north western international river basin district
North South Shared Aquatic Resource (NS SHARE)

neagh bann international river basin district
North South Shared Aquatic Resource (NS SHARE)

north eastern river basin district
North South Shared Aquatic Resource (NS SHARE)

# North South Shared Aquatic Resource (NS Share)

## Further Characterisation Activities
## Overview assessment of long term issues –
## Climate change literature review
## (Work Package 6, Item 1, sub-package 1)

Environment & Heritage Service
www.ehsni.gov.uk

An Agency within the Department of the
Environment
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AN ROINN COMHSHAOIL, OIDHREACHTA AGUS RIALTAIS ÁITIÚIL
DEPARTMENT OF THE ENVIRONMENT, HERITAGE AND LOCAL GOVERNMENT

INTERREG IIIA

Project part financed by the European Union

# North South Shared Aquatic Resource (NS Share)

### Water Framework Directive

A Directive establishing a new framework for Community action in the field of water policy (2000/60/EC) came into force in December 2000. This Water Framework Directive (WFD) rationalises and updates existing legislation and provides for water management on the basis of River Basin Districts (RBDs). The WFD was transposed into national law in Northern Ireland by the Water Environment (Water Framework Directive) Regulations (Northern Ireland) 2003 and in the Republic of Ireland by the European Communities (Water Policy) Regulations 2003. The primary objective of the WFD is to maintain the "high status" of waters where it exists, prevent deterioration in existing status of waters and to achieve at least ***"good status"*** in relation to all waters by 2015.

### NS Share Study Area

NS Share is a cross border project and incorporates three River Basin Districts as set out in the joint North/South Consultation paper *Managing our Shared Waters*:

1. North Western International River Basin District (NWIRBD);
2. Neagh Bann International river Basin District (NBIRBD);
3. North Eastern River Basin District (NERBD).

The NW and NB are International River Basin Districts as they share their waters between Northern Ireland (NI) and Republic of Ireland (ROI). The NERBD is contained wholly within NI.

### NS Share Project

The overall objective of the project is to strengthen inter-regional capacity for environmental monitoring and management at the river basin district level, to improve public awareness and participation in water management issues, and to protect and enhance the aquatic environment and dependent ecosystems.
The NS Share project aims to facilitate delivery of the objectives of the WFD within the project area between August 2004 and March 2008.

The NS Share project is funded by the EU INTERREG IIIA Programme for Ireland / Northern Ireland. The Department of the Environment (NI) and the Department of the Environment, Heritage and Local Government (ROI) are implementing agents for the project. Donegal County Council is the project promoter. Technical support is proivded by the Environment and Heritage Service an agency within the Department of the Environment (NI), and the Environmental Protection Agency (ROI). RPS Consulting Engineers in association with Jennings O'Donovan are the principal consultants.

Assistance was also provided by the Marine Institute, Central Fisheries Board, Geological survey Ireland, Geological survey Northern Ireland, Loughs Agency, North West Regional Fisheries Board, and Cavan, Leitrim, Longford, Louth, Meath, Monaghan, and Sligo County Councils.

Project publications are available at [www.nsshare.com/publications](www.nsshare.com/publications)

***PREFACE***

*The work presented in this paper was carried out as part of the NS SHARE project, which is funded by the European Union INTERREG IIIA programme for Ireland/Northern Ireland. The implementing agents for the NS SHARE project are the Department of Environment (DOE), Northern Ireland, and the Department of Environment Heritage and Local Government (DEHLG), Republic of Ireland. Donegal County Council (DCC) is the project promoter.*

*All data, drawings, reports, documents, databases, software and coding, website and digital media and publicity material produced as part of this project shall be the property of the DOE/DEHLG who will use, reproduce and distribute same as they see fit.*

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## Abbreviations

| | |
|---|---|
| AFBI | Agri-Food and Biosciences Institute |
| CIS | Common Implementation Strategy |
| C4I | Community Climate Change Consortium for Ireland |
| DARD | Department of Agriculture and Rural Development |
| DCAL | Department for Culture, Arts and Leisure |
| DoE (NI) | Department of Environment, Northern Ireland |
| DEFRA | Department for Environment Food and Rural Affairs |
| DEHLG | Department of Environment Heritage and Local Government |
| EEA | European Environment Agency |
| EHS | Environment and Heritage Service |
| EPA | Environmental Protection Agency |
| FCB | Fisheries Conservancy Board |
| GtC | Giga tonnes of carbon |
| $GtCO_2$ | Giga tonnes of carbon dioxide |
| IPCC | Intergovernmental Panel on Climate Change |
| ppb | parts per billion |
| ppm | parts per million |
| TAR | Third Assessment Report. 'Climate Change 2001' (IPCC) |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WFD | Water Framework Directive |

# EXECUTIVE SUMMARY

This literature review aims to consider climate change in the context of the Water Framework Directive in Ireland and Northern Ireland, whilst also taking the wider UK, European and International perspective into account. It therefore draws on recent, relevant, literature and research on climate change in Northern Ireland, and the Republic of Ireland, particularly SNIFFER (2002 & 2007), Hulme *et al*. (UKCIP02, 2002) and Sweeney *et al*. (2002 & 2003). In addition, recent literature and research from Europe and further International studies are also reviewed e.g. and IPCC (2007). The review examines how climate change might affect the implementation and achievement of the objectives of the Water Framework Directive up to 2015, and how the Agencies can incorporate this in to their planning.

Green house gases in the atmosphere (including carbon dioxide, methane, nitrous oxides and a number of gases that arise from industrial processes) are rising, as a result of human activity (Stern Review, 2006). The sources of these gases include; power (24%), land use (18%), agriculture (14%), industry (14%), transport (14%), buildings (8%), other energy related emissions (5%) and waste (3%) (Stern Review, 2006). The current level of greenhouse gases in the atmosphere is equivalent to approximately 430 ppm $CO_2$, compared with 280 ppm before the industrial revolution (Stern Review, 2006). These concentrations have already led to more than half a degree Celcius warming of the world, with a further half degree warming over the next few decades expected, because of the inertia in the climate system. The Stern Review calculated that the dangers of unabated climate change would be equivalent to at least 5% of global GDP each year, while in contrast, the costs of action to reduce greenhouse gas emissions to avoid the worst impacts of climate change can be limited to around 1% of global GDP each year. Further evidence of the costs which could increase with furture impacts of climate change includes the estimated economic impacts of drought events in the last 30 years of €85 billion in the EU (EEA, 2007).

The latest assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) projects that global average temperatures in 2100 will be between 1.8-4.0$^{o}$C higher than the 1980-2000 average (best estimate, likely range 1.1-6.4$^{o}$C). Sea levels are projected to rise 0.18-0.59m by 2100 (based on observed rates of ice flow from Greenland and Antarctica). More frequent and intense extreme weather events (including droughts and flooding) are also expected.

The mitigation of climate change is essential at an international and regional level, and the UK and Irish governments have many policies in this regard (DEHLG 2000 & 2006; DCMNR

2007; SNIFFER 2002 & 2007; DEFRA 2006). However, even if emissions were stabilised at today's rate, increases in temperature and associated impacts will continue for many decades to come (Stern Review, 2006). Therefore, adaptation is essential. Adaptation could be explicitly incorporated into the implementation of the WFD in various ways, for example:

- The European Environment Agency suggests impact assessments for each river basin district and inclusion of associated catchment wide actions in the programme of measures (EEA, 2007).

- SNIFFER (2007) focus their efforts on adaptation and also on the need to introduce measures (plans, policies and procedures).
- EEA (2007) point out that while temperature increases by the 2080s are predicted to be 2.5-4.5$^{o}$C in winter, the warming by the 2020s is predicted to be 0.5-1.6$^{o}$C (depending on the model), with natural temperature variability likely to dominate until the 2030s. Therefore, the task now is to include adaptation measures to cover likely impacts caused by such a temperature increase and changes in precipitation in the timeframe of the delivery of the WFD by 2015.

# 1.0 CLIMATE CHANGE: BACKGROUND AND TRENDS

A recent report (EEA, 2006) which compiled and analysed past and projected greenhouse gas emissions from EU Member States and other European Environment Agency (EEA) member countries states the following:

- Total EU 23 greenhouse gas emissions rose slightly in 2004 by 0.3% compared with 2003 and were 5% below 1990 level;
- With existing policies and measures, EU 23 greenhouse gas emissions are projected to be 2.1% below 1990 level by 2010;
- With additional policies and measures greenhouse gas emissions are projected to be 5.6% below 1990 level by 2010;
- Greenhouse gas emissions in the pre-2004 EU Member States (EU 15) in 2004 were 0.9% below 1990 levels. This means the EU 15 was little more than a tenth of the way towards achieving the 8% emissions reduction from base year level (i.e. 1990) required by 2008-2012 under the Kyoto Protocol;
- Latest projections for 2010 show that the combined effect of existing and additional domestic policies and measures, Kyoto mechanisms and 'carbon sinks' (i.e. $CO_2$ removal by land use change and forestry activities) would bring emissions down to 8.0% below the EU 15 base year level.

The report shows that Sweden and the UK are the only two countries which project that existing domestic policies and measures will be sufficient to meet their targets. Ireland on the other hand has projected that they will miss their target with currently planned additional domestic policies and measures and/or use of Kyoto mechanisms and/or carbon sink activities. Ten countries, including Ireland, have allocated financial resources for using the Kyoto mechanisms with a total amount of about €2830 million for the whole 5-year Kyoto Protocol commitment period (2008-2012).

Ireland's target is to limit emissions to 13% above 1990 levels over the five year period from 2008 to 2012, within the overall EU target to reduce emissions to 8% in the same timeframe (www.environ.ie, Progress report on the Implementation of the National Climate Change Strategy). The National Climate Change Strategy (DEHLG), published in 2007 (for 2007-2012), sets out how Ireland will meet its Kyoto target, with measures identified which are underway and others to be put in place.

However, a press release (http://www.epa.ie/news/pr/2007/feb/name,13108,en.html), published on the 15th February 2007 which provided the Environmental Protection Agency's (EPA) annual estimates on Greenhouse Gas emissions in Ireland showed:

- Tonnage of Greenhouse Gas emissions were 1.9% higher than in 2004;
- The main increase was from transport emissions which increased by 6.9% (an increase of almost 870,000 tonnes);
- Substantial increase from energy generation of 2.4% (increase of 380,000 tonnes) attributable mainly to increased use of peat in power stations;
- Emissions from agriculture continued a downwards trend and are 1.8% lower than in 2004.

Overall, Ireland's emissions rose by 1.9% in 2005, when compared with 2004, which means than Ireland's emissions in 2005 were 25.4% above the 1990 baseline level. Agriculture remains the largest contributor to overall emissions at almost 28% (http://www.epa.ie/news/pr/2007/feb/name,13108,en.html). This means that the Kyoto flexible mechanisms will be important in the 2008-2012 period i.e. the purchase of carbon credits, for Ireland to meet its commitments. The EU Emissions Trading Scheme is one of the policies being introduced across Europe to tackle emissions of carbon dioxide and other greenhouse gases and combat the serious threat of climate change. The scheme commenced on 1 January 2005. The first phase ran from 2005-2007 and the second phase will run from 2008-2012 to coincide with the first Kyoto Commitment Period. Further five-year periods are expected subsequently. The scheme will work on a "Cap and Trade" basis. EU Member State governments are required to set an emission cap for all installations covered by the Scheme.

The United Kingdom's target under the Kyoto protocol is to reduce emissions to 12.5% below 1990 levels, and as stated above, it is one of only two countries which projects that existing domestic policies and measures will be sufficient to meet their targets. In fact, the UK projects that they will go significantly beyond their Kyoto commitment and reduce their greenhouse gas emissions by 23-25% by 2010 (HM Government, 2006). DEFRA launched a Climate Change Bill which was published in draft form on the 13th of March 2007 (The Climate Change Bill was introduced in Parliament on 14th November 2007 and completed its passage through the House of Lords on 31st March 2008. It will shortly go to the House of Commons for consideration. The aim is to receive Royal Assent by summer 2008.). This will put into law a target for the UK to reduce carbon dioxide levels to 60% of 1990 levels by 2050 with an interim target of 26%-32% reduction by 2020.

Total carbon dioxide emissions in Northern Ireland were around 2.9% of the UK total in 2004 and have increased by 3.6% since 1990 (Baggott *et al*., 2006). The largest sources and sinks were power generation (29.5%); manufacturing industry and construction; other (14.6%); road transport (29.7%); residential (20.6%); land converted to cropland (7%); land converted to grassland (sink, -8.4%); and land converted to settlements (3.5%) (Baggott *et al*., 2006). Road transport is the largest cause of emissions, and has risen 49.8% from 1990 to 2004 compared with a 9.1% rise in the UK (Baggott *et al*., 2006). Reductions in greenhouse gases are not as marked in Northern Ireland as in the UK as a whole for a number of reasons. Partly this reflects the different sector mix, the smaller industrial base, a larger agricultural sector, and historically low availability of natural gas (HM Government, 2006). A report on the 'Implications of Climate Change for Northern Ireland: Informing Strategy and Development', published in 2002, identified key impacts which include potentially adverse effects on public health, the likelihood of more accidents and damage from extreme weather events and threats to vulnerable eco-systems (HM Government, 2006).

In 'Green House Data 2006' submitted under the 'United Nations Framework Convention on Climate Change' (UNFCCC, 2006), changes in Green House Gas (GHG) emissions from individual Annex I parties (1990-2004) shows the UK at -14.3% in comparison with 1990 levels. The overall conclusions of the 2006 data are that there is a need to intensify efforts in industrialised countries to reduce greenhouse gas emissions. Transport remains the main sector where emission reductions are needed. During the 1990-2004 period, an increase of 23.9% in emissions was observed, while other areas such as agriculture, industrial processes and the energy sector all showed a decrease (-20%, -13.1% and -0.4% respectively) (UNFCCC, 2006).

**Intergovernmental Panel on Climate Change (IPCC)**

In February 2007, Working Group I of the IPCC adopted the Summary for Policymakers of the first volume of "*Climate Change 2007*", also known as the Fourth Assessment Report (AR4) - "*Climate Change 2007: The Physical Science Basis*". The document assesses the current scientific knowledge of the natural and human drivers of climate change, observed changes in climate, the ability of science to attribute changes to different causes, and projections for future climate change.

The summary states that '*Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and* *land-use change, while those of methane and nitrous oxide are primarily due to agriculture* (IPCC, 2007)'. The global atmospheric concentrations of carbon dioxide have increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (IPCC, 2007). In addition, although there is year-to-year variability in growth rates, the underlying annual carbon dioxide concentration growth-rate was larger during the last 10 years, than it has been since the beginning of continuous direct atmospheric measurements. The increased concentration of atmospheric carbon dioxide is attributed primarily to **fossil fuel use**, with **land use change** providing another significant but smaller contribution (IPCC, 2007). Carbon dioxide emissions associated with fossil fuels have increased to **7.2 [6.9 to 7.5] GtC** (26.4 [25.3 to 27.5] $GTCO_2$) per year in 2000-2005, and emissions associated with land-use change are estimated to be **1.6 [0.5 to 2.7] GtC** (5.9 [1.8 to 9.9] $GtCO_2$) per year over the 1990s (although these estimates have high uncertainty).

Global atmospheric methane levels have increased (1774 ppb in 2005, IPCC 2007). It is *very likely*[1] that the observed increase in methane concentration is due to anthropogenic activities, predominantly **agriculture** and **fossil fuel use**, but relative contributions from different source types are not well determined (IPCC 2007). Global atmospheric nitrous oxide concentration has also increased (319 ppb in 2006, IPCC 2007), with more than a third of emissions attributed to anthropogenic sources and are primarily due to **agriculture**.

Since the Third Assessment Report (referred to as TAR), progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets over the past decade. However, data coverage remains limited in some regions.

The direct observations of recent climate change detailed in this summary are:

- Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The updated 100-year linear trend (1906-2005) of 0.74 [0.57 to 0.92] $^oC$ is therefore larger than the corresponding trend for 1901-2000 given in the TAR of 0.6 [0.4 to 0.8] $^oC$. The

[1] In the Summary report for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

linear warming trend over the last 50 years (0.13 [0.10 to 0.16] $^{o}$C per decade) is nearly twice that for the last 100 years. The total temperature increase from 1850-1899 to 2001-2005 is 0.76 [0.57 to 0.95] $^{o}$C;

- New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR;
- Average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold;
- Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise;
- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic ice sheets);
- New data since the TAR now show that losses from the ice sheets of Greenland and Antarctica have *very likely*[1] contributed to sea level rise over 1993 to 2003. Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamic ice loss is sufficient to explain most of the Antarctic net mass loss and approximately half of the Greenland net mass loss. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall;
- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is as yet unclear. There is high confidence that the rate of observed sea level rise increased from the 19th to the 20th century. The total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m;
- For 1993-2003, the sum of the climate contributions is consistent, within uncertainties, with the total sea level rise that is directly observed. These estimates are based on improved satellite and in-situ data now available. For the

period of 1961 to 2003, the sum of climate contributions is estimated to be smaller than the observed sea level rise. The TAR reported a similar discrepancy for 1910 to 1990.

