Ireland at Risk

CRITICAL INFRASTRUCTURE

ADAPTATION FOR **CLIMATE CHANGE**

An ounce of prevention is worth a pound of cure.

Cover image:

Flooding at Mallow, Co Cork, in 2009. We can expect to see more flooding like this, unless adaptation measures are implemented. Image courtesy OPW.

Ireland at Risk
No.2

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Supported by:

Arup Consulting Engineers; Cork County Council; Department of Environment, Heritage & Local Government; Dublin City Council; Environmental Protection Agency (EPA); ESB; Office of Public Works (OPW)

Acknowledgement

This report is based on presentations and discussions at a symposium, involving experts from across the island of Ireland, convened by the Irish Academy of Engineering in Dublin in April 2009.

It is now widely recognised that Ireland must adapt to the impacts of climate change. The engineering profession will play a central role in identifying the climate change challenges facing us across the island, and in proposing and implementing appropriate and cost-effective adaptation measures. This report focuses on the key adaptation strategies needed for critical infrastructure, specifically: energy supply, water services and flood alleviation. Our aim is to ensure that the engineering profession contributes fully in formulating policy and in planning for the potentially dramatic developments expected over the coming century.

The Irish Academy of Engineering wishes to acknowledge the significant input of those experts who contributed their expertise and opinions at the April workshop in Dublin Castle and in reviewing early drafts of this report. We also acknowledge the work of Mary Mulvihill in editing the report. The Irish Academy of Engineering thanks the many agencies, organisations and individuals that supported this project.

We are grateful to the institutions and individuals who provided illustrations for this report, in particular: the British Geological Survey, Dublin City Council, the Environment Agency UK, Arup Consulting Engineers Cork, OPW, Scott Wilson Consulting Engineers, and Dr Peter Coxon TCD.

The views expressed here are those arising from the workshop, and do not necessarily reflect the views of the various bodies that supported the project

This report, and the full text of the keynote papers presented at the Dublin workshop, are available online at www.iae.ie.

ISBN 1-898012-09-1

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Foreword

The causes of climate change are complex, but the consequences are increasingly clear. Consider New Orleans after Hurricane Katrina: an example of how climate change coupled with poor planning and zoning decisions can lead to social and economic disaster.

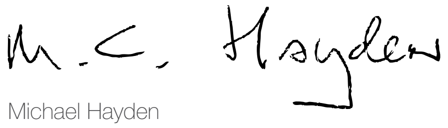
Efforts to deal with climate change to date have focused on mitigation, in particular trying to reduce greenhouse gas emissions. But even if we could successfully cap emissions, we will not stop never mind reverse the effects of climate change over the next 50 years. So we must adapt to the changes. And with climate change already underway, adaptation is now urgent in Ireland as elsewhere.

Timing is of the essence. From the time when the need for a London (Thames) barrage was identified until it was fully operational took 50 years. Yet this great work of engineering has proved vital to the protection of London: it is now raised several times a year – more often than originally anticipated – and plans for it over the next 50 years are being developed. Even simpler measures will still typically take 20 years from identification to effective operation. To avoid a legacy of future disasters, policy makers must act now.

This report addresses adaptation issues in three key infrastructural areas: water supply, flood alleviation, and energy infrastructure. It is based on inputs from leading specialists in these fields and the deliberations of a symposium, held in Dublin Castle on April 28th, 2009, and attended by the Minister for the Environment, Heritage and Local Government and an invited audience of researchers, engineers, scientists, policy experts and administrators from all parts of Ireland.

We make 18 key recommendations in this report. Significantly, most of these do not involve immediate capital expenditure, but deal with institutional steps that are necessary to ensure the problem is tackled effectively and economically.

If we move now, significant economic benefits will accrue. If we do 'too little too late', we risk social and economic disaster.



Michael Hayden
President, Irish Academy of Engineering
October 2009

'In every deliberation, we must consider the impact of our decisions on the next seven generations.'

The Great Law of the Iroquois people

'An ounce of prevention is worth a pound of cure.'

Benjamin Franklin

The Way Forward

Summary and key recommendations

Our modern society depends entirely on a reliable water supply, robust flood defences and a dependable energy supply. Without this 'critical infrastructure', life as we know it would quickly come to a halt. Yet this infrastructure is now at risk from climate change: for example, the water supply in many parts of the island will come under severe pressure; our main cities and towns face significant risk of major flooding; and our energy facilities are increasingly at risk from changing weather patterns and more intense storms.

Climate change is already under way, and we cannot stop it. Even if we could cap greenhouse gas emissions at 2000 levels, significant climate change will still occur due to inertia in the climate system. While we must make every effort to reduce emissions and mitigate the impact of climate change, the reality is that we must now begin to adapt to an inevitable new future.

The first step will be to identify vulnerable infrastructure and decide what is critical; then, to review its security and prioritise adaptation measures. We must ensure that existing infrastructure is resilient and can cope with an altered climate. Simultaneously, new infrastructure must be designed with climate change in mind, and be flexible enough to be adapted as climate change progresses. Bear in mind that, for a power station, the period from original concept through to commissioning and on to the end of its useful life can be up to 80 years – a long time, in the context of climate change.

Climate change poses challenges for Ireland, but it also presents us with opportunities. We will continue to be a relatively 'water rich' country and should be able to attract foreign direct investment when other countries will be struggling to meet their water needs. But we will only realise this potential if we adapt, streamline and develop our water infrastructure, taking climate change into account, and starting now. This is why we urgently need a co-ordinated, long-term all-island climate change adaptation plan.

The Governments of Northern Ireland and the Republic have begun to address the challenge of adapting to climate change. The Irish Academy of Engineering welcomes this, and submits this report as a key input to that work. Our recommendations are based on expert contributions from climate change scientists, engineers and infrastructure experts from across the island of Ireland. Eighteen of the key recommendations are outlined in this summary. Significantly, most of these do not involve immediate capital expenditure, but deal with the institutional steps that are necessary to ensure the problem is tackled effectively and economically, notably the establishment of water resource authorities, and the designation of 'lead agencies' responsible for co-ordinating and overseeing adaptation in Northern Ireland and the Republic of Ireland.

This report outlines how best to proceed to meet the challenge of adapting our infrastructure for climate change. It is more cost effective and cheaper to act now and adapt, than wait until it is too late, as highlighted in the UK Stern Report. If we do not now put in place the appropriate policies and measures, the impact on society and the economy could be devastating and put us all at an unacceptable risk.

Managing adaptation

Adapting to climate change is one of the key challenges facing Governments, society, policy makers, researchers and engineers and is of such importance that it should be managed centrally. The Academy supports initiatives by both Governments in preparing climate change adaptation plans.

1. An all-island statutory plan: An existing government department or agency in each jurisdiction should be assigned 'lead

Scott Wilson Consulting Engineers

Flood defences at Newcastle, Co Down: well-designed defences will be essential to protect infrastructure and homes against rising sea levels and storm surges. To this end, the Governments of Northern Ireland and the Republic of Ireland must develop and implement coastal protection plans.

'We urgently need a co-ordinated, long-term all-island climate change adaptation plan'

agency' status, to take an overarching view of the impact of climate change on critical infrastructure, propose policy and recommend actions, and co-ordinate implementation. These lead agencies should have statutory powers and responsibilities to co-ordinate on a cross-sectoral basis and to develop an all-island climate change adaptation plan. Government in both jurisdictions should consider assigning responsibility for climate change adaptation to a designated Minister or Minister of State.

2. Establish an adaptation framework: Each lead agency should establish a framework for addressing adaptation within its jurisdiction, to coordinate the risk assessment and adaptation processes, and communicate to and educate asset owners. This framework should include targets for assessments and adaptation plans and their eventual implementation. Where there is potential interaction or conflict, for example between water and power supplies, it may also need to prioritise the adaptation measures.

Design standards and research

All new infrastructure should be designed to cope with the future climate and especially the more severe events expected with climate change.

3. Review engineering design standards: Engineers and climate change researchers should collaborate to identify the climate parameters that are critical to infrastructure design, and the research needed to enable the engineering profession to amend current design standards. The engineering profession should constantly review design standards and amend these as uncertainty about climate change reduces

4. Co-ordinate research: The two lead agencies should adopt a structured and co-ordinated approach to identify and agree the research priorities; how this research will be funded and carried out; monitor its implementation; and communicate the results on an all-island basis.

5. Research for infrastructure: A significant portion of the climate change research undertaken in the short- to medium-term, should address the needs of those designing, planning and producing policy for new infrastructure in general and for critical infrastructure in particular.

Water supply

Water is essential for the survival of all life on Earth, and fundamental to industry, business and farming. The challenges of climate change reinforce the fact that we must treat water as an essential and scarce resource. In addition, Ireland's water supply networks are currently not interconnected, and therefore lack resilience and the ability to compensate if one source of supply fails for any reason.

