ADAPTATION PLANNING

Developing Resilience to Climate Change in the Irish Transport Sector

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Department of Transport, Tourism and Sport

Preface

The Minister for Transport, Tourism and Sport has prepared a Transport Sectoral Adaptation Plan under the non-statutory *National Climate Change Adaptation Framework*, 2012.

The Transport Sector considered within this Plan comprises the entirety of the national transport network, including land transport (road and rail), maritime (port) and aviation networks. The Plan outlines initial research and analysis on the likely effects of climate change on the Irish Transport Sector and proposes actions to develop climate resilience within the sector. It is a high-level plan endeavouring to identify where vulnerabilities lie at a broad level and, accordingly, is not infrastructure specific.

A preliminary draft was prepared for public and stakeholder consultation undertaken in the period between December 2016 and February 2017. The consultation process allowed stakeholders an opportunity to comment on likely impacts, vulnerabilities and risks, with particular reference to cross-sectoral concerns, to Ireland's transport system from climate change and the challenges and opportunities identified therein.

A statutory National Adaptation Framework (NAF) is being prepared under the Climate Action and Low Carbon Development Act, 2015 and will be submitted to Government for approval before the end of 2017. Following approval of the NAF by Government the preparation of a statutory sectoral adaptation plan addressing transport sector matters will be a legislative requirement in 2018.

Table of Contents

Preface 1

Table of Contents 2

Foreword 3

1. Introduction 4

2. Strategic Environmental Assessment and Appropriate Assessment 11

3. Climatic Trends in Ireland 13

4. Transport Sector Profile 16

5. Methodology I: Determining the Vulnerability of the Transport Sector to Impacts of Climate Change 23

6. Methodology II: Examining the Impact of Severe Weather Events and Climate Change on the Transport Sector 26

7. Categories of Adaptation Options 50

8. Current Measures that Assist in Adaptation Planning 51

9. Next Steps to Enable Climate Change Adaptation Progress in the Transport Sector 59

10. Monitoring and Reviewing 67

11. Conclusion 68

12. References 69

13. Annex I: Detailed Table of Impacts 72

14. Annex II: Ongoing Adaptation Research 81

15. Annex III: Glossary 86

16. Annex IV: Acronyms 88

Foreword

Adapting to our changing climate represents a considerable challenge - and presents significant opportunities for the Irish Transport Sector.

It is becoming increasingly apparent that our climate is changing on a global level and that these changes will have far-reaching consequences for Ireland in the years to come. The frequency and severity of recent extreme weather events, and the adverse impacts these have had for the transport sector, have underlined a pressing need for us to instigate action at national, regional and local levels to plan for adaptation.

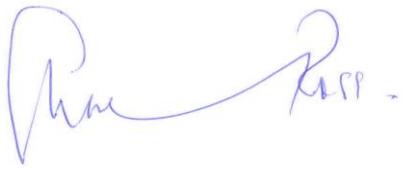
Developing Resilience to Climate Change in the Irish Transport Sector represents an important step in 'future-proofing' the functioning of our transport networks to ensure that the sector continues to deliver on every level for the Irish economy and society.

This Plan assesses our state of preparedness for the predicted changes to Ireland's climate in the years to come. It also shows our commitment to supporting Transport stakeholders in making rational, evidence based decisions as they adapt to the challenge of climate change.

Under the provisions of the *Climate Action and Low Carbon Development Act*, 2015, a *National Adaptation Framework is* currently being developed by the Department of Communications, Climate Action and the Environment. The *Framework*, which will be submitted to Government shortly, will require the preparation of statutory sectoral adaptation plans every five years.

This Plan is, therefore, not a complete roadmap towards climate resilience but rather a significant stage in our journey towards safeguarding critical Transport services and infrastructure from the impacts of climate change and their associated environmental, economic and social costs.

The suite of measures set out in this Adaptation Plan will lay strong foundations on which to build our long-term vision of a low-carbon, environmentally sustainable and climate-resilient Transport Sector for Ireland by 2050.



Shane Ross TD
Minister for Transport, Tourism and Sport

1. Introduction

Our climate is changing and the associated transformation poses particular challenges for Irish transport. The transport sector is inherently sensitive to the effects of climate change and the impacts of numerous recent severe weather events on key transport infrastructure and services have demonstrated that as well as physical damage to transport networks, climate change can have negative repercussions across the economic, social, environmental and public health spheres.