(p.5-7, IPCC, 2007)

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (see p. 8 of IPCC 2007). Some of the main observations include:

- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years;
- Significant increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia;
- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics;
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour;
- Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent;
- There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increase of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater.

(p.8, IPCC, 2007)

Table SPM-2 from IPCC (2207) is reproduced below and illustrates recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20$^{th}$ century trend (also see footnote 1 for interpretation).

**Table 1** Table SPM2 from IPCC (2007)

**Table SPM-2.** Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

| Phenomenon[a] and direction of trend | Likelihood that trend occurred in late 20th century (typically post 1960) | Likelihood of a human contribution to observed trend [b] | Likelihood of future trends based on projections for 21st century using SRES scenarios |
|---|---|---|---|
| Warmer and fewer cold days and nights over most land areas | *Very likely* [c] | *Likely* [d] | *Virtually certain* [d] |
| Warmer and more frequent hot days and nights over most land areas | *Very likely* [e] | *Likely (nights)* [d] | *Virtually certain* [d] |
| Warm spells / heat waves. Frequency increases over most land areas | *Likely* | *More likely than not* [f] | *Very likely* |
| Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas | *Likely* | *More likely than not* [f] | *Very likely* |
| Area affected by droughts increases | *Likely* in many regions since 1970s | *More likely than not* | *Likely* |
| Intense tropical cyclone activity increases | *Likely* in some regions since 1970 | *More likely than not* [f] | *Likely* |
| Increased incidence of extreme high sea level (excludes tsunamis) [g] | *Likely* | *More likely than not* [f, h] | *Likely* [i] |

Table notes:

[a] See Table 3.7 for further details regarding definitions.

[b] See Table TS-4, Box TS.3.4 and Table 9.4.

[c] Decreased frequency of cold days and nights (coldest 10%).

[d] Warming of the most extreme days and nights each year.

[e] Increased frequency of hot days and nights (hottest 10%).

[f] Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.

[g] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[h] Changes in observed extreme high sea level closely follow the changes in average sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in average sea level. {9.5.2}

[i] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Further evidence from paleoclimatic studies support the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years (IPCC, 2007). Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely*[1] higher than during any other 50-year period in the last 500 years and *likely*[1] the highest in at least the past 1300 years.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely*[1] due to the observed increase in anthropogenic greenhouse gas concentrations.

This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (IPCC, 2007).

Projections of future changes in climate are also dealt with in the summary. It is stated that for the next two decades a warming of about 0.2$^o$C per decade is projected for a range of emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1$^o$C per decade would be expected. Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21$^{st}$ century that would *very likely*[1] be larger than those observed during the 20$^{th}$ century (IPCC, 2007). Further projections included are:

- Snow cover is projected to contract;
- Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES (Special Report on Emissions Scenarios) (IPCC, 2000);
- It is *very likely*[1] that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent;
- It is *likely*[1] that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs (sea surface temperatures). There is less confidence in projections of a global decrease in numbers of tropical cyclones;
- Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century;
- Increases in the amount of precipitation are *very likely*[1] in high-latitudes, which decreases are *likely*[1] in most subtropical land regions;
- It is *very likely*[1] that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21$^{st}$ century. Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases in greenhouse gases. It is *very unlikely*[1] that the MOC will undergo a large abrupt transition during the 21$^{st}$ century.

Based on current understanding of climate carbon cycle feedback, model studies suggest that to stabilise at **450 ppm carbon dioxide**, could require that cumulative emissions over the 21st century be reduced from an average of approximately 670 [630 to 710] GtC (2460 [2310 to 2600] $GtCO_2$) to approximately 490 [375 to 600] GtC (1800 [1370 to 2200] $GtCO_2$). Similarly, to stabilise at 1000 ppm this feedback could require that cumulative emissions be reduced from a model average of approximately 1415 [1340 to 1490] GtC (5190 [4910 to 5460] $GtCO_2$) to approximately 1100 [980 to 1250] GtC (4030 [3590 to 4580] $GtCO_2$). (IPCC, 2007)

**The Stern Review on the Economics of Climate Change**

The Stern Review Report on the Economics of Climate Change (www.sternreview.org.uk)**,** published in October 2006, is the most comprehensive review on the economics of climate change to date. The review was carried out by Sir Nicholas Stern, Head of the Government Economic Service (UK). The Report states that there is still time to avoid the worst impacts of climate change, if we act now and act internationally. Governments, businesses and individuals all need to work together to respond to the challenge. Strong, deliberate policy choices by governments are essential to motivate change. Delaying action, even by a decade or two, would take us into dangerous territory.

The first half of the Review focuses on the impacts and risks arising from uncontrolled climate change, and on the costs and opportunities associated with action to tackle it. The Review emphasises that economic models over timescales of centuries do not offer precise forecasts – but they are an important way to illustrate the scale of effects we might see.

The Review finds that all countries will be affected by climate change, but it is the poorest countries that will suffer earliest and most. Unabated climate change risks raising average temperatures by over 5°C from pre-industrial levels. Such changes would transform the physical geography of our planet, as well as the human geography – how and where we live our lives.

Adding up the costs of a narrow range of the effects, based on the assessment of the science carried out by the IPCC in 2001 (the TAR), **the Review calculates that the dangers of unabated climate change would be equivalent to at least 5% of GDP each year**.

The Review goes on to consider more recent scientific evidence (for example, the risk that greenhouse gases will be released naturally as the permafrost melts), the economic effects on human life and the environment, and approaches to modelling that ensure the impacts that affect poor people are weighted appropriately. Taking these together, **the Review estimates that the dangers could be equivalent to 20% of GDP or more**.

In contrast, the costs of action to reduce greenhouse gas emissions to avoid the worst impacts of climate change can be limited to around **1% of global GDP** each year. People would pay a little more for carbon-intensive goods, but economies could continue to grow strongly.

If no action to control emissions is taken, each tonne of $CO_2$ that is emitted now is causing damage worth at least $85 – but these costs are not included when investors and consumers make decisions about how to spend their money. Emerging schemes that allow people to trade reductions in $CO_2$ have demonstrated that there are many opportunities to cut emissions for less than $25 a tonne. According to one measure, the benefits over time of actions to shift the world onto a low-carbon path could be in the order of $2.5 trillion each year. The shift to a low-carbon economy will also bring huge opportunities. Markets for low-carbon technologies will be worth at least $500bn, and perhaps much more, by 2050 if the world acts on the scale required.
The Review looks at what this analysis means for the level of ambition of global action. It concludes that the levels of greenhouse gases in the atmosphere should be limited to somewhere within the range **450 - 550ppm CO2e** ($CO_2$ equivalent). Anything higher would substantially increase risks of very harmful impacts but would only reduce the expected costs of mitigation by comparatively little. Anything lower would impose very high adjustment costs in the near term and might not even be feasible, not least because of past delays in taking strong action.

The second half of the Review examines the national and international policy challenges of moving to a low-carbon global economy. Three elements of policy are suggested as being required for an effective response:

- The first is *carbon pricing*, through taxation, emissions trading or regulation, so that people are faced with the full social costs of their actions. The aim should be to build a common global carbon price across countries and sectors.
- The second is *technology policy*, to drive the development and deployment at scale of a range of low-carbon and high-efficiency products.
- The third action to *remove barriers* to energy efficiency, and to inform, educate and persuade individuals about what they can do to respond to climate change. Fostering a shared understanding of the nature of climate change, and its consequences, is critical in shaping behaviour, as well as in underpinning both national and international action.

**Emissions trading:**

- Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries.
- Strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths.

**Technology co-operation**:

- Informal co-ordination as well as formal agreements can boost the effectiveness of investments in innovation around the world.
- Globally, support for energy research and development should at least double, and support for the deployment of low-carbon technologies should increase up to five-fold.
- International co-operation on product standards is a powerful way to boost energy efficiency.

**Action to reduce deforestation:**

- The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large-scale international pilot programmes to explore the best ways to do this should get underway very quickly.

**Adaptation:**

- The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honour their pledges to increase support through overseas development assistance.
- International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought and flood.

**United Nations Framework Convention on Climate Change and the Kyoto Protocol**

Over a decade ago, most countries joined an international treaty - the United Nations Framework Convention on Climate Change (UNFCCC) - to begin to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. A number of nations have approved an addition to the treaty: **the Kyoto Protocol**, which has more powerful (and legally binding) measures. The **Kyoto Protocol** (which came in to force in February 2005) is an amendment to the international treaty on climate change, assigning mandatory targets for the reduction of greenhouse gas emissions to signatory nations. 168 countries and one regional economic integration organization (the EEC) have ratified the Protocol to date (Source: www.unfccc.int/kyoto_protocol/items/2830.php, accessed March 2007). Of these, 35 countries and the EEC are required to reduce greenhouse gas emissions below levels specified for each of them in the treaty. The individual targets for Annex I Parties are listed in the Kyoto Protocol's Annex B. These add up to a total cut in greenhouse-gas emissions of at least **5% from 1990 levels in the commitment period 2008-2012**.

Key provisions in the agreement include:

- An international regulatory framework for the operation of international emissions trading (from 2008) and the other flexible mechanisms of the Protocol;
- Strictly controlled access to additional carbon sinks e.g. through sustainable forestry management practices;
- A strong compliance regime to facilitate, promote and enforce compliance with the Protocol and to underpin its environmental integrity, including a requirement to make up any shortfall in meeting national emissions reductions targets, plus a 30% penalty;
- New and additional funding of €450 million per annum by the EU, it's Member States and some other developed countries to assist developing countries adapt to climate change.

(DEHLG, 2002)

# 2.0 CLIMATE CHANGE INDICATORS

Indicators of climate change provide critical information regarding climate trends, and also provide an early warning system by providing data which may indicate an environmental problem (Sweeney *et al*., 2002).

Environment and Heritage Service (EHS, DoE(NI)) maintains a database on 13 indicators of climate change, which is updated annually, including rainfall (Armagh Observatory), temperature (Armagh Observatory), and the responsive behaviour of birds and insects (e.g. Copelands Bird Observatory).

Northern Ireland's climate change indicators are documented in EHS (2004). They are:

1. Air temperature
2. Number of 'hot' and 'cold' days each year
3. Rainfall seasonality
4. Annual rainfall
5. Snow days
6. Position of the Gulf Stream
7. Length of growing season
8. Potato production
9. Date of the first sighting of the swallow
10. First appearance of the large white butterfly
11. Mean river flow in the River Bush
12. Groundwater levels in Killyglen and Dunmurry
13. Sea level in Northern Ireland

A report on 'Climate Change Indicators for Northern Ireland' (2004) indicated that since 1840, nine of the fifteen warmest years on record have occurred since 1990. It also pointed to evidence of:

- Average temperature increasing;
- An increase in the growing season;
- Number of snow days decreasing; and
- Swallows and butterflies being sighted progressively earlier in the year.

A number of initiatives have been taken in Northern Ireland such as:

- The promotion of awareness of climate change. EHS issued a guidance booklet for public bodies on climate change impacts in Northern Ireland;

- The DOE has also published a Planning Policy Statement on Planning and Flood Risk (PPS15 -http://www.planningni.gov.uk/areaplans_policy/PPS/PPS.htm). It seeks to reduce flood risks to people, property and the environment and adopts a precautionary approach to decision making, taking account of climate change and acknowledging wider sustainable objectives (HM Government, 2006).

In Ireland, potential primary and secondary indicators were investigated by Sweeney *et al*. (2002) using the Irish Meteorological monitoring network supported by Met Éireann. The study found that there was evidence in the records for primary indicators consistent with climate change effects, and that there was evidence of linked ecosystem changes in secondary indicators. The primary indicators investigated were temperature (annual, maximum and minimum, hot/cold days, frequency of frost days from e.g. Valentia Observatory, Birr, Malin Head, Rosslare) and precipitation (annual, seasonal, geographical distribution, intensity). Secondary indicators investigated were:

- Tree phenology (Phenology is the study of the timing of natural events. These events include flushing or budburst, flowering, fruiting and autumn leaf-fall). (Data from Valentia Island, John F. Kennedy Arboretum, Johnstown Castle and National Botanic Gardens);
- Production levels of warm weather crops (e.g. maize);
- Bird, bat, insect, and plant species distribution;
- Human health, energy and economic factors; and
- Palaeo-records.

Tree phenology proved to be the most valuable secondary indicator due to relatively long historical records. Overall, the study supported that an integrated monitoring strategy be put in place to focus on the observation of climate change.

Current research is focused on the development of a set of climate change indicators in line with European and global studies (McElwain & Sweeney, 2006).

# 3.0 CLIMATE CHANGE - IRELAND

## Climate

The following observed changes in Ireland's climate have been documented by the Community Climate Change Consortium for Ireland (C4I, www.c4i.ie, accessed January 2007). In line with the global picture, Ireland's average temperature has increased by about 0.7°C over the last 100 years, and the rate of increase has been higher in the last couple of decades. The increase has not been uniform over time, with a warming period from 1910 to the 1940s, followed by a cooling period up to the 1960s. The current warming period commenced around 1980. 2006 was the warmest year on record at both Malin Head and Phoenix Park, which have observations dating back over 100 years, and also at Casement Aerodrome, Kilkenny and Rosslare. In line with the IPCC report, 10 of the 15 warmest years in the last century have occurred since 1990. In the last 100 years, 2006 was the second warmest year, 1945 being slightly warmer, and the last 10 years have been the warmest decade. While they can be less categorical about wind speeds, there is some evidence of a reduction in annual average wind speeds, with a corresponding decrease in the frequency of high wind speeds and gusts. Increases in total annual rainfall in parts of the West and North have been observed, with some increase in the number of days with heavier rain but there is no clear pattern of change in other areas.

The following predictions are also documented by the C4I. Temperatures in Ireland are predicted to increase by 1.25-1.5°C by 2040 compared to 1961 to 2000. Rainfall is expected to increase in winter by about 15% and summer projections range from no change to a 20% decrease. Extreme rainfall events show more marked changes with more events occurring in autumn and a 20% increase in 2-day extreme rain amounts, especially in northern areas. Taking the projected precipitation changes into account, a hydrological study of the Suir catchment area carried out by the C4I showed a significant increase in the number of extreme discharge events and a slight increase in their intensity, leading to an increased probability of flooding in the future. Another C4I study focuses on how the rise in global temperature might affect the intensity and frequency of storms in the North Atlantic. The frequency of very intense storms was found to increase by a factor of 2 by the end of this century compared to the end of the 20th century although there was a slight decrease in the total number of depressions.

## Scenarios and Impacts

Sweeney *et. al*. (2003) presents an assessment of the magnitude and likely impacts of climate change in Ireland over the course of the current century. It approaches this by establishing scenarios for future Irish climate based on global climate model projections for the middle and last quarter of the present century. These projections are then used to assess probable impacts in key sectors such as agriculture, forestry, water resources, the coastal and marine environments and biodiversity.

High spatial resolution scenarios were generated using a statistical downscaling technique applied to Global Climate Model (GCM) output from the Hadley Climate model to project likely changes in Irish climate from the 1961–1990 averages. The results of this analysis suggest that:

- Current mean January temperatures in Ireland are predicted to increase by 1.5°C by mid-century with a further increase of 0.5–1.0°C by 2075;
- By 2055, the extreme south and south-west coasts will have a mean January temperature of 7.5–8.0°C. By then, winter conditions in Northern Ireland and in the north Midlands will be similar to those currently experienced along the south coast;
- Since temperature is a primary meteorological parameter, secondary parameters such as frost frequency and growing season length and thermal efficiency can be expected to undergo considerable changes over this time interval;
- July mean temperatures will increase by 2.5°C by 2055 and a further increase of 1.0°C by 2075 can be expected. Mean maximum July temperatures in the order of 22.5°C will prevail generally with areas in the central Midlands experiencing mean maxima up to 24.5°C;
- Overall increases of 11% in precipitation are predicted for the winter months of December–February. The greatest increases are suggested for the north-west, where increases of approximately 20% are suggested by mid-century. Little change is indicated for the east coast and in the eastern part of the Central Plain;
- Marked decreases in rainfall during the summer and early autumn months across eastern and central Ireland are predicted. Nationally, these are of the order of 25% with decreases of over 40% in some parts of the east.