6. Establish water resource authorities: The Republic of Ireland and Northern Ireland should each establish a Water Resource Authority. These two authorities should co-operate closely, jointly control the island's available water resources, prepare policy and strategy, and manage these resources on a whole catchment basis, from 'source to tap', for the common good. Day to day management of the water supply infrastructure, and implementation of water policy and strategy should be on a regional basis, consistent with the EU Water Framework Directive, River Basin Districts. The Water Resource Authorities should publish medium-term forecasts of water usage and demand, taking account of climate change projections.

7. Plan for competing demands: We will need new policies to establish priorities to deal equitably with competing demands for available water resources. Both climate change and demographic projections predict a serious imbalance between areas where rainfall will be most plentiful (the west and northwest), and areas of greatest need (the east and southeast). Climate change will also alter the needs and demands of water users in Ireland, particularly where irrigation will be required. The continuing use of water for energy also needs to be considered.

A long-term plan is needed in both the Republic of Ireland and Northern Ireland to ensure the necessary infrastructure is provided in a timely and appropriate way. These plans should ensure that sustainable water supplies, both surface and groundwater, are available across the island, while recognising the needs of individual stakeholders and protecting water quality.

8. Plan for future water supplies: Climate change will significantly affect the amount, seasonality and regional distribution of rainfall, and thus water availability for domestic, commercial and agricultural use. The proposed Water Resource Authorities should plan for how water will be harvested, managed and distributed to meet society's future needs.

9. Implement universal water charging: People who are not charged for water have no incentive to conserve it and reduce consumption. Currently, water usage in Ireland is significantly higher than elsewhere in Europe. This, coupled with climate change and a growing population, could lead to water shortages in Ireland in the medium and long-term. We need a fresh approach if scarce supplies are to be conserved. A universal charging policy should be implemented for all water users, while making due allowance for affordability issues in the domestic sector.

10. Complete risk assessment for water quality: The proposed Water Resource Authorities should carry out risk assessment

Changing rainfall patterns could increase the risk of landslides: heavy rains and local geology combined to trigger this landslide, which destroyed the four-star Holbeck Hall Hotel in North Yorkshire in 1993.

in relation to the quality of their water supplies and prepare contingency plans to deal with unexpected pollution events. The existing sewerage infrastructure was not designed to cater for the more intense rainfall we expect in future and which is likely to overwhelm parts of the network, causing local flooding and polluting water sources. We could also see more soil and peat erosion, landslides, and the spread of agricultural pollutants, all of which would damage water quality.

Flood alleviation

The cities and towns of Ireland are nearly all located by the coast, or on a large river, or both. Likewise, much of our industry and general infrastructure is coastal, notably power stations, communications and transport hubs. All are therefore at risk from floods and storm surges and, in the long-term, from rising sea levels and coastal erosion. The potential economic consequences of these climatic changes, and the misery inflicted on people in these areas, would be enormous.

11. Assess flood risks: A formal flood risk assessment should be carried out for each critical infrastructure asset. This assessment should identify its frequency of exposure to a hazard, its resilience to exposure and the consequences of its failure. Then we can identify the adaptation measures needed and, by subjecting each to technical, economic, social and environmental analysis, prioritise them. We need national agreement on standards, methodologies and actions to ensure that the risk assessments are carried out to an appropriate international standard, and to provide guidelines for their implementation.

12. Delineate flood plains: We must develop a robust methodology to delineate

'The future of some major population centres could be threatened'

flood plains, taking account of the most up-to-date estimates of the effects of climate change.

13. Implement coastal protection plans: The Governments of Northern Ireland and the Republic should develop and implement coastal protection plans for all coastal areas at risk from erosion or flooding. Most of the larger cities and towns on the island are by the coast – for example, Belfast, Dublin, Waterford, Cork, Limerick, Galway, Derry – and thus particularly vulnerable to inundation caused by rising sea levels and extreme weather events. The viability of some major population centres could be threatened.

14. Manage and control development: Guidelines published in both jurisdictions to support planners, should be rigorously implemented in prohibiting inappropriate development in areas subject to high risk of flooding. The guidelines should be revised as new information on climate change becomes available. Adherence to the guidelines should be monitored by Government and formally reported.

15. Improve flood warnings: We urgently need systems for forecasting surges and issuing coastal flood warnings where appropriate. We may need new methodologies to assist engineering calculations and flood forecasting, and a reliable tide gauge network with quality-controlled data processing and archiving.

16. Review of design standards: The lead agencies proposed above should facilitate discussions between the engineering profession and climate change researchers to develop new methodologies for improving our estimates of flood flows, rainfall intensities and sea levels.

Existing flood risk management uses statistical analyses of historic records to determine the appropriate flood flows or water levels. In future, however, river flows, rainfall intensities and sea levels will be more extreme than in the past. Hence, we need to devise new methodologies for designing infrastructure to serve the community for several decades to come.

Energy supplies

Energy is vital for all medical, domestic, business, farming and industrial activity. A high-quality energy infrastructure, capable of adapting to the challenges of climate change, is also essential for Ireland to attract and retain high-tech industrial investment, and for the island to achieve competitive energy supplies and balanced regional development.

The interconnectedness over the National Grid means that energy supplies have considerable resilience, but the energy sector has critical infrastructure throughout the island that is increasingly vulnerable to flooding or damage from extreme weather. This includes power stations, sub-stations, and gas and oil terminals; many of these plants also have facilities such as cable tunnels and basements, thus increasing the risk from flooding. In addition, rising sea levels will pose problems for coastal installations, and have implications for wave and tidal power generation.

17. Produce asset risk registers: All owners of energy infrastructure should carry out a preliminary climate change risk analysis and prepare a risk register by the end of 2010, using climate change parameters decided by the energy regulator in each jurisdiction in consultation with the lead agency and the owners of energy infrastructure.

18. Review power requirements: In future, substantial extra energy may be needed for additional pumping for water supplies, wastewater disposal and agricultural irrigation, and for air-conditioning. The energy regulators in both jurisdictions should commission reports on how energy demand could increase with climate change. ■

Why we should worry

Key vulnerabilities

Modern life depends entirely on critical infrastructure. Our energy networks, water supplies and flood protection schemes allow us to live in the 21st century. But it's a fragile connection: take away these supports and we would be catapulted instantly back in time by several centuries. Yet, much of this infrastructure is hidden – often, literally, underground – and we usually take it for granted. Only when a service is interrupted or lost do we truly appreciate it.

Without electricity, we cannot power our hospitals, or pump drinking water from reservoirs, or treat sewage, or power the phone networks, or drive our industries, or pump fuel. With no electricity or water, hospitals could provide only essential services and then only as long as the generators lasted.

Hurricane Katrina, the Australian drought, and the flooding in England in 2007 (see panel: When catastrophe hits), are extreme cases, but they are a salutary lesson of just how vulnerable critical infrastructure can be, and why we must act to ensure that catastrophes such as these do not occur in Ireland. There is now international acceptance that climate change is happening, and that we may already be seeing small but significant changes in Ireland. Even if we succeed in capping greenhouse gas emissions at 2000 levels, significant climate change will still occur, due to inertia in the climate system. In Ireland, we can expect the coming century to bring, among other things, higher sea levels, more storms and more intense storms, warmer temperatures and warmer waters, more flooding, summer droughts and changing rainfall patterns.

These changes could put our critical infrastructure at risk, both directly and indirectly. Storms, lightning and violent winds could bring down power lines, knock-out communication networks, and create dangerous working conditions for repair crews. Summer droughts could put a strain on water supplies. Floods could submerge underground installations, destroy lives, homes and businesses, and cause untold economic damage. Rising sea levels threaten nearly all of Ireland's cities and major towns.

The biggest challenge is the uncertainty associated with climate change. If we knew with confidence what was going to happen, it would be easier to take decisions. Flood defences, for example, must be designed to withstand extreme events, but climate models have difficulty predicting extremes, although they are good at predicting the future averages.

The key now is 'adaptation' for an increasingly uncertain future. The UN's Intergovernmental Panel on Climate Change (IPCC) has repeatedly highlighted the scale of the challenge facing the world. The EU's Green Paper, *Adapting to Climate Change in Europe: Options for EU Action* (2007), identifies why individual countries must now develop and implement adaptation strategies. In Europe, nowhere is more vulnerable than the Netherlands: with one quarter of its land area and 60% of the population below sea-level, the Dutch government is committed to spending over €1 billion a year on flood protection and adaptation measures. Significantly, the Governments in Northern Ireland and the Republic of Ireland have also now recognised the need for adaptation, and both have begun to develop national adaptation strategies.

