and cumulative risks.
- Information is needed on external impacts of climate change on vulnerable domestic markets and supply chain management and on the impacts of climate-related human migration.
- Identification of possible opportunities for Ireland is needed (e.g. agriculture, tourism, industry).
- Any new approaches to climate risk management should ideally be placed within an adaptive risk management framework.

4.2.3 Development and assessment of adaptation options (including costs and benefits)

The development and assessment of adaptation options required to manage climate risk must include a range of considerations that include grey, green and soft approaches. The assessment of adaptation options should be based on a multi-criteria analysis that would include consideration of efficacy, costings,
win–win situations, etc. Although a body of research is emerging on costing climate change impacts and adaptation, there are still substantial gaps in our knowledge of what climate change is and how much it will cost the Irish state (public and private) over the coming decades.

Future requirements

● A full range of adaptation options must be included in decision-making, with particular attention paid to green approaches (e.g. green infrastructure).
● The costs of current and future climate change impacts and adaptation must be established for a range of key sectors. This must be based on a consistent framework applicable across all sectors and relevant to different types of impact to ensure comparability and consistency in the use of climatic and socio-economic projections.
● The role of the insurance industry must be established, particularly in response to extreme weather events.
● Cross-sectoral comparative metrics and indicators should be developed to enable high-level assessment of the scale and urgency of adaptation requirements.
● Tools should be created for the assessment of the effects on other sectors, up- or downstream in supply chains, macroeconomic (general equilibrium) effects and changes in behaviour as a result of changes in risk exposure (moral hazard risk) of adaptation measures.

● Information must be made available on sources of funding for adaptation actions.

4.2.4 Development and implementation of effective governance structures

In the EU Member States, governance bodies are common ways to co-ordinate adaptation actions across sectors and levels of governance (EEA, 2014). Nationally, the multilevel governance of adaptation is being co-ordinated by the Department of Communications, Climate Action and Environment (DCCAE) through a National Adaptation Steering Committee and other supports. The aim is to progress sectoral and regional adaptation planning, and encourage sharing of knowledge and learning, while avoiding maladaptation, conflicts of interests, and poorly integrated planning and decision-making with expensive, unjust and far-reaching consequences.

Future requirements

● Further and deeper horizontal and vertical co-ordination of adaptation efforts as the implementation of adaptation progresses.
● The participation of multiple stakeholders, including the business and local communities, must be explored with a view to ratcheting up adaptation action at all levels of decision-making.

The authors look forward to engagement with other groups in further improving, elucidating and developing these recommendations.
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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>GCM</td>
<td>Global climate model</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>ICT</td>
<td>Information and communication technology</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>IPCC AR5</td>
<td>IPCC Fifth Assessment Report which is subdivided into 3 working group reports (WG1: Physical Scientific Basis, WG2: Impacts, Adaptation and Vulnerability and WG3: Mitigation of Climate Change)</td>
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<tr>
<td>MOC</td>
<td>Meridional overturning circulation</td>
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<tr>
<td>NUIG</td>
<td>National University of Ireland, Galway</td>
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<td>NUIM</td>
<td>National University of Ireland, Maynooth</td>
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<td>OPW</td>
<td>Office of Public Works</td>
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<td>RCM</td>
<td>Regional climate model</td>
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<td>RCP</td>
<td>Representative concentration pathway</td>
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<td>SLR</td>
<td>Sea level rise</td>
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<td>SRES</td>
<td>Special Report on Emissions Scenarios</td>
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<td>TCD</td>
<td>Trinity College Dublin</td>
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<td>THC</td>
<td>Thermohaline circulation</td>
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<td>UCC</td>
<td>University College Cork</td>
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<td>UCD</td>
<td>University College Dublin</td>
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Appendix 1  Experts Consulted in the Development of This Document

Attendees at Review Meeting, Dublin, 4 September 2015

● Dr Barry O’Dwyer, University College Cork (UCC)
● Dr Conor Sweeney, University College Dublin (UCD)
● Dr Craig Bullock, UCD
● Dr Eugene Farrell, National University of Ireland, Galway (NUIG)
● Dr Florence Renou-Wilson, UCD
● Dr John Coll, National University of Ireland, Maynooth (NUIM)
● Dr Matthew Jebb, Botanic Gardens
● Dr Michael Bruen, UCD
● Dr Michael Jones, Trinity College Dublin (TCD)
● Dr Paul Nolan, UCD
● Professor Peter Thorne, NUIM
● Dr Ray McGrath, Met Éireann (retired)
● Professor Robert Devoy, UCC
● Dr Rowan Fealy, NUIM
● Dr Seamus Walsh, Met Éireann
● Dr Thomas McDermott, UCC

Additional Chapter Support

● Dr Conor Murphy, NUIM
● Dr Eleanor O’Rourke, Marine Institute
● Dr Caroline Cusack, Marine Institute
● Dr Nichola Hughes, EPA
● Dr Gary Lanigan, Teagasc

Editorial Support

● Dr Margaret Desmond, EPA/UCC
● Mr Phillip O’Brien, EPA/NUIG
● Dr Frank McGovern, EPA
● Mr Seosamh O’Laoi, Department of Communications, Climate Action and Environment (DCCAE)
● Ms Maria Jacob, EPA (intern)
Is féidir obair na Gníomhaireachta a roint ina trí phriomhréimse:

Rialú: Déanaimid córais éifeachta rialaithe agus combhioniú comhaibhsaíocht a chur i bhfeidhm chun torthaí maithte comhaibhsaíocht a sholáthar agus chun diriú orthu síocháin leis na cónaí ná cíos sin.