(Sweeney *et al.*, 2003)

Forward planning is needed now for adaptation to climate change in Ireland. In key areas such as agriculture, water resources, coasts, marine and the natural environment, impacts are likely to be significant. Sweeney *et al*. (2003) provides a perspective as to how changing climate may necessitate changes in current practices. The following impact assessments are documented:

***Agriculture***

The scenarios produced (Sweeney *et al*., 2003) were used as inputs to crop simulation models for a range of present and potential future crops. The simulation results show that the expected climate changes will have a major impact on Irish agriculture which, though significant, cannot be regarded as catastrophic:

- For livestock production, the expectation of more frequent summer droughts will require supplementation of grazed grass;
- Maize silage is increasingly likely to replace grass silage, potentially increasing grazing land areas. At the same time, increased production of grain maize is expected;
- Barley is another potentially important source of energy for supplemental feeding of livestock. The expected increases in cereal grain production may be expected to reduce the cost of feed barley. However, extra irrigation costs may bring the economic viability of the crop into question;
- For potato crops, drought stress will be the most important limiting factor determining its viability and it is likely that potatoes may cease to be a commercially viable crop over much of Ireland;
- Spring barley yield increases of approximately 25% are likely by 2055 with harvesting time earlier than today;
- Maize grain yields are expected to increase dramatically, in western areas by more than 150% on today's national average value;
- Soybean will remain a marginal crop. Although as temperature conditions become more favourable, precipitation changes mean that any gains could be negated by drier summers.

(Sweeney *et al*. 2003)

Agricultural land use distributions are predicted to alter, a sharpening of east to west contrasts is likely with livestock production dominating more to the west, and arable production dominating eastern Ireland. Planning for irrigation requirements may be needed, particularly in the east.

***Water Resources***

Using the climate scenarios as inputs to a hydrological model a number of likely impacts were suggested:

- A widespread reduction in annual runoff is suggested; this will be most marked in the east of the country;
- Winter runoff is predicted to increase;

- All areas will experience a major decrease in summer runoff, particularly in the east of the country. These reductions are likely to average approximately 30% over large parts of eastern Ireland by mid-century;
- The magnitude and frequency of individual flood events will probably increase in the western half of the country;
- Seasonal flooding may occur over a larger area and persist for longer periods of time. Areas such as the Shannon basin will be vulnerable to these changes;
- Turloughs in western Ireland will also be particularly vulnerable to these changes;
- During the summer months, long-term deficits in soil moisture, aquifers, lakes and reservoirs are likely to develop. It is likely that the frequency and duration of low flows will also increase substantially in many areas.

(Sweeney *et al*., 2003)

These projected changes include increases in evaporative losses during summer months, which will have a knock on effect on reservoir yields. There is also the threat of water pollution, with a greater frequency of low flow conditions, which would provide problems for the dilution of effluent. Sweeney *et al*. (2003) recommend that minimum flow constraints are determined more conservatively, particularly where new urban or agricultural discharges are envisioned. They also recommend that greater incorporation of groundwater protection is considered as aquifers become increasingly important as sources of water supply as competition for reduced surface resources intensifies.

***Forestry***

Forests covers 9% of the land area of Ireland, a figure which it is planned to double by 2030 (Sweeney *et al*., 2003). In planning for the future, Sweeney *et al*. (2003) recommend that foresters must select species that will perform optimally over a full rotation of 40–50 years. Increased $CO_2$ concentrations and warmer temperatures are expected to benefit Irish forest growth, however decreased summer rainfall would have the opposite effect. Increased pest and disease incidence is also detailed as a secondary effect (e.g. green spruce aphid, pine weevil, great spruce bark beetle). Other negative effects on this sector which may occur include increased fire damage and increased deer and squirrel populations.

Sweeney *et al*. (2003) state that there is no reason to believe that Sitka spruce will not continue to be viable as the mainstay of commercial forestry in Ireland. Despite this, there is a need to assess different provenances and species in long-term research trials. It is also recommended that the national tree-breeding programme should be re-assessed in the light of current knowledge on potential climate change with a view to the selection of traits that will accommodate and capitalise on these changes. The potential for the production and transplanting of containerised nursery stock should also be reassessed. Finally, it is urged that climate change scenarios should be included in the Forest Inventory and Planning System currently operated by the Forest Service in the Department of Marine and Natural Resources (FIPS2007 is expected in 2008).

***Natural Ecosystems and Biodiversity***

The projected increases in temperature, combined with a longer growing season, were found to have the potential to cause distributional and behavioural changes in Irish species (Table 2 reproduced here from Sweeney *et al*. (2003, Table 1 in that document).

Habitats vulnerable include salt marshes and sand dunes which are vulnerable to sea-level and climate changes and may experience significant changes in species composition. Montane heaths are suggested to be particularly sensitive to climate change as many montane species are at the lower altitude/southern latitude edge of their distribution, with limited migration potential, and an increase in temperature combined with summer drying may prove detrimental for this habitat in Ireland. Similarly, peatlands are expected to suffer considerably from summer drying.

***Marine Ecosystems***

The extent to which actual changes will happen is difficult to predict for the marine environment. A notable impact exists with respect to salmon farming however, where an increase in sea temperature may have serious consequences. Salmon are near the southern range of their distribution and any increases in temperature could harm the commercial viability of farms and render them subject to increased algal bloom, pest and disease problems (Sweeney *et al*. 2003).

**Table 2** Potential effects of climate change on natural ecosystems and biodiversity in Ireland (Table 1 from Sweeney *et al*., 2003)

| **Distributional changes** |
|---|
| • Decline (in some cases extinction) of Arctic and Boreal relicts, cold-hardy species, water-dependent species, wetland and oceanic species.<br>• Extension of Boreo–temperate species and other species that favour increased temperatures, e.g. deep-rooted calcareous forbs, butterflies, insect predators and pests.<br>• Increases in migrant species – mainly insects and vagrant birds.<br>• Changes in distribution of introduced or invasive species.<br>**Behavioural changes**<br>• Changes in the phenological processes of plants (bud burst, germination and leaf emergence).<br>• Changes in plant decomposition and productivity.<br>• Alterations in competitive interactions between plants.<br>• Increased numbers of generations of many insects which may lead to population growth.<br>• Greater winter survival rates of invertebrates.<br>• Changes in phenological processes of insects, e.g. earlier appearance of butterflies.<br>• Earlier breeding of amphibians.<br>• Possible changes in the competitive relationships between frogs and newts.<br>• Changes in timing of migration, hatching, development and spawning of freshwater fish with negative and positive implications for specific species.<br>• Increased competition for niche space, e.g. *Salvelinus alpinus* (Arctic char) and other species.<br>• Changes in bird migrational patterns.<br>• Earlier breeding of birds and larger and more numerous clutch sizes.<br>• Greater numbers of overwintering birds; reduced mortality but greater competition between species.<br>• Changes in the life cycle of bats.<br>• Greater winter survival rates of bats. |
| • Reduction in birth weight of *Cervus elaphus* (red deer). |

***Sea-level rise and the Irish coast***

Global sea level is projected to rise by approximately 0.5 m by the end of the century. In Ireland, this figure will be modified by local land-level changes. As a general approximation, land retreat of about 1 m can be anticipated on sandy coastlines in Ireland for every centimetre rise in sea level (Sweeney *et al*., 2003). Inundation risk must also take into account storm surge events and high tide frequencies. A value of 2.6 m for extreme water level presently occurs with a return frequency of 12 years on the west coast and 100 years on the east coast. These return periods of extreme water level are likely to reduce considerably as sea levels rise. Combining these extreme water levels with a sea-level rise of 0.49 m places approximately 300 km$^2$ of land in Ireland at risk of inundation.

In situations where land loss cannot be economically defended, it should not be contemplated. Where infrastructure is at risk of inundation, cost-beneficial solutions may exist. This is particularly the case in the cities of Dublin, Cork, Limerick and Galway, and for assets such as railway lines, airports, and power stations. 'Hard' engineering solutions should be viewed as a last resort outside of these categories, as this type of engineering can have dramatic effects further along the coastline. Recommendations for coastal management policies to cope with sea-level rise would include the following:

- no building or development within at least 100 m of 'soft' coastline;
- no further reclamation of estuary land;
- no removal of sand dunes, beach sand or gravel. Measures to protect and rehabilitate dune systems should be implemented;
- all coastal defence measures to be assessed for environmental impact;
- where possible, the landward migration of coastal features such as dunes and marshes should be facilitated.

**National Policies**

The National Climate Change Strategy

To ensure Ireland reaches its target under the Kyoto Protocol and following a comprehensive public consultation process, the Government published the *National Climate Change Strategy* in October 2000. The Strategy provided a framework for action to reduce Ireland's greenhouse gas emissions. Ireland's target is to limit the growth in greenhouse gas emissions to 13% above 1990 levels in 2008-2012. The measures in the strategy cover many areas such as: taxation; energy; transport; the industrial, commercial and services sector; agriculture; forestry; and the built environment. A review of this strategy was carried out in 2002, and a further review was also carried out '*Ireland's Pathway to Kyoto Compliance'* (DEHLG, 2006). The review looked at developments since the 2000 strategy and examined options for achieving further abatement of greenhouse gas emissions in the future. The review found that even with existing policies and measures already implemented or expected to be implemented up to 2012, projections showed that Ireland will continue to face an average annual shortfall in its Kyoto target of some 7.174 million tonnes of $CO_2$e in the 2008-2012 period. This shortfall can be met through:

- Further measures to be decided on by the Government, over and above those already adopted;
- Emissions reductions, or purchase of carbon allowances in lieu of reductions, by installations participating in the EU Emissions Trading Scheme; and
- Use of the Kyoto Protocol flexible mechanisms by Government to purchase carbon allowances.

It also set out the basis for the preparation of a new national climate change strategy to guide Ireland's future efforts both towards meeting its existing Kyoto target and preparing for more stringent greenhouse gas emission reduction requirements in the period beyond 2012. The revised National Climate Change Strategy 2007-2012 was published in April 2007 (DEHLG, 2007). The purpose of the Strategy is;

- To show clearly the measures by which Ireland will meet its 2008-2012 commitment; and
- To show how these measures position us for the post-2012 period, and to identify the areas in which further measures are being researched and developed to enable us to meet our eventual 2020 commitment.

Additional measures have already been developed to add to existing measures, and will reduce Ireland's greenhouse gas emissions by over 17 million tonnes (Mt) of carbon dioxide equivalent in the period 2008-2012. Key additional measures are included in a number of areas such as: energy supply; transport; residential; industry, commercial and services; agriculture, land-use and forestry; waste; public sector; adaptation etc. Some of these include:

- Rebalancing of Vehicle Registration Tax (VRT) and motor tax, supported by improved mandatory labelling;
- 15% of electricity to be generated from renewable sources by 2010 and 33% by 2020;
- Revised Building Regulations in 2008 to aim for 40% improvement on current thermal performance standards;
- Smart meters to be supplied to all electricity customers;
- REPS 4 scheme will support carbon sequestration and reduction of emissions from fertilisers;
- New supports for afforestation;
- €15m multi-annual Climate Change Awareness campaign;
- Major funding for research programmes;
- Flood risk strategy being developed;
- Overall national adaptation strategy to be developed by 2009.

National Development Plan 2007-2013

The €184 billion National Development Plan 2007-2013 builds on the social and economic achievements of the 2000-2006 plan. It was launched in January 2007, and is titled

*Transforming Ireland - A Better Quality of Life for All.* Climate change is incorporated in Chapter 6 of the plan, '*Environmental Sustainability*'. The NDP includes a range of investments which aim to reduce greenhouse gas emissions, such as:

- Public Transport Sub-Programme: €13bn over the next 7 years to promote and facilitate a switch in transport from private cars to public transport;
- Waste Management Sub-Programme: €750m to address problems with legacy landfills, support through private investment, the development of thermal treatment plants to reduce landfill usage, and promote greater use of recycling and recovery;
- Climate Change Sub-Programme: €270m to fund the purchase by the State of carbon allowances as one part of the strategy to meet the targets set out under Kyoto;
- Sustainable Energy Sub-Programme: €276m to fund large-scale development of wind energy capacity and the development of alternative sources of energy such as bio-mass and bio-fuels, ocean energy and solar and geothermal technologies;
- Coastal Protection Sub-Programme: €23m to protect the coastline from the impact of flooding and erosion;
- Environmental Research: €93m, some of which will be directed to further research into the impacts of climate change on Ireland and mitigation measures.

Sustainable Development: A Strategy for Ireland

The aim outlined for Ireland in the sustainable development strategy, published in 1997, was *"to ensure that economy and society in Ireland can develop to their full potential within a well protected environment, without compromising the quality of that environment and with responsibility towards present and future generations and the wider international community".*

Making Ireland's Development Sustainable was produced by the Department of the Environment, Heritage and Local Government for the Johannesburg World Summit on Sustainable Development held in 2002. The report examines progress made in the ten years since the Rio de Janeiro Earth Summit.

## Research

Environmental Protection Agency

The Environmental Protection Agency (EPA) ERTDI programme funds major research projects on climate change and greenhouse gas emissions (see Appendix I for details of projects). Initial research work focuses on the following:

- Improve information on Green House Gas (GHG) emissions;
- Assessment indicators of climate change and possible impacts of climate change for Ireland;
- Study factors influencing the radiation balance.

Funded projects to date include Sweeney *et al*. (2002), Sweeney *et al*. (2003), McGrath *et al*. (2005), and McElwain & Sweeney (2006).

Later research funding is focused on expanding research capacity in a number of areas and building research infrastructure. This work will develop GHG flux measurements in key ecosystem areas e.g. grasslands, peatland and arable land. In addition, a regional climate model based on HIRLAM (High Resolution Limited Area Model) forecast model is being developed along with tools for more in-depth assessment of climate change impacts.

Irish Climate Analysis and Research Units (ICARUS)

ICARUS is an Irish research unit that was formed due to a greater need for research on climate and climate change impacts, with particular relevance to Ireland. Such impacts are likely to have significance for key sectors, such as, water resources, agriculture and environmental planning and on a range of aspects which will impinge on people's everyday life.

Current Areas of Research Include:

- Contemporary Climate Analysis;
- Climate Scenario Generation for Ireland;
- Impact Modelling;
- Hydrological Modelling;
- Sea level Rise- mapping vulnerable zones;
- Flood vulnerability mapping coupled with extreme event analysis;
- Integration of climate and other relevant data into Geographical Information Systems (GIS) to facilitate assessment of likely changes on key sectors;
- Extreme event analysis e.g. return periods of extreme events, such as, storms, heavy rainfall events, extreme temperatures, and flooding.

Also, as part of current work statistical downscaling for the 2050s and 2080s has been carried out by ICARUS, and is at present being refined to downscale to the daily scale (McElwain & Sweeney, 2006). The research unit is based in the Department of Geography, NUI Maynooth.

Community Climate Change Consortium for Ireland - Met Éireann

The Community Climate Change Consortium for Ireland (C4I) was established in 2003 and is based at Met Éireann headquarters in Dublin. It is a collaborative research effort between Met Éireann and the UCD Meteorology and Climate Centre and funding is provided by the Environmental Protection Agency, Met Éireann, Sustainable Energy Ireland and the Higher Education Authority. Its objective is to conduct climate change research, develop regional climate modelling capacity, and provide climate model output to Irish scientists. C4I research focuses on generating projections of Ireland's climate in the future and results to date largely agree with the IPCC report findings. In the Regional Climate Analysis, Modelling and Prediction Centre (RCAMPC), housed in Met Éireann, C4I uses the regional climate model RCA (Rossby Centre Regional Atmosphere Model) from the Rossby Centre to investigate the characteristics of past and future climate of Ireland. Details of current research can be found on www.c4i.ie .

Other

Other research includes work by the Coastal and Marine Resources Centre (CMRC), at University College Cork, on the trends and impacts of climate on coastal areas. The Marine Institute also conducts research on the implications for Ireland’s marine environment and resources arising from climate change.

McElwain and Sweeney (2006) provide details of current research work on climate change in Ireland in Appendix 2 of their report.

# 4.0 CLIMATE CHANGE - NORTHERN IRELAND

**Climate**

The climate in Northern Ireland is changing as it is elsewhere (EHS, 2004):

- Air temperature is rising – a continuous temperature record from the Armagh Observatory since the 1840's shows that annual minimum temperatures are rising, annual maximum temperatures are rising and mean annual temperatures have been steadily rising since the 1980s;
- The number of hot and cold days per year is increasing (an indication of how extreme weather events vary from one year to the next);
- Rainfall records have been kept at the Armagh Observatory since 1930 and show that the proportion of rainfall falling in summer is decreasing, while winters are slightly wetter;
- A continuous record of the number of snow days has been kept at the Armagh Observatory since 1960. Snowfall days have decreased in recent years;
- Climate models also predict that the length of growing season is set to increase in the future, and has been increasing since the 1980s. These trends are being reflected in flora and fauna e.g. the arrival of the swallow which is becoming earlier each year (data from the Copelands Bird Observatory), and the date of the first observation of the Large White Butterfly which is also becoming earlier in the year.