In terms of critical infrastructure, the Irish Academy of Engineering (IAE) decided to focus in this report on three key vulnerabilities:

- **Water supplies:** water is essential for the survival of all life on Earth, and fundamental to industry, business and farming. An adequate and reliable water supply is already a key factor in locating new manufacturing industry, especially pharmaceutical plants. This is likely to become even more of an issue as water supplies become strained in the future.

> 'The key now is 'adaptation' for a more uncertain future'

Mythe Water Treatment Works in Tewkesbury, England, flooded in July 2007, leaving 350,000 households without clean water for 17 days. Unless we act now, disasters such as this could become more common, as intense rainfall in future could pollute drinking water.

When catastrophe hits

In January 1998 the 'Great Ice Storm' left 4 million people without electricity, from upstate New York across eastern Canada to Ontario. Over 30 people died, along with thousands of farm animals, and it was many weeks before full power supply was restored, with damage estimated at US$6 billion. When Hurricane Katrina hit New Orleans in August 2005, the levee system failed. Levee design flaws and poor maintenance exacerbated the USA's worst natural catastrophe, leaving over 1,800 people dead and causing an estimated $100 billion in damages.

Closer to home, Mythe water treatment plant at Tewkesbury, England, was flooded in July 2007. The plant, built on the River Severn floodplain, had never been flooded since opening in 1870. But a torrential rainstorm after a summer of rain, coupled with poor flood protection measures, left the plant under water and 350,000 people without clean water, many of them for several weeks. Across the globe in South Australia, Adelaide residents face a future with little or no water: the Murray-Darling Basin Authority warned in April 2009 that the city's water supply could no longer be guaranteed. The province has been suffering the 'drought of a century', exacerbated by over-pumping for agricultural irrigation.

- **Flood protection:** the cities and towns of Ireland are nearly all located on the coast, from Belfast and Dublin on the east, to Waterford and Cork on the south, past Limerick and Galway on the west, to Derry on the north. Most are also located on large rivers. Likewise, much of our industry and general infrastructure is coastal, notably power stations, communications and transport hubs. All are therefore at risk from floods and storm surges and, in the long-term, from rising sea levels and coastal erosion. The potential economic consequences of these climatic changes, and the misery inflicted on people in these areas, would be enormous.

International developments

CRITICAL infrastructure protection and adaptation to climate change have become major issues internationally. The Netherlands has begun a project to protect private and public infrastructure from security threats, accidents and climate change. The USA's National Infrastructure Protection Plan, launched in 2006, includes the concept of 'utilities helping utilities' to improve resilience during disasters: a mechanism whereby water utilities that sustain damage can obtain emergency assistance from other utilities.

The UK's National Security Strategy (2008), covers pandemics, security threats and transnational crime, alongside extreme natural events such as flooding. Measures will include compiling a national risk register for infrastructure. The European Commission has published several Green Papers (2005-'08) and a White Paper in 2009. To improve the community's resilience to climate change, it sets out a number of proposals, including a database of all the relevant information and research to be shared among Member States.

- **Energy supplies:** the integrity of our power plants, distribution grids, gas supply lines and oil depots are fundamental to society and the economy. Other services, such as water supplies, hospitals, transportation, etc., all depend critically on an adequate and reliable energy supply.

Ireland must therefore urgently identify her vulnerable infrastructure and decide which items are critical. Then, we must review its security and revisit the relevant risk analyses, and prioritise the measures needed to adapt and protect each installation. Adaptation and protection measures should also be included in planning of new infrastructure. This is a multi-disciplinary challenge, bringing together experts in climate change research, engineering design, and planning.

We also need new engineering design standards to ensure that our critical infrastructure is flexible and resilient and can cope with future climate changes and extreme events. Existing standards were developed for historic climate parameters, such as rainfall amounts, wind speeds, sea levels and wave heights. We now know, however, that the past is no longer a guide to the future climate, and hence engineers and climate change experts will need to collaborate to identify both the relevant climate change parameters, and the research needed to enable engineers to amend current design standards.

Failure to do this will put our society and our economy at an unacceptable risk. Acting now will also be far more cost effective than waiting for a catastrophe to occur. This report presents the Academy's view on how best to proceed with this challenge. ■

What the future holds

Key Impacts

Climate change will dramatically affect Ireland, far beyond what we can currently comprehend. In planning for this altered and uncertain future, we need to review in detail the likely climate change scenarios for Ireland, and their implications for the infrastructure that underpins the normal functioning of our society and economy. To that end, the Academy commissioned four keynote papers for a climate change symposium, held in Dublin in April 2009, and reviewing:

- Climate change in Ireland
- Water supply
- Flood protection, and
- Energy infrastructure.[1]

Changing climate

Researchers in Ireland have now successfully refined how climate here is likely to change over the coming century, although significant uncertainty and challenges remain, notably concerning the impact of extreme events. Researchers must therefore work closely with engineers, planners and other end-users of the data to ensure the best possible information is used when making decisions and designing for the future. We must identify the main climate parameters relevant for new engineering design standards, and how these are likely to change over the coming century. This will require substantial research, and should be a priority for climate change research in Northern Ireland and the Republic of Ireland. Despite the uncertainty, work by key research centres across the island means we can now say with some confidence that:

Temperatures are likely to increase everywhere, with summer and autumn possibly 3.4°C warmer by the end of the century. Longer and more intense heatwaves could become more common, and we will probably see less frost.

Precipitation patterns and amounts will change, and we expect wetter winters and drier summers. However, considerable uncertainty remains, with different climate models yielding different projections, and no clear trends yet for spring and autumn in Ireland and the UK.

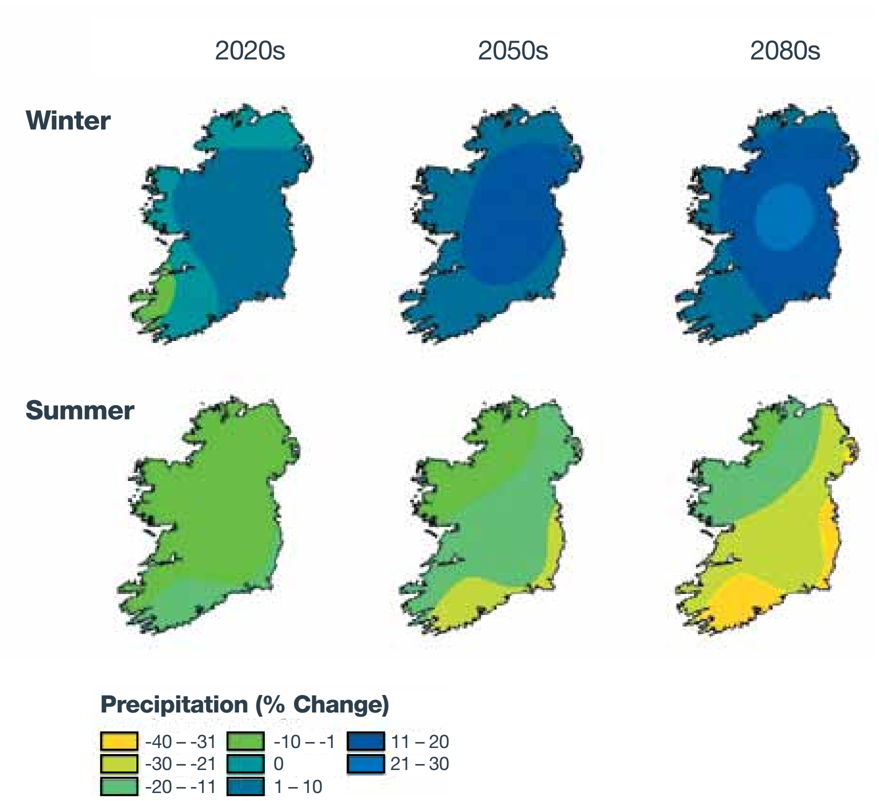
Extreme events will probably become more severe and more frequent, across all climate variables (with the exception of minimum temperatures). Information about extreme events such as storms and floods is essential for planning and design, yet they are notoriously difficult to forecast, and climate models work best with averages. At present we have no reliable data on extreme event changes for design purposes, and this is a major gap in our information.

Wind speeds could be about 10% stronger in winter on average by mid-century (measured at a height of 60-metres), but about 15% lighter in summer. Wind speed is another very uncertain variable, however.

Catchment inflows: we could see 20% more water in catchment areas in winter and spring by mid- to late-century, but as much as 40% less water in summer and autumn. Consequently, we could face more flooding in some months, and yet have less water available for abstraction in others, which would also reduce our ability to dispose safely of effluent. Trends for individual catchments vary, however, depending on the characteristics determining 'runoff response', so future impacts will need to be assessed on a catchment by catchment basis.

River flows: floods are likely to become more frequent. Worse: what we currently think of as a '50-year flood' could, by mid- to late-century, happen once every decade. 'Low flow events' could also become more frequent leading to water shortages.