Eolas: Soláthraisimid sonraí, faisnéis agus measmiú comhaibhsaíocht atá ar ardaítheacht, spriochdírithe agus tráthúil chun bonn eolas a chur faoi cheintreachtaí ar gach bhailéal.

Tacaíocht: Bimid ag saothrú i gcomhar le grúpaí eile chun tacú le comhaibhsaíocht atá glan, tairgiúil agus cosanta go maith, agus le hiompá a chur i gceintreachtaí ar gach bhailéal.

Ár bhFreagrachtáí

Ceadúnú
Déanaimid na gniomhaíochtaí seo a leanas a rialú íosach nach ndéanann siad dochar do sláinte an phobail ná don chomhaibhsaíocht:
- saoráidí dramhaíola (m.sh. látreaín lónta talún, loisfeoirí, stáisiúin áisteach dramhaíola);
- gniomhaíochtaí tionsclaíochta ar scála móir (m.sh. déantaíochta cógachtaíochta, déantaíochta stíneachta, stáisiúin chumhlaícha);
- an diantalmhaíocht (m.sh. muca, éanlaith);
- áis éifeachta agus saoileadh rialaithe Orgánach Géinmhodhnaithe (OGM);
- foinsí radáichte iompaíochta (m.sh. trealamh x-gha agus radadairíte, foinsí tionsclaíochta);
- áiseanna móra stóraíochta peitril.
- scaradh dramhuisce; gniomhaíochtaí dumptaí ar farrage.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iníúchtaí agus cigreachtaí a dhéanann gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseachta dhéanamh ar fhreagrachtáí comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce.
- Maoirseacht a dhéanamh ar fhreagrachtáí cosanta comhshaoil na n-údarás áitiúil.
- Úsáid staidéara agus scoileadh rialaithe Orgánach Géinmhodhnaithe (OGM).
- foinsí radáichte iompaíochta iompaíochta (m.sh. trealamh x-gha agus radadairíte, foinsí tionsclaíochta);
- áiseanna móra stóraíochta peitril;
- scaradh dramhuisce;
- gniomhaíochtaí dumptaí ar farrage.

Monatóireacht, Anaílis agus Tuairiscíú ar an gComhaibhsaíocht
- Monatóireacht a dhéanamh ar chéilíocht an aéra agus Treoir an AE maidir le hAer Glen don Eoraip (CAFÉ) a chur chun feidhme;
- Tuairiscíú neamhspleách le cabhrú le cinnteoireacht a dhéanamh iompair náisiúnta agus na n-údarás áitiúil iompair na hÉireann (m.sh. tuairiscíú tréimhsí ar staíd Chomhaibhsaíocht na hÉireann agus Tuarsaíochta le Tháiscairí).
Background
The background to this report lies with its predecessor, the first State of Knowledge on Climate Change Impacts for Ireland (Desmond et al, 2009). That report filled a large knowledge gap by providing an authoritative synthesis of the available information on climate change impacts and adaptation. Since then we’ve had the publication of the IPCC 5th Assessment Reports (2013) and numerous national level reports on all aspects of climate change science, impacts and adaptation. In addition, we’ve begun to see the implementation of adaptation at sectoral and local levels. This new reality has created an urgent need for an updated synthesis report that accurately reflects the scientific advances made nationally in knowledge and information generation. The report represents the distillation of a large body of work, largely carried out through research activities since 2009.

Identifying Pressures
Changes in Ireland’s climate are in-line with and similar to relevant global trends. Climate change will have diverse and wide ranging impacts on our environment, society, economic sectors and natural resources. The challenge is to provide decision makers at all levels and the general public with high quality information to make informed decisions on policy development and investments that will be resilient to the impacts of climate change.

This report provides: 1) a summary of observed and projected changes in the Irish climate across a number of key parameters; 2) a synthesis of knowledge of ongoing and anticipated climate change impacts across a number of environmental and economic sectors and: 3) recommendations for further steps required to support policy development and aid the implementation of adaptation nationally.

Informing Policy
The information summarised in this report will assist in the development of coherent and rational decision making at the national, sectoral and local level, namely by:

• Providing a high level synthesis of existing climate change information across a number of key parameters such as temperature, precipitation, sea level rise and extreme weather events;

• Providing a syntheses of ongoing and anticipated climate change impacts across a large number of environmental and economic sectors;

• Providing a summary of possible adaptation options;

• Identifying knowledge gaps and suggestions on how they might be filled.

Developing solutions
This report provides Irish decision makers with an authoritative and timely summary of the state of knowledge on climate change impacts. It will assist the development of adaptation strategies and plans at national, sectoral and local level decision making. It is part of the solution to the societal challenge of transitioning to a climate resilient Ireland.