While there is still a degree of uncertainty about the level and extent of the likely impacts, the science in relation to the warming of the climate system is unequivocal (IPCC, 2013) and an exacerbation of existing vulnerabilities is to be expected. Changing weather patterns and violent extremes can cause infrastructure damage and deterioration, disruptions to transport operations and unsafe conditions. It is important to differentiate between weather and long-term climate change, however, the increase in volume and severity of weather events in recent years is highly indicative of future climate trends in Ireland. The impacts of climate change are now being observed across all continents and oceans (IPCC, 2014).

…it will be vital to future-proof the efficient functioning of our transport system so that Ireland can continue to accrue the many benefits of transport to the economy and society in general.

Adaptation planning is crucial for the transport sector as a key player in the Irish economy. The level of service offered by any transport system has the ability to significantly impact on both the economic and social heart of a country. On that basis, and notwithstanding the relative uncertainty associated with climate prediction and variability, it will be vital to future-proof the efficient functioning of our transport system now so that Ireland can continue to accrue the many benefits of transport to the economy and society in general. While investing in the existing transport network based only on the potential of future vulnerability offers more immediately apparent long-term rather than short-term benefits, it is anticipated that integrating climate adaptation measures into transport planning and policies will increase the cost-effectiveness of future infrastructural design, operation and maintenance. It is important, therefore, for industry stakeholders and relevant bodies to recognise the need to take timely action in order to improve the resilience of transport assets and limit reactive remedial expenditure in the years to come. In a recent – and costly - example, €106 million was allocated for urgent repairs to transport infrastructure as a result of the damage caused during Storm Desmond and Storm Frank in late 2015/early 2016. Adaptation actions will be required to avoid or reduce the adverse impacts of climate change and to anticipate possible future changes.

The role of the Department of Transport, Tourism and Sport (DTTAS) will be to translate this scientific consensus into action by facilitating collaboration amongst many different sectoral stakeholders, raising awareness and understanding of climate change at all levels and promoting proactive, rather than reactive, climate actions. Guidance and information on adaptation to climate change is provided by the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). There is now a clearer understanding of how the risks of climate change can be reduced and managed through complementary strategies which focus on adaptation and mitigation (IPCC, 2014).

The Plan aims to better understand the potential implications of climate change at a national, regional and local level through a comprehensive assessment of the issues facing transport infrastructure and services today, integration of contemporary climate research and identification of further climate research opportunities. The knowledge base assembled through this Plan will inform the development of future adaptation policy for the transport sector and help us to build capacity for adaptation, climate resilience and long-term sustainability in our organisations and structures.

1.1 Strategic Focus

An overarching policy to build resilience to the impacts of climate change is being led by the EU Commission through the *EU Strategy on Adaptation to Climate Change*, which was adopted in April 2013. Available online at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013DC0216

This *Strategy* supports action by promoting greater co-ordination and information-sharing between Member States with the aim of ensuring that adaptation considerations are addressed in all relevant EU policies. It sets out a framework and mechanisms for developing preparedness in respect of current and future climate impacts across the EU.

The *Strategy* is accompanied by a generic set of adaptation planning guidelines, which have been used by the Environmental Protection Agency to guide the roll-out of sectoral plans as well as the development of guidelines for local authorities in Ireland.

Aligned to the *EU Strategy on Adaptation to Climate Change* is Ireland's *National Climate Change Adaptation Framework*, published by the Department of Environment, Community and Local Government (now under the aegis of the Department of Communications, Climate Action and the Environment or DCCAE) in

December 2012. Available online at: http://www.dccae.gov.ie/en-ie/climate-action/topics/adapting-to-climate-change/national-adaptation-framework/Pages/default.aspx

The *Framework* brings a strategic policy focus to climate change adaptation at local and national level through the development and implementation of sectoral and local action plans. This includes the development of an Adaptation Plan for Transport.

The evolution of climate policy in Ireland will continue to be an iterative process. In relation to adaptation, this is reflected in the commitment by Government to develop a series of Adaptation Plans over the period to 2050, which is underpinned by the *Climate Action and Low Carbon Development Act 2015*, Ireland's landmark legislation dedicated to responding to the challenges of climate change. These statutory Plans will collectively provide a national strategy for the application of adaptation measures in different sectors to reduce the vulnerability of the State to the negative effects of climate change.

1.2 Transport Sector Focus

This first Adaptation Plan for the transport sector is a high-level plan that is seeking to identify vulnerabilities at a national level across the transport system. The Plan aims to better understand the potential implications of climate change at a national, regional and local level through a comprehensive assessment of the issues facing transport infrastructure and services today, integration of contemporary climate research and identification of further climate research opportunities. The knowledge base assembled through this Plan will inform the development of future adaptation policy for the transport sector and help us to build capacity for adaptation, climate resilience and long-term sustainability in our organisations and structures.