[1] See Appendix 1 for abstracts of these papers. The full texts are available online at www.iae.ie



Wetter winters and drier summers: changing rainfall pattern will be the most important aspect of climate change for Ireland. Source: ICARUS, NUI Maynooth, 2007.

Sea levels will rise, but it is not clear yet by how much – anything from 0.28 m (a conservative IPCC minimum estimate) relative to 1980-'99 to over 1 m by 2100. The rise will depend on local characteristics such as topography.

Storm surges: A more stormy climate, with higher seas and stronger winds will bring higher waves and more storm surges to our shores. Combined with river flooding, these will pose serious risks to our many coastal cities and to key infrastructure.

Water supply

Over 70% of Ireland's water supply is drawn from surface freshwater, specifically lakes, reservoirs and rivers, the remaining 30% or so from groundwater. Demands on and threats to both surface water and groundwater resources have grown dramatically in recent years, fuelled by the competing interests of urbanisation, agriculture, industrial development and tourism, and compounding the threats now posed by climate change. Until now, Ireland has been regarded as relatively 'water rich', but in future we may have less water when and where we need it and, conversely, more water when and where we do not want it. A stressed system is exceedingly vulnerable to even small climate change, but a well managed and resilient system would be less vulnerable even to major change and extreme events. Climate change could stress our water supplies in several ways:

- Summers are likely to be drier, especially in the east of the island, and winters wetter, particularly in the west. Water flow in most Irish streams and rivers could drop dramatically in summer and autumn, but winter flows will increase, with major implications for supplies and ecosystems.

> 'The past is no longer a guide to our future climate, and the future is uncertain'

- If groundwater recharge drops and groundwater levels fall at critical times of the year, this could alter the groundwater–surface water dynamics for entire river systems and ecosystems.
- Rapid run-off during flash floods could mean that, despite the volume of water, aquifers do not have a chance to recharge. A dry winter could leave groundwater systems unable to recharge and recover for the subsequent summer; this would be exacerbated by the severe droughts predicted for mid- to late-century. The most vulnerable catchments are those dominated by surface run-off; those with a sizable groundwater flow component are less at risk.
- Water resources are greatest in the west, while demand is greatest along the eastern seaboard, from Belfast to Cork. This disparity between demand and supply is likely to increase with climate change.
- Climate change will affect water quality both directly and indirectly. Direct effects include warmer water temperatures, and salt contamination of coastal aquifers caused by rising sea levels; indirect effects will come from increasing demands on increasingly limited resources.
- Climate change, a growing population – possibly reaching 8 million by 2100 – and greater commercial demands could threaten water quality, particularly during droughts (when assimilative capacity is down), and floods (when sewerage networks and treatment works overflow).
- Ireland is ideally located to derive potable water by desalinating seawater. However, even with new technologies this remains expensive and energy intensive and produces a brine residue which must be disposed of.
- As climate change progresses, the relationship between energy and water supply, and access to and protection of treatment works during extreme weather events will become more critical.

Flood protection

Most Irish cities and towns are by the coast, or on a river, or both. Historically this was for ease of access and navigation, but these locations leave our towns and their critical infrastructure increasingly at risk of significant flooding and damage. This has major long-term economic and social consequences for Irish cities, industry and critical infrastructure.

- Floods are likely to become more severe and more frequent, with major implications for public safety and property, flood plain development, water quality and insurance costs.
- Some of our flood defence assets were built quite some time ago and, while they still provide a level of protection, may not always be identified as a flood defence. The design standard of protection is probably not known, and their structural condition may be uncertain.
- Drainage networks, particularly in older cities and towns, may date from Victorian times, designed and constructed to meet less demanding rainfall patterns than those we expect in future – already, some recent rain storms have overwhelmed local drainage systems.

Dublin City Council

Two views of Vartry Reservoir, Co Wicklow: empty, in a dry October 1990, and full in a wet September 2009. In future, we may have less water when and where we need it.

- Design of flood defences and flood relief schemes to date was based ultimately on historic weather records and assumed that the same patterns would continue. However, the changes we expect with climate change mean that many existing flood defences will not be able to provide the same level of protection as when they were built.
- Rising sea levels and more frequent and higher storm surges will expose Ireland's coastline to a greater risk of erosion and expose coastal defences to potential damage or collapse, and significantly increase the need for maintenance.

Energy supply

Energy is vital for domestic, business, farming and industrial activity. A high-quality energy infrastructure, capable of adapting to the challenges of climate change, is also essential for Ireland to attract and retain high-tech industrial investment, and for the island to achieve competitive energy supplies and balanced regional development. The interconnectedness of the National Grid provides considerable resilience. However, existing energy infrastructure is still at significant risk from climate change:

- Many of the island's power stations and oil refinery and storage facilities are located on the coast, and therefore vulnerable to rising sea levels, storm surges and higher waves.
- Critical infrastructure across the island, including power stations, sub-stations, gas installations and oil terminals, and below-ground facilities such as cable tunnels and basements, are at increasing risk of flooding.
- Extreme floods will affect dam safety and operating procedures for hydro power stations.
- Higher winter flows and summer shortages could reduce the availability of hydropower and render it less efficient.
- Strong winter wind speeds could benefit wind power generation, but summer reductions would have the opposite effect. Turbines could also be turned off more frequently to prevent damage during extreme weather, again reducing availability.
- Extreme winds could damage overhead power lines.
- Demand for electricity could rise dramatically during heatwaves to power air conditioning systems, and during droughts to pump water for water supplies, waste water systems and irrigation for agriculture.
- The 'water–energy nexus' – the interdependence between energy for water and waste water, and water for energy – will become increasingly complex.

'Resilience: a system's ability to withstand or recover from adversity'

© Reuters/Gordon Jack

A formal flood risk assessment should be carried out for each critical infrastructure asset. The dam retaining Ulley Reservoir, in England, nearly collapsed during the wet summer of 2007, when a spillway was damaged. Residents had to be evacuated, and part of the nearby M1 closed.

What we must do

Recommendations

Managing climate change adaptation

Adaptation for climate change is one of the key challenges facing the Governments of Northern Ireland and the Republic of Ireland, policy makers, researchers, engineers and society. The scale and nature of the challenge is known, we have the climate change research data and advice and the technical knowledge to enable us to address the challenge. However, because there is a lack of demonstrable impacts, and governments typically focus on the short term, we have not yet prepared adaptation implementation plans. We no longer have time for such an approach.

An all-island statutory plan: Climate change adaptation functions, responsibilities and powers must be allocated on a statutory basis, if we are to successfully meet the challenge. We need high-level strategic co-ordination that is centrally managed in both jurisdictions on this island, to take an overarching view of how climate change will affect critical infrastructure, to propose policy, to make recommendations to Government, and to co-ordinate implementation of required actions. This co-ordinating role should be assigned in each jurisdiction to a 'lead agency' – a single stakeholder government department or agency, empowered to bring together all departments, bodies and agencies with statutory functions and responsibilities in this area. These lead agencies should be tasked with directing the overall response to climate change adaptation in each jurisdiction, and liaising with its counterpart to co-ordinate an all-island adaptation plan. This role should be carried out by existing bodies such as the appropriate Government department, or an agency such as Northern Ireland's Environment Agency and the EPA in the Republic of Ireland.

Establish an adaptation framework: The lead agencies proposed above should establish a climate change adaptation framework for both jurisdictions, to co-ordinate the risk assessment and adaptation process, and communicate to and educate asset owners (such as local authorities, energy companies). This framework needs to define, identify and map the elements of critical infrastructure, create a national database of vulnerable assets, and set out an approach to risk management. It should set deadlines for assessments and for preparing adaptation plans, and a timescale for implementation. Where there is potential interaction or conflict, for example between water and power supplies, it will need to ensure coordination of assessments and plans and perhaps even the priority of adaptation measures.

Design standards and climate research

Review engineering standards: All new infrastructure should be designed to cope with the changing weather parameters and the more severe events expected with climate change. Engineers and climate change researchers should collaborate to identify the climatic parameters critical to infrastructure design, and the research needed to enable the engineering profession to amend current design standards. The engineering profession should constantly review design standards and amend these as greater certainty about climate change parameters emerges.

Co-ordinate research: While research in Ireland to date has successfully refined the likely impacts of climate change over the coming century, significant uncertainties remain, especially around extreme events and the 'shoulder' seasons of spring and autumn. Clearly, we need considerable further research to reduce these uncertainties. The limited funding available and the limited research capability on the island, mean that we must identify and agree the research priorities and how this research will be funded and carried out. The 'lead agency' in each jurisdiction should plan and co-ordinate the research, communicate the results across the island and monitor any subsequent implementation. This should avoid duplication and ensure optimum and timely results and value for money.

London's Thames barrier has protected the city from major flooding on numerous occasions, and is now used more often than originally anticipated. Most Irish towns and cities are located on the coast, or on a large river, or both – what protection will they need?