Mean flow data from the Rivers Agency for the River Bush (which enters the Atlantic Ocean near the Giants Causeway in Co. Antrim.), has also been used to study changing rainfall patterns in Northern Ireland (EHS, 2004). Increasing flows may lead to flooding, decreasing water quality, and may also affect fishing and tourism. Mean annual river flows in the River Bush since the 1970s have not shown any significant trend to date. Groundwaters are also being monitored by EHS in order to investigate the affects changes in climate and rainfall patterns could have on groundwater levels. A good link between groundwater levels and rainfall has been found, and therefore groundwater levels could be affected if climate change alters rainfall patterns. Finally, sea levels in Belfast Lough have been measured since 1918 by Belfast Harbour Commissioners. Sea levels have fallen very slightly in Northern Ireland over the period of recording. This differs from Ireland and England, and can be attributed to the isostatic uplift Northern Ireland is experiencing (EHS, 2004).

These changes are expected to accelerate over the coming century. Average temperature may rise by 3$^{o}$C (or more in Co. Fermanagh); summer rainfall may reduce by up to 50% while winters may be 25% wetter (Hulme *et al*., 2002).

**Scenarios and Impacts**

The United Kingdom Climate Impacts Programme (UKCIP) has published a number of scenarios for climate change over the next 80 years – UKCIP02 (DEFRA, 2002) (Note: UKCIP have recently completed a consultation on the next package of climate change information for the UK – "UK 21st Century Climate Scenarios" or UKCIP08, and this will be available in 2008). It presents four scenarios and they are based on low, medium-low, medium-high and high levels of greenhouse gas emissions, with high levels representing the worst case scenario. They provide a method of assessing climate change vulnerability, impacts and adaptation in the UK. UKCIP recommend that all four scenarios are used in any impact assessment or adaptation study. To assist with studies of the impacts of climate change and with assessments of how to adapt to these changes, a set of observed climate data has been prepared to accompany these new scenarios. These data are for a 5km grid for the whole land area of the UK and contain monthly data for 26 surface climate variables for the period 1961 to 2000 (www.ukcip.org.uk). The main predictions are:

- Average annual temperature will increase, with the increases greatest in summer and autumn. The annual temperature rise by the 2080s is 2$^{o}$C for the Low Emissions scenario and 5.3$^{o}$C for the High Emissions scenario (Hulme *et al*., 2002). There will be greater warming in the southeast than in the northwest of the UK;
- Winter precipitation is likely to increase and summers to become drier. This increase in winter ranges from 10 to 20% for the Low Emissions scenario, to between 15 and 35% for the High Emissions scenario. The decrease in summer is up to 35% for the Low Emissions Scenario and 50% or more for the High Emissions scenario. For both winter and summer, the changes in precipitation are largest in the eastern and southern parts of the country. For Northern Ireland, only modest changes in spring precipitation is predicted (less than 5%), and autumn shows slight increases under all scenarios;
- There will be less snow over the entire UK, with the largest percent reductions, maybe up to 90% or more by the 2080s for the High Emissions scenario;
- By the 2020s, natural variations in year to year weather may still in some cases be greater than the changes in average climate due to increased greenhouse gas emissions. This is particularly true for precipitation;
- The contrast between winter and summer climate will increase for all scenarios. Winters will become wetter and summers drier. Temperatures will increase in all seasons. The thermal growing season for plants will lengthen across the UK. Each degree of warming causes a lengthening of the thermal growing season of

about three weeks in the southern areas and of about one and a half weeks in northern areas;

- Cloud cover may decrease, and this is especially so in the south with reductions by the 2080s of about 10% for the Low Emissions scenario and more than 20% for the High Emissions scenario;
- Relative humidity may decrease throughout the year for all scenarios in all but a few areas of northern Scotland;
- A decrease in average soil moisture is predicted for the whole of the UK, with the largest reductions of 40% or more by the 2080s occurring in the High Emissions scenario in the southeast of England. For winter, little change is predicted for Northern Ireland.

Table 3.2 from SNIFFER 2007 (p.14/15), is reproduced here for information, and details UK CIP02 Climate Change Scenarios for Northern Ireland. Where a range is given this relates to the low emissions and high emissions scenarios, but also reflects grid scale geographical variation within the province. Spring represents the average for March, April and May; summer the average for June, July and August; autumn the average for September, October and November; and winter the average for December,
January and February.

**Table 3** UKCIP02 Climate Change Scenarios for Northern Ireland (from SNIFFER 2007)

| Climate variable | | 2020s | 2050s | 2080s |
|---|---|---|---|---|
| Temperature | Annual mean | +0.5 to +1.0°C | +0.5 to +2.0°C | +1.0 to +3.5°C |
| | Spring mean | +0.5 to +1.0°C | +0.5 to +2.0°C | +1.0 to +3.5°C |
| | Summer mean | +0.5 to +1.0°C | +1.0 to +2.5°C | +1.0 to +3.5°C |
| | Autumn mean | +0.5 to +1.0°C | +1.0 to +2.5°C | +1.5 to +4.0°C |
| | Winter mean | 0 to +1.0°C | +0.5 to +1.5°C | +1.0 to +2.5°C |
| | Inter annual variability* | Winter and particularly spring will become more reliably warm. Autumn and especially summer temperatures will vary more widely from year to year. | | |
| | Diurnal range | Winter nights will warm more than winter days; summer days will warm more than summer nights, although summer evenings will be warmer. Overall will decline marginally. | | |
| | Extremes | Extremely warm days will become more frequent; extremely warm days will become hotter. Heat waves will be more likely. The number of cold days will decline. | | |
| | Sea surface | 0 to +1.0°C | +0.5 to +1.5°C | +1.0 to +2.5°C |
| Precipitation | Annual mean | WMV** | Up to -10% | Up to -10% |
| | Spring mean | WMV | Up to +10% | Up to +10% |
| | Summer mean | Up to -20% | -10 to -30% | -20 to -50% |
| | Autumn mean | WMN | WNV | Up to -10% |
| | Winter mean | Up to +10% | Up to +15% | Up to +25% |
| | Snow | Average winter snowfall is likely to decline by between -40% and -100% (i.e. no snow on average) by the 2080s. | | |
| | Inter-annual variability | Summer will become more reliably dry. Precipitation in autumn, winter and particularly spring will become more variable. | | |
| | Extremes | More intense rainfall days in winter and spring. Greater probability that an extreme rainfall event will occur on any given winter day. Evidence that intense summer storms may also increase (but limited by spatial resolution of the model). Seasonally, there is an increased likelihood of very dry summers and very wet winters. | | |
| Cloud cover | | Cloud cover will reduce annually and in all seasons, particularly in summer. | | |
| Relative humidity | | Relative humidity will reduce annually and in all seasons, especially in summer. | | |
| Soil moisture content | | Soils will become drier overall, with soil moisture content declining by as much as 20% in some areas by the 2080s (high emissions). Soil moisture content will actually increase marginally in winter and spring, but this is offset by significant reductions in summer and autumn. | | |
| Wind speed | | Average wind speeds over land are likely to be similar in winter and spring and may decline in summer and autumn. The pattern of change for more extreme events is broadly similar over land; over sea more extreme wind speeds will be similar to those experienced at present, although in summer they will be lower. However, changes in wind speed are only predicted with low confidence. | | |
| Sea level | | Global mean sea level is expected to rise by between 9 and 69cm by the 2080s (the range represents emissions and scientific uncertainty). Regional sea level variations may alter these values by +/- 50%. Relative sea level can be calculated by subtracting isostatic uplift (and adding an allowance for sediment consolidation at the local level). Storm surge heights are not anticipated to increase much beyond the addition of mean relative sea level (unlike in other parts of the UK). However, changes in storm surge heights are only predicted with low-medium confidence. | | |

* Based on model output for 2080s across the four UKCIP02 scenarios
**WMN – within a measure of Natural Variability i.e. no trend detected

SNIFFER, DoE (NI) and EHS funded a research project whose aim was to look at preparing Northern Ireland for a changing climate (SNIFFER, 2007). The five main objectives of this research were to:

1. Provide an analysis, based on the themes of Economic Infrastructure, Built Environment, Natural Environment and Social Wellbeing, of climate change impacts upon Northern Ireland, using the UKCIP02 scenarios and recent research in the field relevant to Northern Ireland;
2. Provide an analysis of the effect on public services (building on the 2005 EHS guidance), specifically on the key outcomes related to the Government's three priority themes of Economic Competitiveness, Equality and Community Cohesion and Better Public Services;
3. Produce a risk analysis of identified impacts with estimated likelihood of risk and resource implications;
4. Produce an adaptation strategy for each impact, identifying the public sector bodies responsible for delivery;
5. Produce a technical report of climate impacts for use by policy experts. In addition, a non-technical summary report has been produced.

The following areas were addressed by the report, and impacts and adaptation assessments are provided for each sector:

- *Conservation, biodiversity and habitats*
- *Fisheries*
- *Agriculture*
- *Forestry*
- *Water resources*
- *Coastal and flood defence*
- Buildings construction and planning
- Business
- Insurance
- Transport
- Energy
- Tourism
- Health

The potential impacts of climate change to each sector above were considered and they were:

- Wetter winters e.g. increased flood risk;
- Drier summer e.g. increased incidence of low river flows;
- Warmer winters;
- Hotter summers e.g. increased incidence of heat related illness/mortality;
- Sea level rise.

Those sectors which have most influence on the water environment from the authors perspective, are italicised in the list above, and the impacts of climate change on these areas could affect the delivery of the WFD. These are summarised below from SNIFFER 2007. Further reference should be made to SNIFFER 2007 for details such as the impacts likely on receptors, the relevant public service area, effects on public service, the risk, adaptation strategies, and the responsible public sector body, and are summarised at the end of each chapter (Chapters 4-17) and are useful for consideration by agencies.

*Conservation, Biodiversity and Habitats*

The changes that are likely to take place under various climate change scenarios are expected to severely compound other impacts of human activity such as habitat fragmentation, agricultural change, invasion of alien species and eutrophication (SNIFFER, 2007). Table 4.1 of SNIFFER 2007 provides some examples of current weather conditions and the problems being caused with which organisations must deal.

**Table 4** Summary of responses from consultation held during the preparation of SNIFFER 2007 (Table 4.1 SNIFFER, 2007)

| Weather/Climate | Examples of how current climate affects organisation |
|---|---|
| Wet | Flooding leads to pollution<br>Wash out of salmon beds<br>Impact on fish migration<br>Reduces no. of field days for habitat monitoring/study<br>Impacts on habitats / species |
| Dry | Impact on wetlands. Areas prone to fire<br>Eutrophication<br>Drought impacts on fry / hatcheries<br>Impact on fish migration<br>Damage to habitats |
| Cold | Impact on certain species due to severe frost – others impacted by lack of frost e.g. on regeneration<br>Delayed development of some species<br>Impacts on fish productivity |
| Hot | Not all habitats would be sustainable in long hot summers |
| Windy | Impact on trees / plants. Certain plants scorched by strong winds off coast.<br>Inhibit development of fish industry. |

Each of the following expected major climate changes from UKCIP02 are likely to impact on biodiversity in Northern Ireland in the future:

- Annual temperatures are likely to rise between 0.5 and 3.5$^{o}$C. Winter and particularly spring is likely to become more reliably warm, while extremely warm days and heat waves will become more frequent;
- Precipitation is likely to be more variable causing summers to be drier and autumn, winter and spring periods to be wetter and more unpredictable;
- Cloud and relative humidity is likely to reduce in all seasons, particularly in summer and overall soil moisture is likely to decline;
- Sea level itself is expected to rise between 9-69cm by 2080;
- Sea surface temperatures could rise between 1-2.5$^{o}$C by 2080;
- Increased heavy localised flooding and strong gales are also likely.

(SNIFFER, 2007)

In summary the likely impacts of climate change on habitats found in Northern Ireland are as follows:

- Wetland habitats such as peat bogs could be at risk of drying out although modelling has predicted that the Cuilcagh/Pettigo peatlands, in Ireland, will experience little change by the 2050s (Berry *et al*., 2005). However, the reduced number of variables used in the bioclimate dataset, may have masked the full extent of the changes;
- On the coast the MarClim research confirms that the impacts of climate change on seashore indicator species are beyond previous scales of variation seen over the last 60 years;
- As a result of increasing rainfall heathlands may develop faster, in northern regions of the UK, this combined with milder winters, is likely to result in extended growth periods. However, whilst conditions may remain suitable for heath communities, species composition of the plant communities may well change (EHS, 2005d);
- In lakes another effect of increases in summer temperatures, is increased risk of eutrophication (West and Gawith, 2005) and an associated decrease in water quality;
- Lastly in bird populations responses to climate change include phonological changes such as changes in breeding success and advancing egg-laying dates, or migration patterns changing in times and space (RSPB, 2004).

(SNIFFER, 2007)

Adaptation strategies for Northern Ireland are in general likely to be measures from Great Britain adapted to suit the climate changes experienced in Northern Ireland. These, as detailed in SNIFFER 2007, could include the following:

- Increasing connectivity of wetlands;
- Reducing nutrient inputs;
- Better management of headwater and river flow;
- Protection of salt marshes and creation of new salt marshes by ‘planned retreat’;
- Monitoring of key habitats, including fens, raised bogs, old growth woodland and acid grassland and fauna and flora sensitive to potential impacts;
- Monitor and limit the introduction of alien species, particularly those associated with plant nurseries and garden centres, ports and shipping;
- Increased awareness of Environmentally Sensitive Areas;
- Managing the wider countryside for biodiversity and not just relying on nature reserves;
- Increasing connectivity between ecosystems and habitats through changes in land management practices and creation of ‘wildlife corridors’.

***Fisheries***

Responsibility for fisheries in Northern Ireland falls under the remit of many different organisations such as:

- Department for Culture, Arts and Leisure (DCAL, Inland Fisheries);
- Fisheries Conservancy Board (FCB);
- Loughs Agency (cross border);
- Department of Agriculture and Rural Development (DARD);
- Agri-Food and Biosciences Institute (AFBI).

The impacts of climate change (wetter winters, drier summers, hotter summers, sea level rise etc.) on fisheries is summarised in Table 5.1 of SNIFFER 2007, and include;

- Wetter winters: increased frequency flooding could lead to decreased fish egg survival and washing away of juvenile salmon;
- Drier summers: lower flows, lower water quality and increased temperatures may lead to fish kills. Reduced stream flow could have negative impacts on salmonid migration triggers. Loss of fly life resulting from low flows, leading to less available fish food.

- Hotter summers: increased temperature in rivers lead to poor freshwater quality leading to fish kills. Increased temperatures can become lethal for some fish such as salmonids.
- Change in distribution of marine fisheries. Increased likelihood of spawning and settlement of cultivated non-native species such as the Pacific oyster, and the northward shift of north-south biogeographic species boundaries such as haddock and cod.

Adaptation Strategies in SNIFFER 2007 include:
Freshwater fisheries

- For species such as Pollan, the impact of climate change per se may be beyond local control. Once introduced species such as roach and zebra mussels are present they are practically impossible to control (as can be seen with the situation with the Zebra mussel in Lough Erne). However, the dominating effects of alien species on native aquatic biodiversity, and even some impacts of climate change, may be minimised if enrichment is abated and the lakes move towards their original trophic state.
- Ensure conservation limits for Atlantic salmon and other species of conservation concern are maintained in order to maintain stock levels.

Marine fisheries

- Need to research new target species to prevent over-fishing these new stocks.
- May be necessary to replace or modify fishing gear in order to exploit different suites of species.
- May need to diversify further the range of fish stocks exploited by the industry in order to minimise risk of over-fishing any single species.
- Fishing port facilities and river management programmes will also need to be considered.

***Agriculture***

The impacts of specific changes in climate on agriculture are summarised in Table 6.3 in SNIFFER 2007, and repeated here for information purposes.