Link research and implementation: Climate change researchers and engineers come from different backgrounds, speak different technical languages and have different modes of analysis. We need a structured dialogue between the two communities to ensure that decisions are not restricted by, but instead benefit from these differing approaches and perspectives.

Establish research priorities: 'Blue sky' research remains important, but the priority in the short- to medium-term should be to address the current information gaps and technical shortcomings around design, planning and policy for infrastructure in general and critical infrastructure in particular. This research should include:

- Develop a range of climate scenarios to address as many sources of uncertainty as possible, each tailored where possible for use by those designing and planning critical infrastructure. These should be jointly commissioned and co-ordinated on an all-island basis, by the lead agency in each jurisdiction, and should initially concentrate on design criteria for extreme weather events.
- Refine regional climate predictions for rainfall, sea levels, wind speeds, wave heights, sea level surges and temperatures.
- Commission an all-island research programme to analyse catchment responses to climate change for Ireland's larger river basins. This will help to ensure optimum management of critical water resources.
- Prepare wind and wave atlases for future climate scenarios.
- Clarify the assumptions and standards for extreme climate events.
- Assess the risk and impact of a number of extreme weather events happening simultaneously.

- Consider moving towards using a probabilistic approach, especially for predicting extreme weather events, akin to that used in the UK climate impacts programme (CIP) 09. Analyse how changes in rainfall, evaporation, river flows, sea levels and surges will affect the 'water-energy nexus'.

- Conduct a detailed study of our coastline's physical response to climate change, given its high susceptibility to erosion, particularly along the eastern seaboard.

Establish observational networks: We need to establish and maintain observational networks to collect data across a range of parameters. These will be essential for several specific research studies, such as survey data on sand reservoirs for beach measurement, and deciding a standard datum for sea level using telemetry.

Learn from others: Engineers usually design for extremes, but forecasting future extreme values is difficult and significant further research is required to adequately quantify some of these extremes. It would therefore help if we could identify countries which currently have a climate similar to Ireland's future climate, and evaluate the engineering design parameters and methodologies they use.

Water supply

Establish Water Resource Authorities: The challenges of climate change reinforce the fact that we must treat water as an essential and scarce resource. To this end, Northern Ireland and the Republic of Ireland should each establish a Water Resource Authority. These two authorities should co-operate closely, jointly control the island's available water resources, prepare policy and strategy, and manage these resources on a whole catchment basis, from 'source to tap', for the common good. Day to day management of the water supply infrastructure, and implementation of water policy and strategy should be on a regional basis, consistent with the EU Water Framework Directive, River Basin Districts.

Plan for competing demands: Climate change will alter the needs and demands of water users across Ireland, particularly where irrigation will be required. We will need new policies to establish priorities to deal equitably with competing demands for scarce water resources. Both climate change and demographic projections predict a serious imbalance between areas where rainfall will be most plentiful (the west and northwest), and areas of greatest need (the east and southeast). A long-term plan is needed in both the Republic of Ireland and in Northern Ireland to ensure the necessary infrastructure is provided in a timely and appropriate way. These plans should ensure that sustainable water supplies, both surface and groundwater, are available across the island, while recognising the needs of individual stakeholders and protecting water quality.

Plan for future water supplies: Climate change will significantly affect the amount, seasonality and regional distribution of rainfall, and thus water availability for domestic, commercial and agricultural use. We must begin immediately to adapt to the inevitable, and plan for how water will be harvested, managed and distributed to meet society's future needs. The Governments of the Republic of Ireland and Northern Ireland must act now to develop co-ordinated adaptation strategies for the water sector.

Investigate future water sources: The most critical part of any water supply is its sources. Water can be supplied from three sources: surface freshwater, groundwater and salt water. We currently abstract about 70% of our needs from surface water, but relying on one source leaves us vulnerable to the changing rainfall patterns predicted for the coming century. We should urgently investigate the potential contribution of all three sources, and adopt a balanced approach for future water supply schemes, having regard to source capacity, use of strategic storage, energy costs and security of supply.

Survey groundwater resources: Increased winter rainfall in the north and west of Ireland will unfortunately fall on areas underlain by 'poorly productive' aquifers, most of which are at their recharge acceptance limits, and so this additional rainfall cannot be captured. Nevertheless, some groundwater sources could be further developed, but we need more detailed information on the quality, quantity and potential yields of aquifers, to ensure the optimal use of these resources.

Investigate water supply sustainability: The threats posed by climate change and the long-term sustainability of current surface and groundwater extraction schemes needs to be investigated to consider: the impact of changing rainfall patterns and low flows on the quantity and quality of water available; the increased risk of pollution; and the potential impact on ecosystems. We will need to develop a defined risk assessment methodology for this investigation.

Complete water quality risk assessment and contingency planning: The existing sewerage infrastructure was not designed to cater for the more intense rainfall we expect in future and which is likely to overwhelm parts of the network, causing local flooding and polluting water sources. Traditional storm-water drainage systems can already cause environmental degradation, and this could worsen with more frequent and extreme events. We could also see more soil and peat erosion, landslides, and the spread of agricultural pollutants, all of which could damage water quality. Each water authority should ensure that its risk registers and contingency plans are sufficiently resilient to deal with unexpected pollution events.

Review low flow options: With rainfall patterns changing both seasonally and regionally, we need to review how we deal with low flow situations, storing water when and where possible to deal with future shortages. Options could include bankside storage, aquifer storage and recovery (ASR) and use of 'cut away' bogs as reservoirs. We should also review the cost / benefit analysis of connecting the water networks between our main centres of population as a means of reducing risk and dealing with low flow situations.

Use technology to capture data: We need more accurate data, including spatial data, to investigate the sustainability of current water resources and future options, and to enable us to optimally manage our water resources. Modern technology, including GIS, should be used in collecting and disseminating this data.

Review the desalination option: Saltwater is virtually limitless, but desalination is expensive – though new membrane technology has reduced costs significantly – and it can be difficult to produce potable water. Any comparison between desalination and other options must take account of the environmental impacts, including greater energy use and disposing of the brine residue.

Implement universal water charging: Water usage in Ireland is significantly higher than elsewhere in Europe. This, coupled with climate change and a growing population, could lead to water shortages in Ireland in the medium and long-term. We need a fresh approach if scarce supplies are to be conserved. People who are not charged for water have no incentive to conserve it and reduce consumption. Measures to improve demand management should include regulation and universal water pricing for all users, while making due allowance for people's ability to pay in the domestic sector.

Flood protection

The Academy is aware that significant work is underway in both jurisdictions to develop a risk-based approach to flood management. We fully support this and the on-going co-operation between the OPW and the Rivers Agency, which have been given an added impetus by the need to meet the requirements of the EU Floods Directive.

Adapting to the impacts of climate change is so important, likewise the need to ensure co-ordination of actions and responsibilities across Government, that we have set out here the recommendations that we believe are needed, acknowledging that some of these are in hand. Where that is the case, we urge both Governments to continue to prioritise the availability of resources to complete these programmes.

Assess flood risks: We need a formalised flood risk assessment process to identify and prioritise adaptation measures. For each piece of critical infrastructure we must identify its frequency of exposure to flooding, its resilience, and the consequences of its failure. Then we can identify the adaptation measures needed and, by subjecting each to technical, economic, social and environmental analysis, prioritise them.

While this risk assessment is best carried out by the asset owners, some less technical owners may lack awareness of the issues, or the technical ability to undertake the assessment. Hence, we need national agreement on standards, methodologies and actions to ensure that the risk assessments are carried out to an appropriate standard, and to provide guidelines for their implementation.

Complete flood risk maps and management plans: Both the Republic of Ireland and Northern Ireland are making significant progress in meeting the requirements of the EU Floods Directive to produce flood maps by December 2013. Local consultation and involvement is imperative at all stages in developing catchment plans, to ensure the necessary support for and confidence in the process and all decision making.

The Republic of Ireland's OPW has completed production of historic flood maps.[2] Its catchment flood risk assessment and

© Arup

Ballygannon, Co Wicklow: rising sea levels and more severe storms could put sections of our rail networks at risk.

[2] See www.floodmaps.ie

management (CFRAM) programme is now producing predictive flood maps for rivers and, with the National Coast Protection Strategy Studies, will develop flood maps for the Irish coast.

Northern Ireland's Rivers Agency published its 'Strategic Flood Map (NI) – Rivers & Sea' in November 2008,[3] illustrating the areas that have flooded from rivers and the sea in the past and those estimated to be prone to flooding now and with climate change to 2030. It provides additional information on the location of existing flood defences and highlights the areas that benefit from these defences. It is not suitable, however, to providing information at individual property level, which will require more detailed mapping.

Delineate flood plains: We must develop a robust and acceptable methodology to delineate flood plains. This should take account of the most up-to-date estimates of the effects of climate change.

Manage and control development: Guidelines published in both jurisdictions to support planners should be rigorously implemented to prohibit inappropriate development in areas subject to high risk of flooding. The guidelines should be revised as new information on climate change becomes available. Adherence to the guidelines should be monitored by Government and formally reported.

Identify significant flood defences: Major flood defence assets (such as embankments, walls and other structures that provide flood protection) must be identified and recorded. These are not always known or obvious and could therefore be removed or damaged as part of some development or other work at their location. Such an asset register is planned under the Republic of Ireland's CFRAM programme, and is already included in the Northern Ireland Strategic Flood Map. Local authorities should use the resulting information when managing planning and development by planning authorities, developers and the public.

Control the removal of flood defences: Flood defence assets are essential to safety. Their removal – even those in private ownership – must be subject to planning approval and associated conditions, following appropriate research and analysis, and recognising that in some cases, it may be appropriate to dismantle some or all of a defence to improve onshore 'sediment husbandry'.

Implement coastal protection plans: The Governments of Northern Ireland and the Republic should develop and implement coastal protection plans for all areas at risk from erosion or flooding. To optimise the use of available funding, these coastal protection plans should provide objective and transparent procedures for deciding on which approach to adopt in areas at risk, and how to prioritise competing schemes. These risk data and decision making procedures should be integrated into the next phase of spatial strategies and regional and county development plans.

Improve flood forecasting and warning: We urgently need systems for forecasting surges and issuing coastal flood warnings where appropriate. Current flood prediction methodologies are based on historical records, and assume that future events will be statistically similar to past ones. Climate change means this assumption is longer valid, and we may need new methodologies to assist engineering calculations and flood forecasting.

Install a tide gauge network: A reliable tide gauge network, with quality-controlled data processing and archiving, needs to be established in both the Republic and Northern Ireland. This would be used to monitor sea level changes and provide data for numerical models, and for real-time input to the proposed

[3] See www.riversagencyni.gov.uk/index/strategic-flood-maps.htm

Geevagh, Co Sligo: we are already experiencing an increase in bog slides, similar to the one which inundated these sporting facilities.

coastal warning system. Modern technology, including GIS, should be used to capture and disseminate the data; using altimetry would minimise the number of gauges required.

Review the effectiveness of mitigation measures: Sustainable and successful flood mitigation measures must be catchment-based, taking account of factors such as land use management and forestry practice. However, the potential gain from some measures is poorly defined and decision makers would benefit from better information. The lead agency in each jurisdiction should review the effectiveness of proposed flood mitigation measures.

Review of design standards: The lead agencies proposed above should facilitate discussions between the engineering profession and climate change researchers to develop new methodologies for improving our estimates of flood flows, rainfall intensities and sea levels.

Existing flood risk management uses statistical analyses of historic records to determine the appropriate flood flows or water levels. In future, however, river flows, rainfall intensities and sea levels will be more extreme than in the past. Hence, we need to devise new methodologies for designing infrastructure to serve the community for several decades to come.

Increase public awareness: Greater public awareness of the risks of flooding would help to ensure public support for flood protection measures and controls (for example on floodplain development), and improve decision-making. We must develop and publicise appropriate information, which should include the flood mapping and flood asset registers being developed in both jurisdictions. Ultimately, this could even save lives and property.

Energy supplies

Produce asset risk registers: All owners of energy infrastructure should carry out a preliminary climate change risk analysis and prepare a risk register, using climate change parameters decided by the energy regulator in each jurisdiction in consultation with the local lead agency and the owners of energy infrastructure. The two energy regulators should set a date of no later than end 2010 for completing these asset risk registers. (Some energy infrastructure owners have already begun this process, which is to be welcomed, but it is uncertain how rigorous these studies were and which climate change parameters were used.)

Walham electricity substation, Gloucestershire, July 2007: a temporary barrier (blue) kept peak flood waters at bay, but the crisis came within inches of a blackout that would have affected 500,000 homes, hospitals, critical infrastructure and industry.

Review plant output: Climate change could reduce power plant output, leaving Ireland needing additional generating capacity. The energy regulator in each jurisdiction should commission a preliminary report on how climate change could affect output, and the implications for generation capacity. Factors to consider include:

- Hydro power plants will suffer when winter flows increase and summer flows reduce.
- As the sea or river water used to cool power plants warms with climate change, plant efficiency will fall.
- As ambient temperatures rise, environmental constraints on cooling water discharge into rivers, lakes and sea could cause power plants to reduce output or even shut down in extreme cases.
- The output from intermittent renewable power plants relying on wind, run-of-river hydro and wave power, will change as the average wind speed, river flow and wave height change.

Review power requirements: In future, substantial extra energy may be needed for additional pumping for water supplies, wastewater disposal and agricultural irrigation. The use of air-conditioning is also likely to increase. The energy regulators in both jurisdictions should commission reports on how climate change could increase energy demand.

Review water impoundment standards: Safety standards for water impoundment should be reviewed by the owners, and operating and maintenance procedures amended taking account of climate change scenarios. The Republic of Ireland should enact legislation to manage the safety of significant impounded bodies of water.

Review wave energy issues: Wave and tidal power plants are vulnerable to sea level rises and especially to storm surges and higher waves. When planning and designing plant, owners and promoters of wave and tidal plants should take into account climate change scenarios communicated by the lead agency in the relevant jurisdiction.

Implement coastal protection measures: Coastal protection measures should be implemented for oil refinery and storage installations, gas and other pipelines, power generating stations, and electricity substations. ■

Appendix 1:

Keynote Abstracts

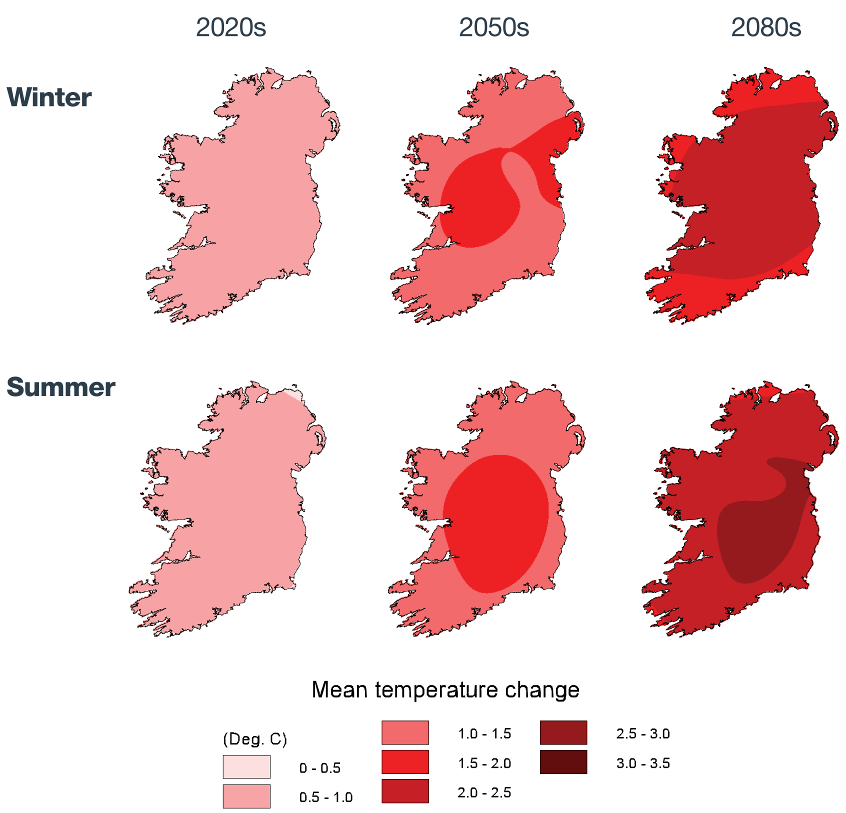
The full text of the four keynote papers is available on the Irish Academy of Engineering website: www.iae.ie.

1: Climate change: meeting the challenge of adaptation

Conor Murphy & Rowan Fealy, Irish Climate Analysis and Research Units (ICARUS), Dept. of Geography, NUI Maynooth

Work on climate change in Ireland to date has been successful in refining the likely impacts over the coming century. However, significant uncertainty and challenges remain and researchers in this critical area must work closely with end-users of data to ensure the best possible information is used for decision making and designing for the future. While acknowledging that some uncertainty remains, the following is a summary of likely changes in the key climate parameters.