**Table 5** Climate Change Impacts: Agriculture (Table 6.3, p.53, SNIFFER 2007)

| Climate change | Impact on receptor |
|---|---|
| Wetter winters | Potential drop in some crop yields<br>Greater difficulties in accessing fields (water logging) – problematic harvesting and ground preparation<br>Increase in wet weather animal health problems<br>Pest & disease problems<br>Impact on drainage systems |
| Drier summers | Potential impacts on crop yields<br>Increased need for irrigation and change in farming methodology e.g. for potatoes<br>Potential for new crops or crop varieties to be introduced<br>Increased need for greater water supply – cost implication |
| Warmer winters | Increased change in range of native / alien pest & disease problems e.g. potato blight. Chemical intervention may increase<br>Reduced vernalisation<br>Animals can be left in fields for longer / housing period decreased<br>Increased grazing on freer draining soils<br>Reduction in frost damage<br>Lengthening of growing season |
| Hotter summers | Potential need for greater ventilation / cooling systems in animal housing<br>Increased need for shade<br>Heat may benefit some crops, though may damage others |
| Sea level rise | Loss of coastal, estuary and floodplain agricultural land – major implications for polder areas at Lough Foyle<br>Erosion of land and salinisation of ground water |
| Reduced soil moisture | Possible increase in crop stress, with implications for yield e.g. grass yield. Further implications in NI of providing winter fodder due to reduced silage crop. |
| Change in Storminess | Increased crop damage<br>Increased soil erosion<br>Damage to agricultural buildings / changes in building specifications |
| Other | Potential implications for farm management – though note there are many other factors such as grant schemes, government policies, consumer patterns etc. |

Adaptation strategies included in SNIFFER 2007 include:

- Research into new crop varieties that will be able to cope with the particular anticipated climate of Northern Ireland. These new varieties will need to be economically viable. Research may be available from other countries (CLA Climate Change Working Group – Climate Change and the Rural Economy) and use should be made of this.
- Shifting crops or livestock to areas with the best conditions for efficient production – this may involve greater use of upland area that have been previously considered and designated in Northern Ireland as ‘less favourable’.
- Changes to farming practice and timings that will optimise rates of production. This would apply to both crops and livestock.
- Introduction of existing crops that have been previously unviable in Northern Ireland.

- Adoption of new technologies or systems that have not been used on a large scale in Northern Ireland to date e.g. more widespread irrigation may become necessary.
- Increased and improved monitoring surveillance of arable and livestock pests to ensure that pests not native to Northern Ireland are not introduced or able to gain a foothold.
- Education for the members of the agricultural sector on the impacts of climate change and the opportunities that this may provide.

***Forestry***

The impacts on forestry are summarised in Table 7.1 of SNIFFER 2007, and are categorised as either impacting on:

1. Woodland ecosystem function and quality, or
2. Commercial woodland management and timber production.

These include:

- Wetter winters:

  1. Enhanced water-logging leading to reduced stability and fine root death, potentially limiting rooting depth and making some species more vulnerable to summer drought.

  2. Enhanced water-logging leading to reduced stability and fine root death; inability of forest infrastructure (forest roads and culverts) to cope;
- Drier summers:

  1. Oxidation of peat; change in competition between species; loss of habitat through frost/heathland fires.

  2. Timber 'crack'; trees weakened and more susceptible to disease; productivity could fall on some sites and some species that are currently planted could prove unsuitable for commercial timber production on some sites; high water use of trees compared to other vegetation may raise land use issues; loss of productive woodland through forest fires.

Adaptation strategies for forestry must take a long term approach. Win-win or no regret adaptive actions are more difficult in the forestry sector as a result of the requirement to be appropriate to current and future climates. An example of a simple approach is suggested e.g. not planting a species already at the drier end of its climatic range. This can be further enhanced by adopting a strategy of planting mixed species stands, as all species are unlikely to be affected to the same extent. See Tables 7.2 and 7.3 in SNIFFER 2007 for further potential adaptation strategies.

***Water Resources***

Various bodies have responsibility for the water resource in Northern Ireland. They are:

- Northern Ireland Water (formerly Water Service): Supply and distribute water, when supplied for domestic or food production purposes. Provide and maintain sewers for draining domestic sewage, surface water and trade effluent. Make provision for effectually dealing with the contents of sewers.
- Water Council: Provides advice to DRD Water Service on the exercising of its functions.
- Water Appeals Commission: Considers appeals against decisions taken by DRD Water Service on a specified range of functions.
- EHS Water Management Unit: Protection of the aquatic environment, through water quality monitoring, discharge control and management of pollution.

Potential impacts on water resources are detailed below in Table 6 and Table 7.

**Table 6** Climate Change Impacts: Water Resources (Table 8.3, p. 75, SNIFFER 2007)

| Climate change | Impact on receptor |
|---|---|
| Wetter winters | Greater runoff, erosion of soil and leaching of agrochemical and agricultural wastes, leading to water quality problems with implications for aquatic life, abstractions and river users.<br>Potential damage to river channels from more intense rainfall, leading to aquatic damage.<br>Increased rainfall provides opportunity for winter storage, benefiting the Water Service and farmers. |
| Drier summers | Lower flows leading to problems for users relating to abstraction, ability to dilute effluent, aquatic ecology and recreation.<br>Increase demand for water, potentially affecting the ability of abstractors to meet requirements.<br>Reduction in volume of sewer base flow may result in blockages.<br>Reduced flushing of estuaries and lakes and increased residence time of pollutants may lead to deterioration of water quality with implications for shell fisheries, lake ecology and abstractors. |
| Warmer winters | Increase in pests and change in life cycle of aquatic and land-based organisms. |
| Hotter summers | Increase in river temperatures, reduction in dissolved oxygen concentrations and effects on aquatic life.<br>Problems with reservoir water quality associated with changes in temperature, solar radiation and wind speed.<br>Increase demand for water and water-intensive products and activities, potentially affecting the ability of abstractors to meet requirements but providing opportunities for manufacturers. |
| Sea level rise | May lead to saline intrusion of freshwater aquifers, affecting abstractions. |
| Changes in soil moisture | Higher soil moisture deficits in summer and autumn will delay winter recharge.<br>Lower summer groundwater tables may increase risk of pollution infiltration, affecting abstractions and groundwater-fed ecology.<br>Increased soil wetness in winter may enhance leaching and threaten groundwater, affecting abstractions and groundwater-fed ecology. |
| Change in Storminess | Summer storms, following extended dry periods, may reduce water quality, affecting aquatic life.<br>Storms may lead to more Combined Sewer Overflows and impacts on water quality, affecting aquatic life. |
| Increase in evaporation | Reduction in open water storage e.g. in lakes, which may affect marginal habitats and abstraction. |

Adaptation strategies require a great deal of further research to estimate the impacts of climate change on water resources in Northern Ireland. SNIFFER (2007) recommends that this research should focus on long-term impacts on supplies and water quality effects. Looking at water quality effects would require an inter-disciplinary approach involving water resources, fisheries, agriculture and conservation. In particular, they mention that there are particular uncertainties associated with groundwater effects and with the nature of future rainfall (e.g. distribution). Monitoring will be essential to support this research.

Adaptive strategies are suggested in Table 8.4 of SNIFFER 2007 (and reproduced below in Table 7), and options for maintaining water quality and the health of aquatic ecosystems include:

- Source control, including changes to catchment management and farm practices and reduction of runoff to sewers;
- Creation of wetlands and buffer strips adjacent to rivers;
- Management of invasive species;
- Improved groundwater protection;
- Flow augmentation or water transfer;
- Addition of oxygen to depleted rivers;
- Improved wastewater treatment works;
- Improved effluent cleaning.

SNIFFER 2007 recommends that the short-term focus should be on research and also preparatory work for schemes with long lead times e.g. reservoirs. They identify that adaptation to climate change may also be realised through compliance with legislation such as the WFD and Nitrates Directive and that consideration should be given to adaptation in Programmes of Measures and similar action plans.

***Coastal and Flood Defence***

The Rivers Agency is an executive agency within DARD and it has the statutory responsibility for drainage and flood defences for Northern Ireland. The potential impacts of climate change on this sector include (see Table 9.3 SNIFFER 2007 for full account):

- Wetter winters: Increased fluvial flooding, affecting floodplain areas including settlements, farms, agricultural land and natural heritage. Increased pluvial flooding, with particular impacts on urban infrastructure, built heritage, business, homes, the economy and health.
- Drier summers: May delay the onset of flood season, with benefits in terms of flood risk.
- Warmer winters: Will reduce snow-related flood events, with benefits to those flood plain areas which traditionally suffered from such events.

The approach towards adaptation strategies at present can be characterised by this sector as building adaptive capacity, although there are elements of 'wait and see' and the adoption of adaptive actions (SNIFFER, 2007). Flooding is not as severe in Northern Ireland as it is in other parts of the UK, and the impacts of climate change, particularly at the coast are more uncertain. Therefore, more research is required in the short term. The strategic assessment of flood and erosion risk under climate change (most appropriate on a catchment or coastal cell basis) is identified as an initial adaptation strategy for many of the impacts identified (see Table 9.4 in SNIFFER 2007).

**Table 7** Impacts and Adaptation Summary: Water Resources (Table 8.4, SNIFFER 2007)

| Ref | Impact on receptor | Public Service Area* | Effect on public services | Risk | Resource implications | Adaptation strategy^ | Responsible public sector body |
|---|---|---|---|---|---|---|---|
| 1 | Increased rainfall causing erosion of soil and leaching of agrochemical and agricultural wastes with problems for aquatic life, abstractions and river users. | Water supply; Leisure; Conservation. | May affect ability to provide clean environment; lower compliance with water quality standards; will cost more to treat water. | Minor threat | Increase in costs | Changes to catchment management and farm practices, improved treatment works. | Water Service, Local Councils, EHS |
| 2 | Increased winter rainfall provides opportunity for water storage by Water Service and farmers. | Water supply; Business support. | Additional water available (to partly offset summer losses) | Major opportunity | Increase in costs – new infrastructure | Build or increase capacity of reservoirs. | Water Service, DARD |
| 3 | Lower flows cause problems for users relating to abstraction, ability to dilute effluent, aquatic ecology and recreation. | Water supply; Leisure; Conservation. | May affect ability to provide clean environment; lower compliance with water quality standards and effluent discharge consents; problems with abstraction. | Major threat | Increase in costs | Winter storage / recharge and summer augmentation; water transfer; improved effluent cleaning. | Water Service, Local Councils, EHS |
| 4 | Reduction in volume of sewer base flow may result in blockages, leading to environmental health and flooding problems. | Water supply. | Will require cleansing. | Minor threat | Increase in staff time | Cleansing; sewer re-design. | Water Service |
| 5 | Drier, hotter summers will increase demand for water and water-related products and activities affecting ability of abstractors to meet requirements. | Water supply; Leisure; Conservation; Community awareness. | May become more expensive or difficult to meet demand. Farmers may also have problems. | Minor threat | Increase in costs | Demand management; increase supply for peak periods. | Water Service, DARD, Local Councils, Community Groups |
| 6 | Drier, hotter summers will increase demand for water efficient products. | Business support. | Opportunity to facilitate new industry. | Minor opportunity | Staff time | *Assist business start-up*. | DETI, Invest NI |
| 7 | Lower summer runoff leading to reduced flushing of estuaries and lakes with implications for shell fisheries, lake ecology and abstractors. | Water supply; Health advice and promotion; Conservation. | Lower compliance with quality standards; will cost more to treat water. | Minor threat | Increase in costs | *More regular monitoring*; improved treatment works. | Water Service, EHS, Food Standards Agency, Local Councils |
| 8 | Increased temperatures may cause problems with river and reservoir water quality e.g. DO depletion, algal blooms, physiological impact on fish. | Water supply; Conservation. | Lower compliance with water quality standards. | Major threat | Increase in costs | Addition of oxygen to rivers; flow augmentation. | Water Service, EHS |
| 9 | Higher evaporation and lower inflows leading to reduction in open water storage e.g. Lake Neagh, which may affect marginal habitats and abstraction. | Water supply; Conservation. | Deterioration of designated sites; less water for abstraction. | Minor threat | Increase in costs | Augmentation; *strategies to cope with greater fluctuations in water level*. | Water Service, EHS |
| 10 | Increase in pests and change in life cycle of aquatic and land-based organisms. | Conservation. | Change quality of designated sites. | Minor threat | Increase in costs | Management of invasive species and site conservation. | EHS |

| Ref | Impact on receptor | Public Service Area* | Effect on public services | Risk | Resource implications | Adaptation strategy^ | Responsible public sector body |
|---|---|---|---|---|---|---|---|
| 11 | Lower summer groundwater tables may increase risk of pollution infiltration. | Water supply; Conservation. | May damage groundwater-fed ecology and increase cost of water treatment for private abstractors. | Minor unknown risk | Increase in costs | Revision of areas of groundwater protection; *monitoring*. | Water Service, EHS |
| 12 | Increased soil wetness in winter may enhance leaching and threaten groundwater. | Water supply; Conservation. | May damage groundwater-fed ecology and increase cost of water treatment for private abstractors. | Minor unknown risk | Increase in costs | Revision of areas of groundwater protection; *monitoring*. | Water Service, EHS |
| 13 | Saline intrusion of freshwater aquifers due to sea level rise, affecting abstractions. | Water supply. | May increase cost of water treatment for private abstractors. | Minor unknown risk | Increase in costs | Freshwater recharge; accept loss. | Water Service, EHS |
| 14 | Storms may cause more Combined Sewer Overflows, damaging aquatic life. | Water supply; Leisure; Conservation. | Will affect fish, ecological status of rivers and use for leisure. | Major threat | Staff time for monitoring and clear-up | Upgrade sewage treatment works; reduce runoff to sewers. | Water Service, EHS, Local Councils |
| 15 | Summer storms, following dry periods, may lead to high pollutant loads, damaging aquatic habitats. | Conservation. | Will affect fish and status of rivers. | Minor threat | Staff time for monitoring | Source control; create wetlands and buffer strips adjacent to rivers. | EHS |

## National Policies

Department for Environment Food and Rural Affairs (DEFRA)

DEFRA published 'Climate Change The UK Programme 2006: Tomorrow's Climate Today's Challenge' in 2006. The report includes a chapter applicable to Northern Ireland and details the actions that are being taken in relation to climate change. Some of the work undertaken and completed by the DoE (NI) includes:

- Incorporation of climate change into the Sustainable Development Strategy;
- Analysis of the impacts of climate change which the DoE (NI) promotes and is developed and co-ordinated through UKCIP;
- Publication of a strategy development document on climate change (SNIFFER, 2002);
- Publication of information on impacts and adaptation strategies for Northern Ireland (SNIFFER 2007);
- Maintenance of a database on indicators of climate change by the EHS (EHS, 2004); and
- A Renewable energy policy - the Northern Ireland Renewables Obligation, and a funding package of £59M for environment and renewable energy.

Sustainable Development Strategy for Northern Ireland

In Northern Ireland's Sustainable Development Strategy 'A Sustainable Development Strategy for Northern Ireland: First Steps towards sustainability' (DoE, 2006), a chapter is devoted to climate change and energy (Chapter 4, p.91). The strategic objectives on climate changes and energy are:

- To reduce greenhouse gas emissions, principally by promoting energy efficiency and the use of renewables;
- To establish Northern Ireland as a world class exemplar in the development and use of renewable energy;
- To plan and prepare for climate change impacts in Northern Ireland.

The third objective has been achieved by the publication of SNIFFER 2007, detailed above, and it is envisaged that this will be updated every 5 years.

DoE have also committed to continue to maintain a database on 13 indicators of climate change (see Section 2.0 for details).

## Research

Scottish and Northern Ireland Forum for Environmental Research (SNIFFER)

SNIFFER identifies and manages environmental research on behalf of the Scottish Environment Protection Agency (SEPA), Environment and Heritage Service (EHS), the Scottish Executive, Scottish Natural Heritage (SNH) and the Forestry Commission - and other stakeholders. They carry out research on climate change and have a number of on-going and completed projects on the topic (see www.sniffer.org.uk). SNIFFER recently completed a project titled 'Preparing for a changing climate in Northern Ireland' prepared on behalf of the Department of Environment in Northern Ireland and the Environment and Heritage Service. This report examines the ways in which Northern Ireland must prepare to meet both the opportunities and threats presented by the impacts of a changing climate. It focuses specifically on the impacts on and the need for adaptation by, the public sector in Northern Ireland, and is discussed further in Section 5.0 below. SNIFFER also prepared the report 'Implications of Climate Change for Northern Ireland: Informing Strategy Development' (2002).

Department of Environment Northern Ireland (DoE (NI))

The Climate Change Unit works with GB Departments and other Devolved Administrations to develop and implement a wide range of government policies in Northern Ireland. Northern Ireland is playing its part in reducing carbon and greenhouse gas emissions in line with UK wide targets. It plays a role in ensuring that the impacts of climate change are known and that adaptation strategies are adopted. In 2004, the DoE compiled a set of Climate Change Indicators for Northern Ireland – these include: air temperature; the number of snow days each year; and the arrival date of the swallow (EHS, 2004). These indicators are specific to Northern Ireland, and provide a good idea of how climate has been changing up to the present and how the environment has been responding (see section 2.0 for more). Climate change impacts and adaptation are focused on e.g. through the preparation of reports such as SNIFFER (2007).