- Temperatures are likely to rise everywhere relative to the present, with greatest increases suggested for summer and autumn of up to 3.4°C by the end of the century.
- With warmer average temperatures, we can expect a change in extreme events, with more intense and longer heatwaves likely, and less frost.
- Precipitation remains an uncertain variable, with different modelling approaches predicting differences in the extent and spatial distribution of changes. We do see, however, a robust signal of greater seasonality, with wetter winters and drier summers likely. No clear trend is evident yet for spring and autumn.
- As changes in average climate progress, changes in extremes can be expected, with the magnitudes likely to increase and extreme events for all climate variables (with the exception of minimum temperatures) likely to become more frequent.
- Increases of 8-11% in 60m-height average wind speeds are likely in winter by mid-century, and decreases of 14-16% in summer, but assessment of this variable to date has been subject to high levels of uncertainty.
- In relation to stream flow, we expect significant increases in winter and spring flows, in the order of 20% in winter by mid- to late-century. Reductions of over 40% are likely in summer and autumn in many catchments. Individual catchments show different signatures of change, however, depending on characteristics determining runoff response.
- Flood events are likely to become more frequent, with the current '50-year event' likely to become a '10-year event' by mid- to late-century. While uncertainty remains, low flow events are also likely to become more frequent.
- IPCC scenarios suggest a likely sea level rise of between 0.28 to 0.43m by the end of the century, relative to 1980-'99. However, recent thinking suggests that this may be too conservative, and increases of over 1m have been suggested. Localised rises will also depend on local characteristics, such as isostatic rebound of the land and topography.



Ireland will be warmer: average temperatures are likely to increase everywhere in the coming decades. Source: ICARUS, NUI Maynooth, 2007.

Increased storminess, higher sea levels and stronger wind speeds will all contribute to higher waves and storm surges. Combined with riverine flooding, these will pose serious flood risks in many of our coastal cities and for key infrastructure.

Even if greenhouse gas emissions were capped at 2000 levels some degree of climate change can be expected due to inertia in the climate system. In light of these findings there is a requirement to urgently review the security of critical infrastructure; to prioritise adaptation measures for existing infrastructure; and to incorporate adaptation provisions in all new infrastructure. Failure to do so would place unacceptable risk on the wellbeing of society.

2: Critical Infrastructure – water supply

Michael Phillips, Dublin City Engineer, Dublin City Council

In Ireland, we still take water for granted, but not for long. As climate change takes effect, there will be increasing disparity between the places where water availability is greatest (the west and north-west), and where it is most needed (east and southeast).

By 2026, Ireland's population could hit 7.8 million. More people, demanding more water, together with more irrigation, mean supply would have to double (assuming adequate sources are available), and prioritisation will become an issue. Ireland will remain relatively 'water rich', but to ensure a sustainable supply we will need to reduce demand, through long-term planning and pricing policies, conservation, harvesting and even re-using non-potable water.

The implementation of the EU Water Framework Directive, the Flood Directive and the creation of River Basin Management Plans have resulted in

Climate change will affect drinking water quality both directly and indirectly.

an integrated approach to managing the quality of the river catchments. This approach will greatly assist in defining acceptable limits and reducing threats to the catchments.

Currently, 70% of our water comes from surface freshwater, and about 30% from groundwater. The key part of any supply is the quantity and quality of the source. Water quality in Irish rivers has improved in recent years, but increasing pressure on sources heightens the risk of pollution, and we will need bank-side storage reservoirs to allow pollution 'incidents' to pass inlet pipes and ensure clean raw water.

The issues for adaptation are: Where will the significant water resources be located? How can the resources be quantified and protected sustainably? How can we effectively educate users about demand and re-use? How can we prepare a strategy to reduce uncertainty?

In a resilient system, every town or city would be able to draw on more than one source, but the Irish networks are not interconnected (for example, Dublin is not connected to Waterford). In Dublin, supply and demand is already finely balanced, and with reservoirs holding at most three day's supply, the region needs additional storage capacity.

Ireland is small, so building new pipelines to ensure continuity of supply is not technically difficult, but it would be costly: Dublin is currently investing €10 million to replace 10km of pipeline, but with 800km of watermains over 80 years old, significant investment is needed.

Adequate energy is critical in ensuring the delivery of potable water. Some treatment plants have generating units (e.g. hydro), but most rely on the national grid to power their pumps, although Dublin city is fortunate in that 80% of its water falls by gravity from treatment works in Kildare and Wicklow. Modern water treatment is sophisticated and, to maintain supply, it is also essential that staff have the relevant training. The following are some of the other factors that will affect water infrastructure:

- Pipelines will be more prone to cracking, due to greater soil movement from wetting and drying cycles
- Assets on flood plains and coasts will be at increased risk from flooding, storm damage, coastal erosion and rising sea level
- Existing sewerage was not designed for the more intense rainfall expected
- Dams will be more prone to siltation, resulting from increased soil erosion, or overtopping due to storms.

Currently, it can take 10 years to implement decisions about infrastructure in Ireland. Given the uncertainty about future climate change, how can we plan for a 20- or even 40-year time horizon? The challenge is to develop a better understanding of the known hazards, and the changing and newly emerging vulnerabilities, particularly in relation to identifying critical infrastructure so as to ensure that the basic services can be maintained to the public in times of adversity.

3: Flood Protection Infrastructure

Tony Smyth, Director of Engineering Services, Office of Public Works (OPW), Dublin

Flood defences that protect critical infrastructure from flood damage can themselves be considered as critical infrastructure. They include recently built defences; older structures (e.g. Land Commission embankments), which may provide some flood protection but are not always identified as such, and whose design and condition may be uncertain; and urban drainage networks, much of which may date from Victorian times.

Traditionally, the design of flood defences was based on historic data, but climate change means design must now take account of future predictions for rainfall, river flows and sea levels. The OPW, which runs a sizeable flood defence programme, already 'climate checks' its designs against two scenarios of climate change, including a possible average sea level rise of one metre. While the standards for newly designed flood defences take climate change into consideration, these allowances are based on current science, and most be reviewed and updated as further research is undertaken.

Drainage networks designed and built in the past may not be able to cope with the more frequent and intense rainfall we expect in future.

In the Republic of Ireland, the OPW has begun a catchment flood risk assessment and management (CFRAM) programme to develop and implement an integrated, pro-active and catchment-based approach, to ensure effective management of existing and potential future flood risks. Pilot studies are underway on four catchments, as a prelude to a national programme, and climate change is considered at every stage.

The CFRAM programme will generate both a flood asset database (recording and identifying major flood defences, and informing the relevant owner), and flood extent maps, showing areas at risk from flooding. The OPW, with the Dept. of Environment, Heritage and Local Government published draft guidelines on 'The Planning System and Flood Risk Management' in 2008.

The approach in Northern Ireland is similar, where the Rivers Agency has already developed asset management plans for its flood defences, and produced a strategic flood map. The Department of Environment (NI) Planning Policy Statement 15 (PPS 15) deals with planning and flood risk for Northern Ireland.

The biggest challenge is the uncertainty associated with climate change. If we knew with confidence what was going to happen, it would be easier to take decisions. Flood defences must be designed to withstand extreme events, but climate models have difficulty predicting extremes. This uncertainty means that we have to implement policies based on emerging data and assumptions. To address this uncertainty, the OPW has identified three areas requiring urgent research:

- Rainfall and climate
- Catchment response
- Sea level and storm surges.

Providing adequate and resilient flood protection to our towns and cities is expensive. This research will help reduce uncertainties, and allow engineers to design, build and maintain the most cost-effective flood defences.

4: Energy Infrastructure: adaptation for climate change

Michael Mackey (Head of Engineering), & Tom Bree (Manager, Environmental Engineering), ESBI Engineering

Every day, we hear of new initiatives in the energy sector to mitigate climate change. While major changes are underway in energy infrastructure, little attention has been given to climate *adaptation.*

Ireland's location in the Atlantic Ocean off Northern Europe has major implications for our energy supply. We are heavily dependent on importing fossil fuels over long distances, yet we have a favourable setting for renewable generation from wind and ocean power. The Northern Atlantic is linked to the Arctic Ocean, however, where climate and conditions are changing fast. Future energy infrastructure development must therefore address two distinct issues:

- The exploitation of renewable energy resources
- Withstanding the environmental impacts of climate change.

In the energy sector, the lead-time from planning to operation can be 10 to 30 years. Although this has speeded up significantly in recent years, thanks to technological advances, projections for energy supply and demand must still look forward 20 to 40 years, and take account of socio-economic factors and climate change. In the context of energy supply, the latter can include flooding of gas network marshalling stations and electricity substations, or the destruction of electricity lines by high winds. Hence the energy sector must address a wide range of adaptation issues, including:

Dublin City Council

An eastern by-pass option for Dublin: the proposed transport embankment would also protect the vulnerable Ringsend and Sandymount areas against the floods, storms surges and rising sea levels.