DEFRA

The UK Government commissions research to support the development of the policy response to man-made climate change. It funds a Climate Prediction Programme at the Met Office's Hadley Centre. Their work continues to underpin the Government's climate change policy. The UK Government also contributes to the development of the Advanced Along Track Scanning Radiometer (AATSR) satellite instrument (to measure highly accurate sea surface temperatures) on the European Space Agency's ENVISAT satellite.

The UK Government also sponsors the UK Climate Impacts Programme (UKCIP) which was set up in 1997. The Programme has attracted a large number of representatives from both public and private sector organisations who have participated in regional and sector assessments of the impacts of climate change.

Elsewhere, the UK supports research which will help developing countries deal with climate change. Current research includes an assessment of how to improve climate modelling and monitoring for Africa, and an investigation into the impacts of climate change on Chinese agriculture.

The UK also plays a significant role in the Intergovernmental Panel on Climate Change, which has carried out major studies into the science, impacts and response measures to climate change since it was set up in 1988.

In 2005-06, DEFRA spent more than £35 million on research, from funding the Hadley Centre who analyse the trends in the climate system, to studying the effects of changing temperatures and rainfall on the tourism industry.

In March 2006 DEFRA launched the UK Government's new Climate Change Programme. The new programme, which includes a Northern Ireland chapter, sets out the Government’s commitments both at an international and at a domestic levels which aims to meet the challenge of climate change.

# 5.0 CLIMATE CHANGE AND THE WATERFRAMEWORK DIRECTIVE

The report '**Climate Change and the European Water Dimension'** produced by the Directorate General Joint Research Centre, details climate change impacts on European Waters (http://www.espace-project.org/publications/Library/Climate_change_impacts_on_European_waters-Fact_Sheet.pdf). The report is used to assess existing water policy and whether it can accommodate real or anticipated impacts of climate change. Recommendations were made and those key to the water sector were:

Adaptation and Some Actions:

- Develop and apply regional climate change models at the sub-regional and river basin scale to assess potential response of land and water systems, and mitigation strategies with associated costs.
- Quantify at the European and river basin scale the impacts of climate change on *water quality* of surface water and ground water, and water classification for river basin management by coupling river basin – coastal zone models in a climate changed world.
- Quantify at the European and river basin scale the impacts of climate change on *water quantity*, its spatial-temporal distribution including extreme events such as floods and droughts, and availability of surface and ground water under different scenarios and uses, and the associated costs of adaptation.
- Evaluate the effectiveness of different protection measures in trans-national river basins with hydrological models as a response to possible increase in extreme events.
- Evaluate the impacts of climate change on the remobilization, redistribution and emission of contaminants (as a result of warming and extreme events.
- Establish long term monitoring at the pan- European scale of marine/coastal systems using earth observing satellites and other tools of those parameters sensitive or indicative of climate change.

The main text of the Water Framework Directive (WFD), Common Implementation Strategy guidance (CIS) and associated policy documents were reviewed by the EEA to assess the way climate change is being treated (EEA, 2007). Their conclusion was that while climate change was not included in the main text of the Directive, it can include the longer term implications of climate change. It also states that '*if sufficient account of climate change implications is taken, the WFD can provide a powerful adaptive management tool*'. The CIS's projected work includes consideration of how to include climate change more into water management e.g. under the WFD (EEA, 2007). In addition, an impacts and adaptation work programme was set up as part of the European Climate Change Programme in 2006 (ECCP II). It recognises that the WFD is a key instrument in climate adaptation policies in the water sector (EEA, 2007).

Climate change has the potential to alter a number of biological, chemical, hydrological and quantitative parameters used by the WFD to assess ecological status (EEA, 2006). A study conducted by Wilby *et al.* (2006), summarised these impacts on some of these parameters, and is copied below in Table 8 for information.

EEA (2007) also list some key questions and concerns in relation to the delivery of the WFD, such as:

- climate change will alter hydromorphology, and physico-chemical quantitative parameters underpinning the biological status of water bodies;
- climate change will increase the frequency of extreme flooding events;
- climate change will increase the frequency of drought conditions and water scarcity. (EEA, 2007)

**Table 8** Potential climate change impacts on ecological status (Wilby *et al*., 2006)

**Table 2.1 Potential climate change impacts on ecological status**

| Parameters | Examples of impacts |
|---|---|
| Physico-chemical | Changes in water temperature and dissolved oxygen<br>Decreased dilution capacity of receiving waters<br>Increased erosion and diffuse pollution<br>More frequent flushing of combined sewer outflows<br>Photoactivation of toxicants<br>Exceedence of water quality standards |
| Biological | Changing metabolic rates of organisms<br>Changing ecosystem productivity and biodiversity<br>Climate space of plant and animal distributions<br>Fish migration patterns and dispersal corridors<br>Increased eutrophication and prevalence of algal blooms<br>Changes in aquatic fauna and flora at reference sites<br>Changes in species assemblages in designated areas |
| Hydro-morphological | Changing river flows and sea levels lead to coastal erosion<br>Indirect impacts from land-use practices and agriculture<br>Hydrological connectivity of slopes, channels, and coastal zones<br>Diffuse and point sources of sediment<br>Long-term bed-load and channel change<br>Geomorphological processes creating dynamic/diverse habitats |

**Source**: Wilby *et al*., 2006b.

EEA (2007) state a number of areas in which climate change has the potential to impact on the basic principles and tools of the WFD including:

1. Climate implications for reference conditions and status definitions;
2. Economic analysis and climate change uncertainty;
3. Disproportionate cost and technical feasibility;
4. Climate change, natural variability and programmes of measures.

The report states that '*Despite the large uncertainties attached to climate change projections over WFD timescales there are several strategies that could be pursued to ensure that programme of measures (POMs) realise their intended environmental outcomes*:

- Measures should be considered in terms of the time needed to implement them and the intended design life with respect to anticipated rates of climate change. 'No regrets' POMs that are quick to implement and have low climate sensitivity such as changing food-stuffs for livestock to reduce diffuse nutrient loads), may be preferable to measures that have long planning horizons, high capital costs and structural inertia (such as new water treatment works);
- Improved long-range forecasts are a further example of a 'no-regrets' adaptation option. Although decadal forecasting is still in its infancy, early results show promise. As with seasonal forecasting, there may be scope for collective action on improving forecasting systems for Europe;
- Measures can be appraised using the full range of historic climate variability data made possible by data mining or reconstruction. If WFD objectives are not met under these circumstances it is unlikely that the measures will be robust to climate change over the coming decades. The appraisal process may even lead to a revision (downwards) of baseline goods and services. For example, inclusion of data about early nineteenth century droughts reduces estimates of present reliable water supplies from some reservoirs in the east of England by as much as 16% (EA, 2006).
- In the absence of certain climate change projections of lengthy historic records, climate sensitivity testing can still be applied to each option. For example, the costs and benefits of flood defence schemes in the United Kingdom are evaluated using a 10% increase in peak flows up to 2025 and 20% increase thereafter up to 2100. Screening of options using standard climate change allowances can help test the relative robustness of each measure in the face of deep uncertainty;
- Finally, even with perfect knowledge of the climate evolution over the next few decades, the outcome of different POMs may be far from certain. For example, monthly river flow projections for the 2020s prepared for the UK water companies

strategic water plans show large uncertainties due to the water resource model structure and parameterisation. These arise because of poorly characterised or partially understood representation of natural processes in the models. Improving existing decision-support tools may be a more tractable option than reducing uncertainty in near-term climate change projections.

(EEA, 2007, p.31 & 32)

# 6.0 THE WAY FORWARD

The EEA and the German Ministry for Environment carried out a climate change and water survey, which was distributed to the national focal points and the pilot river basin districts (EEA, 2007). It was undertaken to provide a 'stock take' of existing practice, and collect information on awareness, vulnerability to climate change, and to compile potential adaptation and measures and strategies. Ireland was a respondent to this survey. The research needs especially at a European level, were identified in the following areas:

- **Climate change modelling**: there was general agreement on the need for enhanced regional climate change scenarios, or the scaling down from global to regional and from regional to local climate scenario information. Uncertainties also need to be addressed and the consequences of climate change versus natural variability are still not known;
- **Modelling of changes in water resources**: requests were made for regional and local data to be merged with hydrological models, and to improve the accuracy of hydrological and hydraulic models, including groundwater. The need to improve the coupling of climate and hydrological models was also highlighted;
- **Observation**: with respect to the observation of climate change trends, respondents pointed to the need to maintain observation networks, and suggested including remote sensing techniques in hydrological monitoring;
- **Impacts and vulnerability**: the need for research on the vulnerability of European societies to climate change impacts was felt by many Member States. Respondents were concerned about several specific issues, including water-related climate change impacts on individual sectors (for example impacts of heavy rainfall and drought on sewage systems), the quantification of impacts, the socio-economic consequences of climate change impacts (for example of sea-level rise), the relationship between climate change impacts and land use (e.g. impacts on peatlands, sensitivity and responses of habitats and species), research into the long term use of recycled water in agriculture, and desertification.
- **Adaptation**: several respondents saw a need for research to develop adaptation measures and assess their effectiveness and efficiency. For example, research should help to design tools that demonstrate the economic benefit and cost-effectiveness of adaptation at the river-basin scale, and to develop indicators for successful adaptation measures.

(EEA, 2007)

It is a recommendation from this literature review that downscaling of climate change models, and hydrological modelling is further assessed as part of scenario development for this task.

Climate change modelling and the scaling down from global to regional to local models is seen as a priority in order to improve scenario development and improve information on climate impacts and vulnerability, and inform adaptation measures. With better regional and local model information, and uncertainties reduced, incorporation of climate change in to River Basin Management Planning can be informed. Some downscaling of global models has already been performed for Ireland (Sweeney and Fealy, 2006). Improved hydrological modelling will also better inform this process. Again, some work has already been conducted on this subject (Elsaesser *et al*., 2006; Semmler *et al.*, 2006; Murphy and Charlton, 2006).

In December 2006, the Water Directors agreed at their meeting in Finland to start a new Common Implementation Activity on water and climate change. A milestone succeeding this agreement was the Conference on Climate Change and the EU Water Dimension, held in Berlin on 12-14 February 2007. Key messages from this Conference are:

- It is time to adapt now! Scientific evidence urges action;
- EU water and marine policy should be used to factor in climate change;
- A successful adaptation strategy needs a common and integrated approach;
- The “user pays principle” needs to be fully implemented;
- Further research activities are necessary;
- Do not forget the world outside the EU!

With these key messages in mind, the new CIS activity on Climate Change will focus on making the best use of existing EU water legislation, identifying adaptation measures at different scales and providing input to the science community.

Ireland and Northern Ireland will include a background document on Climate Change in their River Basin Management Plans.

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# APPENDIX I

## EPA-Funded Research: Climate Change

Reports from completed projects are available on the EPA website at
http://www.epa.ie/EnvironmentalResearch/ReportsOutputs/

Completed doctoral theses are available through the relevant college library.

| | | | |
|---|---|---|---|
| PROJECT TITLE | Community Climate Change Consortium for Ireland (C41) | | |
| LEAD ORGANISATION | Met Eireann | | |
| CONTACT | Dr. Peter Lynch | | |
| PROJECT TYPE | Capability Development | | |
| START DATE | 15/12/2001 | STATUS: | Ongoing |
| TOTAL BUDGET (€) | 1,270,000 | | |
| PROJECT DESCRIPTION | The overall objective of C4I is to consolidate and intensify the national effort in climate change research, by building a capability for carrying out regional climate modelling in Ireland, and putting in place a framework and a mechanism whereby the entire community of environmental scientists in Ireland can benefit from a Regional Climate Modelling and Prediction Facility. Greater opportunities for participation in upcoming European and other international research programmes will be created. The C4I consortium will greatly improve our chances of attracting substantial European funding for ongoing research. Specific targets of the Project include the following:<br>- A consolidated consortium of climate change researchers in Ireland<br>- A Regional Climate Analysis, Modelling and Prediction Centre (RCAMPC)<br>- A user interface between the modelling centre and Irish researchers<br>- A computer network interfacing RCAMPC to users<br>- A powerful educational facility for students of environmental science<br>- Greatly improved opportunities for participation in European research programmes<br>- A comprehensive plan for continuation of the consortium.<br>The Regional Climate Analysis, Modelling and Prediction Centre, based at the HQ of Met Éireann in Glasnevin, will be a focus of excellence in climate change, with a critical mass of expertise in climatology, dynamical meteorology, numerical analysis and advanced parallel computing. The Regional Climate Model (RCM) to be implemented will be based on the HIRLAM model (High Resolution Limited Area Model). The Centre will provide a vital service to climate and environmental scientists throughout the country. It will provide substantial assistance to scientists studying climate change, to assist them in utilizing the climate model output for their analysis, to interface their applications models to the main RCM and to carry out integrations with appropriate configurations of the RCM. | | |

Updated August 2005

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| PROJECT TITLE | Accounting For Greenhouse Gas Sources And Sinks In Major Irish Land-Use Categories: Establishment of a Co-ordinating Centre For FLUX Measurements (CCFLUX). | | |
| LEAD ORGANISATION | Trinity College Dublin | | |
| CONTACT | Prof. Michael Jones | | |
| PROJECT TYPE | Capability Development | | |
| START DATE | 01/12/2001 | STATUS: | Ongoing |
| TOTAL BUDGET (€) | 794,853.38 | | |
| PROJECT DESCRIPTION | In support of the European post-Kyoto policy, the CCFLUX project will measure at the field-scale greenhouse gas (GHG) fluxes from major land-use categories to calculate the net global warming potential (GWP) associated with Irish land-use ecosystems. The three key objectives of for CCFLUX are:<br>(i) To provide the EPA with a balance sheet detailing GHG emissions by sources and removal by sinks for selected major Irish land-use categories,<br>(ii) To furnish scientists with the process knowledge required to model GHG fluxes, and<br>(iii) To develop rational mitigation strategies to reduce national GHG emissions. Whilst much attention to date has focussed on greenhouse gas sources and sinks associated with forested landscapes, less attention has been directed towards agricultural, particularly arable and grassland, ecosystems. There is considerable potential for enhancing carbon sinks in agricultural soils through various management practices. In order to achieve its objectives, CCFLUX will:<br>(i) Measure and model GHG fluxes at the field scale for arable systems with contrasting management regimes e.g. conventional versus reduced tillage,<br>(ii) To integrate data from other funded projects on GHG flux measurement in Ireland i.e. grasslands and forest ecosystems and<br>(iii) To contribute to the production of a regional distribution map of GHG fluxes (sources and sinks) for Ireland. | | |

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| PROJECT TITLE | Climate Change in Ireland: Refining the Impacts | | |
| LEAD ORGANISATION | NUI Maynooth | | |
| CONTACT | Dr. John Sweeney | | |
| PROJECT TYPE | Capability Development | | |
| START DATE | 01/12/2001 | STATUS: | Ongoing |
| TOTAL BUDGET (€) | 697,598.67 | | |
| PROJECT DESCRIPTION | An initial exercise in statistical downscaling suggests a mean January temperature in the range 6-7.5°C by mid century over much of the southern half of Ireland, and 7.5-9°C along southern coasts. Mean July temperatures of 16.5-18°C are indicated for as far north as coastal Co. Antrim and Derry. Precipitation scenarios suggest that winter increases averaging 11% will be observed over most of Ireland by the same time combined with summer reductions of the order of 25%. These changes. If realised, can be expected to have significant impacts in the areas of agriculture, water resources, biodiversity, the marine environment and sea level. This project seeks to refine the above projections and explore the likely impacts of climate change in Ireland in greater detail. To do this an enhanced temporal resolution of daily input data will be employed which will enable extreme events to be better characterised. Agricultural impacts will be examined in a holistic manner encompassing growing season, forage supply, field accessibility, soil damage, pollution potential, waste storage and disposal requirements. Water resource changes will be modelled on a catchments basis using the HYSIM model. Comparative analysis of key urban and rural catchments will be undertaken to elucidate the policy implications of climate change for water resource management, in particular the return period for design floods and droughts. In the area of natural ecosystems, spatial aspects of habitat change arising from projected climate changes will be examined as will the response of selected Irish species to ongoing climate change using phenological records. The statistical downscaling approach being undertaken here to drive impact models in various areas will enable synergism to be achieved with the regional climate modelling approach being undertaken in another project in the RTDI programme. This will aid verification of suggested climate change scenarios. As a result of the project the requirements of the sub programme's aims to 'develop practical methods for the integration of environmental considerations into policies and programmes of the main economic sectors' should be assisted. | | |