- Socio-economic models and methodologies for integrating adaptation in predicting future electricity demand
- Prepare wind and wave resource atlases for future scenarios
- Collect information on the climate parameters that will affect the efficiency and capacity factors of energy conversion and storage systems
- Incorporate adaptation in the Codes and Standards for design of power plants, electricity and gas network substations, oil storage and dam safety, based on predictions of extreme rainfall, wind, wave and surges. These will be higher than in most current design situations
- Analyse the so-called 'water-energy nexus' taking account of changes in rainfall, evaporation, river flows, sea level and storm surges
- Coastal protection measures at oil storage installations, pipelines, power generating stations, network substations and seabed cables
- Bioenergy action plan measures, accounting for seasonal changes in crop temperature and water cycle.

Measures to address adaptation must be comprehensive and integrated with other sectors, taking account of multiple factors through national and international policies.

Appendix 2:

Climate change symposium, Dublin, April 2009

The Irish Academy of Engineering standing committee on climate change brought together experts from across the island of Ireland – among them policy makers, owners of critical infrastructure, climate change researchers and engineers – for in-depth discussions to identify the key actions and initiatives needed in adapting Ireland's critical infrastructure for climate change. This symposium took place at Dublin Castle on April 28th, 2009, and was addressed by the Minister for Environment, Heritage and Local Government, John Gormley.

The event was attended by 75 invited senior people from Northern Ireland and the Republic of Ireland. Four keynote papers were circulated in advance, and the keynote authors made presentations on the morning of the workshop, which were followed by an open discussion. Most of the day was given over to detailed discussion in breakout workshops, focused on the three areas of critical infrastructure: water services, flood protection and energy supply (each area was addressed by two breakout groups, making six groups in all). The groups considered a number of pre-set questions, designed to provide a focus for discussion, but deliberations were not limited to these and any input considered important by the groups was welcomed. The pre-set questions were:

- What are the critical pieces of infrastructure that must be protected at all costs and are we in a position to produce risk assessments for these and to prioritise required actions?
- What climate change information do engineering professionals need from researchers or other sources to enable policy makers, planners, designers and those implementing infrastructure projects and adapting existing infrastructure, to adequately address the challenges of climate change?
- How can we ensure that Irish climate change research is as relevant as possible and cost effective?
- What actions, in order of priority, need to be taken and by whom in the short-term to enable those engaged in planning, designing and implementing critical infrastructure to adequately address the potential medium/long-term impacts of climate change?
- Does climate change present opportunities for Ireland and what adaptation measures are required to maximise these?

Each group reported to a plenary session with their considered view of the key issues and the actions required. The workshop concluded with an open discussion. This report is based on the results of the workshop discussions, together with relevant material from the IAE's 2007 report on *'Ireland at Risk: Water – the impact of climate change on the water environment'*.

The Academy was particularly pleased that the Minister for Environment, Heritage and Local Government took time to address the workshop, and we thank him for his interest. We hope that this report will now inform the development of adaptation strategies in both the Republic of Ireland and in Northern Ireland.

Appendix 3:

Symposium participants

Adamson, Mark	Office of Public Works
Aldridge, Pat	NI Rivers Agency
Ballantyne, Luke	Arup Consulting Engineers
Blaney, Garett	Viridian Power
Bray, Colin	Ordinance Survey of Ireland
Bree, Tommy	ESB International
Bruen, Michael	University College Dublin
Caballero, Rodrigo	University College Dublin
Cairns, Bob	DRDNI Roads Service
Callery, Phil	Irish Academy of Engineering
Casey, Jim	Office of Public Works
Christie, Sue	NI Environment Link
Colleran, John	Tobin Consulting Engineers
Cooper, Alan	IAE, & Scott Wilson Consulting Engineers
Cunnane, Con	NUI Galway
Davison, Paul	NI Water
Desmond, Margaret	Environmental Protection Agency
Duffy, Aidan	Dublin Institute of Technology
Duffy, John	Irish Academy of Engineering
Feeley, Enda	Eirgrid
Forde, Brendan	NI Climate Change Partnership
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Appendix 4:

Bibliography

A Community approach on the prevention of natural and man-made disasters, Commission of the European Communities, Brussels, COM (2009) 82

Adapting to Climate Change in Europe – Options for EU Action, EU Green Paper, Commission of European Community, Brussels COM (2007) 354

Adapting to Climate Change: the Challenge for Local Government, S Flood, N. Ni Chiardubháin. Comhar – Sustainable Development Council (2008)

Adapting to climate change: Towards a European framework for action, Commission Staff Working Document EU SEC (2009) 386/2

Adapting to climate change: Towards a European framework for action, EU White Paper Commission of European Community, Brussels COM (2009) 147

An Appeal to Reason – a Cool Look at Global Warming, N. Lawson, Duckworth Overlook (2008)

Challenging the Priorities: an independent review of Northern Ireland's infrastructure, – Institution of Civil Engineers Northern Ireland (2009) http://www.ice-northernireland.org.uk/northernireland/documents/ICE_Challenging_the_Priorities_2.pdf (accessed 14.09.09)

Climate Change Scenarios for the UK, UK CIP02 Scientific Report, UK CIP, DEFRA Hadley Centre and Tyndall Centre (2002)

Climate Change: Adapting to the Inevitable, UK Institution of Mechanical Engineers (2009) http://www.imeche.org/NR/rdonlyres/FA401F02-3193-4A19-826A-3FEEFB89DEDE/0/ClimateChangeAdaptationReportIMechE.pdf (accessed 14.09.09)

Delta Commission Report, The Netherlands (2008) http://www.deltacommissie.com/en/advies (accessed 14.09.09)

Development and flood risk - guidance for the construction industry, CIRIA, C624 (2004) http://www.ciria.org

How the water industry is adapting to climate change, Water UK briefing document (2008). http://www.water.org.uk/home/policy/climate-change/adaptation-briefing (accessed 10th April 2009)

Implications of Climate Change for NI: Informing Development Strategy. Scotland and NI Forum for Environmental Research (SNIFFER) Report SR(02)13 (2007) http://www.sniffer.org.uk

IPCC Climate Change and Water. Technical Paper of the IPCC. Bates, B.C., et al. IPCC Secretariat Geneva (2008) http://www.ipcc.ch/publications_and_data/publications_and_data_technical_papers_climate_change_and_water.htm (accessed 14.09.09)

IPCC Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the IPCC. Houghton, J.T., et al. (eds.), Cambridge University Press (2001)

IPCC Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Parry, M.L., et al. (eds.) Cambridge University Press (2007)

IPCC Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Solomon, S., et al. (eds.). Cambridge University Press (2007)

Ireland at Risk – Water: the impact of climate change on the water environment, Irish Academy of Engineering (2007) http://www.iae.ie/site_media/pressroom/documents/2009/Jun/09/Ireland_at_Risk_Water.pdf (accessed 14.09.09)

Ireland in a Warmer World. Scientific Predictions of the Irish Climate in the 21st Century. McGrath, R., et al. Community Climate Change Consortium for Ireland (2008) http://mathsci.ucd.ie/~plynch/C4I.pdf (accessed 14.09.09)

Learning Lessons from the 2007 Floods, The Pitt Review UK Cabinet Office (2008) http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html accessed 14.09.09

National Climate Change Strategy 2007-2012, Department of the Environment, Heritage and Local Government (2007) http://www.environ.ie/en/Publications/Environment/Atmosphere/PublicationsDocuments/FileDownLoad,1861,en.pdf (accessed 14.09.09)

Planning Policy Statement PPS 15. DOE NI Planning Service (2006) http://www.doeni.gov.uk

Resource scenarios for England and Wales: shaping planning for the 2050s, Dinnis C. et al. Water 21 (IWA Journal), April 2009.

Summary of the state of knowledge on climate change impacts for Ireland, Desmond, M. et al., Climate Change Research Programme (CCRP) 2007-2013, Report Series No. 1, EPA Ireland (2009)

The Economics of Climate Change: The Stern Review, Stern N., Cambridge University Press (2007)

UK Climate Projections Science Report: Climate Change Projections (UKCIP09), Murphy J M et al., UK Meteorological Office (2009)

Appendix 5:

Acronyms

C4I	Community Climate Change Consortium For Ireland
CCCma	Canadian Centre for Climate Modelling and Analysis
CFRAM	Catchment Flood Risk Assessment and Management
CSIRO	Commonwealth Scientific and Research Organisation, Australia
DRD	Department of Regional Development
ECHAM	European Centre Hamburg Model
EPA	Environmental Protection Agency
GCM	Global Climate Model
HadCM	Hadley Centre Coupled Model
IAE	Irish Academy of Engineering
ICARUS	Irish Climate Analysis and Research Units
IPCC	Intergovernmental Panel on Climate Change
NI	Northern Ireland
OPW	Office of Public Works
RCM	Regional Climate Model
RoI	Republic of Ireland
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SRES	Special Report on Emissions Scenarios
UKCIP	United Kingdom Climate Impacts Programme

Design by: Yellowstone Communications Design

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ISBN 1-898012-09-1
This report is available online at **www.iae.ie**