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| **PROJECT TITLE** | CELTICFLUX - Measurement and Modelling of GHG Fluxes from Grasslands, Forests and Peat lands in Ireland. | | |
| **LEAD ORGANISATION** | University College Cork | | |
| **CONTACT** | Prof. Gerard Kiely | | |
| **PROJECT TYPE** | Capability Development | | |
| **START DATE** | 01/12/2001 | **STATUS:** | Ongoing |
| **TOTAL BUDGET (€)** | 907,889.39 | | |
| **PROJECT DESCRIPTION** | We are measuring the $CO_2$ flux from grassland in County Cork since July 2001. From May/June 2002, we will be measuring the $CO_2$ flux from a peat land in County Cork and also from managed grassland at Johnstown Castle. Over the project period, we will have five years of continuous $CO_2$ fluxes, which will give us an understanding of the seasonal and inter-annual variation. For one year, at the peat land site we will also be measuring the $CH_4$ flux. For one year at each of the two grassland sites we will be measuring the $NO_2$ flux. Both the $CH_4$ and $NO_2$ concentrations are determined using a tunable diode laser absorption spectrophotometer. All gas concentration measurements are made at 10Hz. We are currently developing models at the plant and field scale to model the GHG fluxes from the two different ecosystems. The goal of the project is to help Ireland to estimate its GHG sequestration from the different ecosystems. | | |

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| **PROJECT TITLE** | Assessing the applicability of an emissions trading regime in a small open economy | | |
| **LEAD ORGANISATION** | University College Dublin | | |
| **CONTACT** | Prof. Frank Convery | | |
| **PROJECT TYPE** | Doctorate | | |
| **START DATE** | 01/09/2002 | **STATUS:** | Ongoing |
| **TOTAL BUDGET (€)** | 76,184.28 | | |
| **PROJECT DESCRIPTION** | Emissions' trading has emerged as an important 'flexible mechanism' in the context of meeting Greenhouse Gas Emission targets in the context of the Kyoto Protocol. The European Commission has proposed a draft directive for a EU-wide emissions trading scheme. This project will develop modalities showing how a small open economy such as Ireland can maximise the benefits from participation is emissions trading, both as regards climate change and as a means of addressing other environmental challenges. The methodology will involve a review of theory and practise in other countries, and interviews with key potential 'players' in Ireland and at EU level. | | |

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| **PROJECT TITLE** | Long-term environmental change in lower Lough Corrib and its catchments: a multidisciplinary palaeoecological study | | |
| **LEAD ORGANISATION** | NUI, Galway | | |
| **CONTACT** | Prof. Michael O'Connell | | |
| **PROJECT TYPE** | Doctorate | | |
| **START DATE** | 01/01/2003 | **STATUS:** | Ongoing |
| **TOTAL BUDGET (€)** | 75,000 | | |
| **PROJECT DESCRIPTION** | The project represents the first serious attempt to document long-term changes – both natural and anthropogenic – in the Lough Corrib catchments, the largest freshwater body in the Republic of Ireland. It involves pollen and macrofossil analyses, and stable isotope investigations on thick marl and peat deposits in the lower Corrib basin with a view to investigating, as comprehensively as possible, palaeoenvironmental change over the course of the post-glacial. Limnic changes, including lake levels and trophic status, will be documented, and the effects of climate change and human activity on the limnic and terrestrial environments will be critically studied. | | |

Updated August 2005

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| PROJECT TITLE | Greenhouse Gas Fluxes in Blanket Peat land |
| LEAD ORGANISATION | University College Cork |
| CONTACT | Dr. Gerard Kiely |
| PROJECT TYPE | Doctorate |
| START DATE | 19/05/2003 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 75,000 |
| PROJECT DESCRIPTION | Peat lands are important stores and sinks of greenhouse gases. Despite this very little is known about greenhouse gas (GHG) balances in Irish peat lands. This project will measure fluxes of carbon dioxide and methane in intact blanket peat land using chamber methods. These techniques have been widely using internationally and have been tested under Irish conditions. The project also provides information about the relationship of GHG fluxes to environmental and climatic variables. Modelling will be used to develop annual GHG budgets. These annual budgets will be compared to those developed using flux tower measurements at the same site. |

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| PROJECT TITLE | Modelling of N20 fluxes from Grasslands and CH4 Fluxes from a blanket peat land |
| LEAD ORGANISATION | University College Cork |
| CONTACT | Prof. Gerard Kiely |
| PROJECT TYPE | Doctorate |
| START DATE | 01/08/2003 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 75,000 |
| PROJECT DESCRIPTION | We are measuring $CO_2$ fluxes at Cork grassland for the past year, We have started to measure $CO_2$ fluxes at a further two sites: Wexford Grassland and a Kerry peat land. We have just started to use a Tunable Diode Laser Absorption Spectrophotometer (TDLAS) and a 3D sonic anemometer at a farmed grassland site (County Cork) to measure N20 fluxes (for one year) and will move the TDLAS to managed grassland (nutrients application control) for the second year. In year three we will set up the TDLAS at the peat land site in County Kerry to measure fluxes of $CH_4$. The 10Hz obtained generates 33MB of raw data per day or 1200MB per year. The new TDLAS is the first of its kind in Europe. Data will be used to develop models at the leaf, canopy and field scale. Data will also be used to develop models that can predict how climate perturbations - such as increased $N_2O/CH_4$, increased precipitation and a rise in temperature alter the NEE or the terrestrial carbon sink. The data will include generalisations and extrapolations of annual balances of fluxes over the national estate of grassland (peat land) to provide policy makers with estimates of the source/sinks associated with these two dominant Irish land covers. A database will be updated regularly in a public domain web page and end products will be transferred to policy makers so that mitigation strategies can be developed. This proposal compliments ongoing flux chamber work at the Agricultural Research Station in Wexford and $CH_4$ microbiological work by Dr. Flaherty (University College Galway) and geochemical analysis by Professor Hayes (University of Limerick) |

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| PROJECT TITLE | Climate Change and Health in Ireland: A National Vulnerability Assessment |
| LEAD ORGANISATION | NUI, Maynooth |
| CONTACT | Dr. John Sweeney |
| PROJECT TYPE | Doctorate |
| START DATE | 01/10/2002 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 71,000 |
| PROJECT DESCRIPTION | Climatic controls on the incidence of a range of environmentally related human health problems will be examined under present climate conditions in Ireland. These will include both direct (e.g. heat/cold stress) and indirect (e.g. asthma, food poisoning) impacts. The use of spatially detailed climate scenarios for the middle and end of the century will then be used to model changes in likely incidence at a spatial resolution of $10km^2$. This will be aggregated to Health Board areas and ultimately to a national scale to provide a national vulnerability assessment. Key vulnerable sub groups will be identified for priority monitoring. |

Updated August 2005

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| **PROJECT TITLE** | Greenhouse Gas Emissions and Climate Change - Methane and Nitrous Oxide Emission Factors |
| **LEAD ORGANISATION** | University College Dublin |
| **CONTACT** | Dr. Frank O'Mara |
| **PROJECT TYPE** | Large Scale |
| **START DATE** | 01/11/2000 **STATUS:** Ongoing |
| **TOTAL BUDGET (€)** | 644,841.56 |
| **PROJECT DESCRIPTION** | Estimates of greenhouse gas emissions from Irish agriculture amounted to 32% of national emissions in 1998. The main sources of the agricultural emissions are enteric fermentation (50%), agricultural soils (35%) and manure management (11%). The main gases involved are methane and nitrous oxide (58 and 38% of total emissions, respectively). The methane originates mostly from enteric fermentation in ruminants, while the nitrous oxide originates mostly from agricultural soils. The national inventory for methane from enteric fermentation is calculated using animal numbers and emission factors for the quantity of methane produced per animal per year. Currently international default emission factors published by the Intergovernmental Panel on Climate Change (IPCC, 1996) are used, as no specific national information is available. Emission rates are affected by diet and thus the use of the IPCC default values can result in errors in Ireland's inventory. An objective of this research project is to establish more precise emission factors for enteric fermentation of Irish ruminants. A national farm survey will be carried out to establish the diets of farm animals and waste management practices. These data will be used to establish an improved inventory of annual emissions rates for the national herd. A second objective of the project is to evaluate the range of measures that might be used to reduce emissions per animal. For example, the effectiveness of strategic use of concentrate feedstuffs, type of oil added to the diet, and the addition of substances such as fumaric acid to the diet will be investigated. Nitrous oxide emissions arise naturally from soils and from the application of inorganic and organic nitrogen. Some European studies have shown that grassland has higher emissions per unit of nitrogen fertiliser added than arable land. The few measurements made of nitrous oxide emissions from Irish grazed pasture showed increases in nitrous oxide emissions as nitrogen fertiliser inputs increase. As grassland soils account for over 90% of land use in Ireland, they are an important contributor to Ireland's nitrous oxide inventory. The inventory calculation is based on factors published by IPCC (1996) that again may not accurately reflect the actual situation in Ireland. A third objective of the project is to provide more precise data on nitrous oxide emissions from grazed grassland with particular emphasis on the effect of nitrogen fertiliser inputs. The IPCC defaults values will then be evaluated in the light of data generated. In conclusion, this project will provide more accurate inventories of a significant proportion of Ireland's greenhouse gas emissions, and will investigate strategies for reducing the quantities of these gases emitted. |

Updated August 2005

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| **PROJECT TITLE** | Greenhouse Gas Emissions and Climate Change - Impact of Land Use and Land-Use Change on Carbon Emission/Fixation |
| **LEAD ORGANISATION** | Queen's University Belfast |
| **CONTACT** | Dr. Roy Tomlinson |
| **PROJECT TYPE** | Large Scale |
| **START DATE** | 01/11/2000 **STATUS:** Ongoing |
| **TOTAL BUDGET (€)** | 153,954.47 |
| **PROJECT DESCRIPTION** | Understanding greenhouse gas emissions from anthropogenic and natural sources as well as sequestration of carbon from the atmosphere into 'sinks', is an important factor in assessment of the national contribution to reducing such emissions. Soils store more carbon than vegetation, but plants are the conduits through which $CO_2$ is taken from the atmosphere and soil carbon stores are changed. In order to protect, maintain and where practical increase carbon stores it is essential to know the carbon stocks and fluxes of land cover types and land-cover/soil combinations. The Revised IPCC Guidelines for National Greenhouse Gas Inventories 1996, demonstrate that inventories of carbon stocks in vegetation (biomass) require knowledge of the extent of land cover types in Ireland and the carbon density (tonnes C/ha) of each cover type. In this research the extent of cover types is being taken from the CORINE Land Cover database for 1990 and later will be taken from that for 2000. Carbon density for each cover type is being derived using a variety of sources, including annual agriculture statistics, and following established methodology. Forests account for a large proportion of biomass carbon stocks and additional methods of estimating their contribution are being pursued. Inventory of soil carbon stocks requires maps of soil types, property data for those soil types and land cover on them, so that soil carbon densities (tonnes C/ha) can be calculated. The project is compiling a database containing the dominant soil in each 2km by 2km grid square, the property data for those soils and the dominant land cover (in 1990 and 2000) on each dominant soil. Peat is a major soil carbon store and particular attention is being paid to estimates of carbon densities for peat of different depths. |

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| **PROJECT TITLE** | Greenhouse Gas Emissions and Climate Change - Modelling Carbon Fluxes from Irish Peat lands, based on extending PORTACH and PEATSAT including the development of a national carbon fluxes inventory for Irish Peat lands |
| **LEAD ORGANISATION** | University College Dublin |
| **CONTACT** | Prof. Shane Ward |
| **PROJECT TYPE** | Large Scale |
| **START DATE** | 01/11/2000 **STATUS:** Ongoing |
| **TOTAL BUDGET (€)** | 134,592.24 |
| **PROJECT DESCRIPTION** | Ireland has a large peat resource, covering some 17 % of its total land area. Peat lands contribute significantly to the national fluxes in greenhouse gases (GHG). Estimated methane emissions from peat lands (ca. 0.4 Mt/annum) rank alongside those from ruminant animals (ca. 0.49 Mt/annum) as the main sources of methane emissions in Ireland. Therefore, any inventory of Ireland's GHG fluxes should take account of those associated with peat lands. Young peat lands actively sequester atmospheric carbon (as $CO_2$), while old mature bogs emit considerable quantities of methane. There are several peat land-use policies that influence carbon fluxes (emissions/sequestration); hence effective management of peat lands can impact on national GHG fluxes. Given the extent of peat lands and their carbon fluxes, it is necessary to quantify the national peat land resource, classify it, assess the GHG fluxes associated with each class and hence estimate the contribution of peat lands to the total national GHG fluxes. This project will address these by:<br>1. Using satellite imagery to quantify and classify the national peat resource;<br>2. Modelling the GHG fluxes associated with each class;<br>3. Interfacing the satellite imagery with the GHG fluxes models to produce an inventory of the total national GHG fluxes associated with peat lands and peat land-use change (e.g. afforestation, wetlands, agriculture).<br>The study will produce an assessment of the significance of GHG fluxes from peat lands, based on both current land-use and future change projections. It will enable the significance of various peat land-use options to be assessed and will position their significance in a national context. Current estimates indicate that changes in peat land-use can make a tangible contribution towards reducing Ireland's GHG emissions (ca. 2 to 5 % reduction). |

Updated August 2005

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - Emission Inventories for HFC, PFC and SF6 |
| LEAD ORGANISATION | University of Bristol |
| CONTACT | Dr. Simon O'Doherty |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 **STATUS:** Completed (Report Available) |
| TOTAL BUDGET (€) | 40,631.62 |
| PROJECT DESCRIPTION | This project covers the verification of emissions calculated conventionally against those derived from statistical analysis of atmospheric concentrations measured at Mace Head, Co. Galway, and back trajectories (the Nuclear Accident dispersion model [NAME]). The conventional emissions inventory is "top-down" and uses definitive European data on activity - the sales of these substances within Europe - coupled with rigorously tested emission functions to calculate European emissions. The European emissions inventory can be verified against the emissions calculated for Europe using the NAME model. Further subdivision into emissions from each EU member state is accomplished partly with the data that these countries submitted to the UNFCCC and partly using national econometrics to piece together a homogeneous data set that is consistent with the total European data. Finally, in order to assist with the back trajectory dispersion modelling, the emissions are distributed geographically within a member state, based on population density. It is intended that the process is iterative, with verification leading to improvements in both modelling processes so that uncertainties can be significantly reduced. The results described in the project correspond to the first iteration in this process, between a calculated Irish inventory and that derived from measurements using NAME. European emissions calculated from activity data and emission functions have been verified against those calculated from atmospheric analyses and back-trajectory calculations using the NAME model.<br>Project conclusions:<br>Emissions from Ireland have been calculated as a subset of the European emissions and distributed geographically by population density. The Irish emissions inventory has been verified against that calculated using NAME. On average, there is very little difference between the two (2%) but this hides substantial differences for individual compounds. Nevertheless, it is clear that the absolute values of these emissions are placed in similar categories of size by both methods. In view of the wide differences in methodology, this adds confidence to the estimates. It has been demonstrated that using the NAME Lagrangian model it is possible to determine the fraction of air arriving at Mace Head from different regions (on a European scale) at different times over a 6-year period. Using this matrix of data along with observations of a range of pollutants at Mace Head it is possible, using the best-fit algorithm called simulated annealing, to derive estimates of emissions over Western Europe. The algorithm starts from a randomly generated emission map and iterates towards the best solution, the process is repeated many times to build up an ensemble of different solution possibilities, all local minima to the equations. The errors due to inaccuracies in the modelled meteorology and dispersion and the observations are difficult to quantify and vary from species to species. The contributions from Ireland to European emissions of HFCs, PFCs and SF6 are very small. The HFC contribution in both 1995 and 1998 was 0.8% of the total emission of manufactured HFC (i.e. excluding HFC-23). Similarly the SF6 contribution was 0.2% of the total. These results show a small growth in PFC emissions, from 0.25 to 0.33%, but the increase is not significant. |

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - Emission Inventories for HFC, PFC and SF6 |
| LEAD ORGANISATION | Clean Technology Centre |
| CONTACT | Dermot Cunningham |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 STATUS: Completed (Report Available) |
| TOTAL BUDGET (€) | 41,892.47 |
| PROJECT DESCRIPTION | An inventory of emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) was estimated for Ireland for 1998 in this study. Such inventories are required to be reported under the United Nations Framework Convention on Climate Change (UNFCCC). This inventory has been compiled through data obtained from relevant sectors and in accordance with UNFCCC guidelines. Each of the industrial gases has a different global warming potential. Therefore overall estimates are reported in terms of kilo tonnes of carbon dioxide equivalent. Estimates in terms of tonnes of gas are also included within the final report. The estimated industrial gas emissions account for 0.2 – 0.3% of all greenhouse gas emissions in Ireland in 1998. The usage (potential emissions) and actual emissions figures are broken down into the individual sources in the main report. The major users of the gases in Ireland in 1998 in terms of carbon dioxide equivalent are the refrigeration and air conditioning industry, the semiconductor manufacturing industry, electricity utilities, and in certain manufacturing industry for leak detection. It was found that none of the industrial gas source categories are key source categories, i.e. when all source categories for the six gases are summed together in descending order of magnitude, the threshold of 95% of total greenhouse gas emissions is reached before the industrial gas source categories are reached. Therefore Tier 1 methodologies are sufficient according to IPPC but Tier 2 is encouraged. Tier 2 methodologies have in fact been used in the estimation of emissions for the majority of sources. Changes in the use of industrial gases since 1998 include increased usage in refrigeration, in metered dose inhalers and an increase in semiconductor production with a corresponding increase in gas usage. Issues in relation to the use of industrial gases in Ireland are the absence of tracking of usage of the gases, the difficulty in obtaining usage and emissions data from companies (although it should be noted that several companies were very forthcoming with useful information in this study), the need to increase collection rates of the spent gases, issues in relation to export of the spent gases for recovery or destruction, and isolated reports of deliberate gas release. The latter two issues are also relevant to HCFCs and CFCs, not just HFCs. The elimination of the use of the industrial gases in certain non-essential applications should be considered - silly string and claxons for non-marine safety applications. |

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| **PROJECT TITLE** | Greenhouse Gas Emissions and Climate Change - Assessment of the Impacts of Climate Change in Ireland |
| **LEAD ORGANISATION** | NUI, Maynooth |
| **CONTACT** | Dr. John Sweeney |
| **PROJECT TYPE** | Large Scale |
| **START DATE** | 01/11/2000 **STATUS:** Completed (Report Available) |
| **TOTAL BUDGET (€)** | 164,535.2 |
| **PROJECT DESCRIPTION** | Statistical downscaling techniques have enabled climatic scenarios to be generated for Ireland for 2055-and 2075 at a resolution of 10km2. These suggest a mean January temperature in the range 6-7.5oC by mid century over much of the southern half of Ireland, and 7.5 - 9oC along southern coasts. A general increase of approximately 1.5oC is apparent by 2055. By mid century winters in Northern Ireland and in the north Midlands will be similar to those of Cork/Kerry during the 1961-90 period. Mean July temperatures of 16.5-18oC are indicated for as far north as coastal Co. Antrim and Derry by mid century. General summer increases of approximately 2oC are apparent with highest values to be found inland away from north and west facing coasts. Winter increases in precipitation will on average amount to 11% by mid century, and up to 20% in the northwest. Summer reductions are of the order of 25% in the south and east. Modelling the agricultural impact of these changes produces changes in the types of crops grown and the pattern of agricultural land use. Maize will become a major crop and soybean will become a viable specialist crop in many areas. Yields of many crops will be linked closely to water availability during the summer months. Some, such as potatoes, will be viable only with irrigation. Considerable investment in infrastructure to store winter rain may be necessary in eastern parts. Grass is seen to suffer drought loss over large parts of the south and east of the country and grass silage may be replaced by maize as a forage crop in livestock systems. Increased problems with slurry storage and spreading in the wetter western part of the country may emerge. The HYSIM model was used to predict water resource changes. This suggested that there will be a reduction in annual runoff that will be most marked in the east and southeast of country. Winter runoff is predicted to increase in the west. All areas will experience a decrease in summer runoff, with the greatest reductions in the east of the country. Per capita water availability in this region is only 12% of that applying in the west and northwest. Significant changes in the natural environment and in biodiversity are also anticipated e.g.<br>~ Increases and changes in distribution of migrant species<br>~ Changes in the phenological processes of plants and insects<br>~ Changes in decomposition, productivity and in competitive interactions between plants.<br>~ Increased numbers of generations of many insects<br>~ Greater winter survival rates of invertebrates.<br>~ Changes in migration, hatching, development and spawning of freshwater fish.<br>~ Increased competition for niche space e.g. Arctic Char and other species.<br>~ Changes in bird migration patterns with greater numbers over wintering.<br>~ Earlier breeding of birds and larger and more numerous clutch sizes.<br>~ Changes in the life cycle of bats.<br>Increased warming is expected to have significant adverse effects on peat land systems. There is likely to be an increase in decomposition, a reduction in peat formation, more erosion, changes in species composition, loss of carbon storage potential, increases in CO2 emissions, a possible increase in CH4 emissions, and an increase in the release of pollutants.<br>Prolonged periods of higher summer temperatures may lead to deoxygenation of water in some rivers and lakes. Increasing temperatures may also increase decomposition of organic soils and weathering of rock, resulting in an increase in pH in some water bodies. Species compositions of various habitats are also likely to change in response to higher CO2.<br>In terms of sea-level changes, areas in the south of the country are likely to feel the effects first, particularly low lying coastal locations with little or no natural protection and located on 'soft' or easily erodable material. Coastal floodplains are especially at risk on occasions when a high tide and storm surge couple with a period of intense rainfall leading to a breach in the carrying capacity of the drainage network. Sea-level rise is projected as a serious problem where there is infrastructure at risk of inundation. In Ireland, the impacts of sea level rise will be most apparent in the major cities of Cork, Limerick, Dublin and Galway. 'Hard' engineering of the coastline should however be viewed as a last resort and only then if the benefits outweigh the loss of land. Climate change in Ireland poses threats in some key areas, but also offers opportunities in others. Successfully addressing the issues of adaptation to climate change in Ireland also addresses wider issues of sustainable development and equity at both a local and national scale. |

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| **PROJECT TITLE** | Greenhouse Gas Emissions and Climate Change - Establishment of Indicators of Climate Change in Ireland |
| **LEAD ORGANISATION** | NUI, Maynooth |
| **CONTACT** | Prof. S. Gerard Jennings |
| **PROJECT TYPE** | Large Scale |
| **START DATE** | 01/11/2000 **STATUS:** Completed (Report Available) |
| **TOTAL BUDGET (€)** | 63,941.47 |
| **PROJECT DESCRIPTION** | Primary indicators of climate change were investigated using the Irish meteorological monitoring network supported by Met Éireann. Temperature records indicate that global trends have been largely replicated in Ireland. Cooling to the end of the 1970s followed warming from the first decade of the 20th century to the mid 1940s. Thereafter rapid warming occurred which continues to the present. A stronger warming trend was apparent in Ireland in the 1930s and 1940s than globally. Similarly, mid century cooling continued somewhat later in Ireland and only since the 1990s has warming ahead of the global mean resumed. The 1990s have been the warmest decade in the Irish instrumental record. Most warming has occurred in winter and maxima appear to be increasing more than minima during this season. For spring, summer and autumn, minima are increasing more quickly than maxima. Stronger indicators of ongoing climate change are in evidence when the number of 'hot' and 'cold' days is examined. A 'hot' day was defined as one when the mean daily temperature exceeds 14oC whereas a 'cold' day had a mean below 0oC. A clear trend exists in both these parameters. In midland locations such as Birr and Kilkenny the number of cold days has halved over the past 50 years while the number of hot days has roughly doubled. The frequency of days with minima below 0oC shows significant decreases of approximately 10 days per annum at some locations. At present Irish climate appears to be warming by slightly over 0.25oC per decade. Significant increases in annual rainfall have occurred in northern parts. Malin Head has shown a 10-year moving average increase of over 40% during the 20th century, with 4 out of its 5 wettest years occurring in the 1990s. Locations further south, such as Birr or Rosslare, show decreased receipts. A more pronounced precipitation gradient appears to be becoming established over Ireland. Some of the annual changes in annual reflect divergences in seasonal precipitation receipt with wetter winters in the west and north contrasting strongly with drier summers in the south and east. Much of the change in temperature and precipitation appears related to the North Atlantic Oscillation. This index explains 50% of the Valencia winter temperature variance and 30% of that at Malin Head. This suggests that quasi cyclical changes in 'westerliness' still exerts a dominant control on year-to-year variations in many climatic parameters in Ireland and these may be masking some of the forcing due to anthropogenic influences. Secondary indicators comprise phenomena, especially in the biological environment, which might be expected to show a response to changes in primary climatic parameters. A wide range of possible indicators was assessed. Some likely future indicators did emerge, such as changes in the production area of warm weather crops such as forage maize and vines. More detailed phenological investigations would be desirable should agricultural indicators be employed. Butterflies and bats were found to have more potential, especially since many species of butterfly are at their ecological limits in Ireland and would be highly sensitive to climate change. While some data sources presently exist for butterflies, these are not adequate to serve as reliable indicators. Bird activity provided one of the most successful secondary indicators. The little egret, reed warbler, pied flycatcher, bearded tit, Mediterranean gull, goosander, lesser whitethroat and blackcap are just some of the new species which have arrived since 1980, possibly in response to warmer conditions. The displacement of some cold-tolerant species has been less dramatic and more data is needed, especially on seabird population changes. Arrival dates for migratory species have been meticulously recorded for some species such as the swallow and here a good indicator seems to exist. It is not clear why such a strong response to temperature changes appears to be occurring. Further work is required to identify the role of climate change in source areas and along the migratory route. Records from the four phenological gardens in Ireland indicated that the beginning of the growing season was occurring earlier at all locations for a number of the indicator tree species. An increase of temperature in spring of 1oC is associated with leaf unfolding occurring 5-8 days earlier. Leaf fall, on the other hand, has shown little change since 1970, except in the southwest where it has become later. The length of the growing season has become longer, especially in the southwest. An increase in the growing season by 9 days for Betula, 3 days for Fagus, and 7 days for Tilia is indicated per 1oC rise in annual temperature. Investigations of socio economic data as indirect indicators of climate change were also undertaken. These sources included changes in energy consumption, insurance claims for weather related damage, changes in domestic tourism. However the appropriate data was not easily accessible and confounding factors, such as economic growth, restricts the usefulness of such approaches. Clearly Irish climate is changing. However, the indicators examined in this study suggest that despite a maritime location buffered by the Atlantic from extremes of climate, Ireland is mirroring, albeit somewhat belatedly the trends apparent at a global scale. |

Updated August 2005

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - An Assessment of the Measurements of Radiatively Active Species Carried out in Ireland and of Radiometric Species |
| LEAD ORGANISATION | NUI, Galway |
| CONTACT | Dr. Aodhagan Roddy |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 76,184.28 |
| PROJECT DESCRIPTION | The potential consequences of global climate change are outlined in the recent Third Assessment Report (Working Group I) of the International Panel on Climate Change established by the World Meteorological Organisation (IPCC, 2001). This document provides guidance to Governments on the causes and impacts of climate change. Various aerosol climate effects are highlighted in this Report. The Report shows that uncertainty in estimates of aerosol effects, i.e. direct refection of sunlight and indirect alerting cloud reflectivity and life time, provide the greatest uncertainties in current understanding anthropogenic impacts on radiative forcing and thereby climate. This problem has been compounded by the lack of quantitative data. This study of composition, sources and radiative properties of aerosols is therefore making an important contribution to understanding of aerosol climate interactions. The main objectives of this work are to:<br>~Progress with measurements of aerosol chemical and physical properties at the primary maritime background atmospheric research station in western Europe, at Mace Head.<br>~Deploy complementary instrumentation to provide aerosol radiative measurements. It is envisaged that validated measurement data will be made available, subject to protocols, to the World Aerosol Data Centre at the EU Joint Research Centre, Ispra, Italy. |

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - An Assessment of the Measurements of Radiatively Active Species Carried out in Ireland and of Radiometric Species |
| LEAD ORGANISATION | NUI, Galway |
| CONTACT | Prof. S. Gerard Jennings |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 76,184.28 |
| PROJECT DESCRIPTION | The aim of the project is to get detailed information on Irish data of importance to studies of radiative forcing. The main data concern anthropogenically enhanced levels of greenhouse gases (responsible for global warming). These include carbon dioxide, methane, nitrous oxide and industrial gases such as replacement chlorofluorocarbons introduced following the Montreal protocol. Aerosol particles also play important roles in determining atmospheric reflectivity and can influence cloud reflectivity and cloud lifetimes. The aerosol effects are considered to have a cooling influence, which may in part counterbalance warming due to enhanced greenhouse gases. Expert subcontractors are contributing to the work by preparing reports on (a) isotopic data which are important for source identification and (b) data on atmospheric aerosols which can counteract global warming. Ireland also has a long history of meteorological and other scientific observations, which can be used to study factors influencing radiative forcing. While some of this work has been well documented and is accessible via international databases other work is less well known and some valuable and unique data sets may be overlooked. A comprehensive review of ongoing and historic work will be prepared. This review of will identify work that contributes to better understand both natural and anthropogenic impacts on the radiative balance. It is intended, through a broad range of contacts in Ireland and abroad, to cast a wide but efficient net in the search for relevant databases. Information on data collected by remote sensing from satellites and aircraft will be obtained. The aim is to provide an avenue to improve the use of diverse data sets through integration with related work. A report will be prepared on the potential development of a national archive of the data mentioned above. Also further work, which could be used to improve current work, will be identified. This information is important for research on climate change and for public policy formulation with regard to climate change issues, such as the implementation of the Kyoto agreement. |

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - Study of the Composition, Sources and Radioactive Properties of Aerosols at a West Coast Location |
| LEAD ORGANISATION | NUI, Galway |
| CONTACT | Dr. Aodhagan Roddy |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 241,250.23 |
| PROJECT DESCRIPTION | The aim of the project is to provide improved knowledge on chemical and physical characteristics of aerosols at a west of Ireland location. Such data are of use in studies of long-range transport of aerosols/particulates and their impacts on the regional radiation balance. The potential consequences of global climate change are outlined in the recent Third Assessment Report (Working Group I) of the International Panel on Climate Change established by the World Meteorological Organisation (IPCC, 2001). This document provides guidance to Governments on the causes and impacts of climate change. Various aerosol climate effects are highlighted in this Report. The Report shows that uncertainty in estimates of aerosol effects, i.e. direct refection of sunlight and indirect alerting cloud reflectivity and life time, provide the greatest uncertainties in current understanding anthropogenic impacts on radiative forcing and thereby climate. This problem has been compounded by the lack of quantitative data. This study of composition, sources and radiative properties of aerosols is therefore making an important contribution to understanding of aerosol climate interactions.<br>The main objectives of this work are to<br>(i) Progress with measurements of aerosol chemical and physical properties at the primary maritime background atmospheric research station in western Europe, at Mace Head. (ii) Deploy complementary instrumentation to provide aerosol radiative measurements. It is envisaged that validated measurement data will be made available, subject to protocols, to the World Aerosol Data Centre at the EU Joint Research Centre, Ispra, Italy. |

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| PROJECT TITLE | Greenhouse Gas Emissions and Climate Change - Study of the Composition, Sources and Radioactive Properties of Aerosols at a West Coast Location |
| LEAD ORGANISATION | NUI, Galway |
| CONTACT | Prof. S. Gerard Jennings |
| PROJECT TYPE | Large Scale |
| START DATE | 01/11/2000 **STATUS:** Ongoing |
| TOTAL BUDGET (€) | 241250.23 |
| PROJECT DESCRIPTION | The aim of the project is to provide improved knowledge on chemical and physical characteristics of aerosols at a west of Ireland location. Such data are of use in studies of long-range transport of aerosols/particulates and their impacts on the regional radiation balance. The potential consequences of global climate change are outlined in the recent Third Assessment Report (Working Group I) of the International Panel on Climate Change established by the World Meteorological Organisation (IPCC, 2001). This document provides guidance to Governments on the causes and impacts of climate change. Various aerosol climate effects are highlighted in this Report. The Report shows that uncertainty in estimates of aerosol effects, i.e. direct refection of sunlight and indirect alerting cloud reflectivity and life time, provide the greatest uncertainties in current understanding anthropogenic impacts on radiative forcing and thereby climate. This problem has been compounded by the lack of quantitative data. This study of composition, sources and radiative properties of aerosols is therefore making an important contribution to understanding of aerosol climate interactions. The main objectives of this work are to (i) progress with measurements of aerosol chemical and physical properties at the primary maritime background atmospheric research station in western Europe, at Mace Head. (ii) Deploy complementary instrumentation to provide aerosol radiative measurements. It is envisaged that validated measurement data will be made available, subject to protocols, to the World Aerosol Data Centre at the EU Joint Research Centre, Ispra, Italy. |

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