The approach to adaptation planning for transport has been guided by the Environmental Protection Agency (EPA)'s funded project *Climate Ireland*, which is a climate change information platform for knowledge exchange and capacity building through the centralisation of existing climate information and data for Ireland. The platform is available online at: https://www.climateireland.ie/#/

Taking account of *Climate Ireland*, the approach used to create this plan followed five steps:

1. **Building the adaptation team: Scope of work –** A stakeholder team was established to scope out and to develop this Plan. The following is a list of organisations that were represented on the team and/or made contributions to the development of the Plan: Transport Infrastructure Ireland (TII), Iarnród Éireann, Dublin Bus, Bus Éireann, Irish Aviation Authority, Commission for

Aviation Regulation, Dublin Airport Authority, Shannon Airport Authority, IBEC/Irish Ports Association, Dublin Port Company, Port of Cork, Shannon Foynes Port, Port of Waterford, Drogheda Port Company, Dún Laoghaire Port Company, Port of Galway, South Dublin County Council, DAFM, DTTAS and DCCAE.

2. **Climate impact and vulnerability screening –** In order to identify the full range of current and potential future climate impacts and vulnerabilities for the transport sector in Ireland, an extensive and national scale assessment was undertaken. This assessment was based on literature review and stakeholder inputs and produced a list of the known range of current and potential future climate impacts. This assessment formed the basis for prioritising current and potential future impacts and vulnerabilities, priority areas and response capacity.

3. **More detailed analysis of priority climate impacts and vulnerabilities –** Climate impacts and vulnerabilities identified as a priority in step 2 (above) were then subjected to more detailed assessment and were reviewed in light of: observed and projected changes to climatic drivers; the current weight of evidence and the confidence in the projected assessment; the magnitude and likelihood of impacts; and the urgency of adaptation actions.

4. **Identifying, assessing and prioritising adaptation options** – An exercise was carried out to identify existing adaptation options based on the current impacts and vulnerabilities identified in step two. These current adaptation options were then used as a basis to identify potential future adaptation options.

5. **Monitoring and review –** The measures identified to establish a robust climate change adaptation plan will be considered in the context of effectiveness, efficiency and equitability. The monitoring system put in place for transport will be part of a larger system that monitors progress at local authority level, as well as national level. The *Monitoring Mechanism Regulation* is the mechanism for reporting to the European Commission (EC) and the United Nations Framework Convention on Climate Change. In the long term, there will be recurring *National Adaptation Frameworks* (NAF) and sectoral plans as provided by the *Climate Action and Low Carbon Development Act 2015*.

In order to advance this adaptation work, DTTAS has been working with an adaptation expert from University College Cork (UCC) since December 2015. This support, which is being funded by the EPA Research Programme, was an important contributor to the DTTAS' progress in advancing through the above process, particularly steps 2 and 3.

1.3 Climate Adaptation Policy Context

It is evident the impacts of climate change will pose significant challenges for Ireland which will be felt at a national level. Responsibility for addressing these impacts, therefore, is collective and not sectoral in nature. It is vital that any climate change activities in relation to the Transport Sector are coordinated within a wider national climate programme.

In addition to transport sector collaboration, DTTAS engaged with other sectors and local authorities currently involved in developing adaptive strategies, both directly and through representation on a steering group chaired by DCCAE. The Local Government sector, in particular, is fundamental in adaptation planning given its role as a front line responder to the impacts of severe weather and climate change related events.

Other relevant plans of particular significance to the Transport Sector include:

Table 1.1: Thematically Connected Planning

Plan	Responsible Body	Relevance to Transport
Emergency Planning	Health Service Executive (HSE), An Garda Síochána and Local Authorities	Transport infrastructure and services are particularly vulnerable to impacts of severe weather conditions.
Flood Defence	Office of Public Works (OPW)	Transport infrastructure and services are particularly vulnerable to impacts of fluvial, pluvial and coastal flooding.
Marine	Department of Agriculture, Food and the Marine (DAFM)	Adaptation measures for maritime transport services and infrastructure; sensitive to marine biodiversity and eco-systems. Cross-sectoral concerns for ports regarding import/export of agricultural produce.
Air Quality	Department of Communications, Climate Action and the Environment (DCCAE)	Recognising the impacts of adaptation measures on air quality concerns the Transport sector.
Health	Department of Health	Climate change impacts to public health for employees and passengers on transport networks.

The schematic overleaf (Figure 1.1) represents an indicative overview of this Plan's position within the overall hierarchy of relevant national climate strategies, plans and policies.

Climate Adaptation Policy Hierarchy

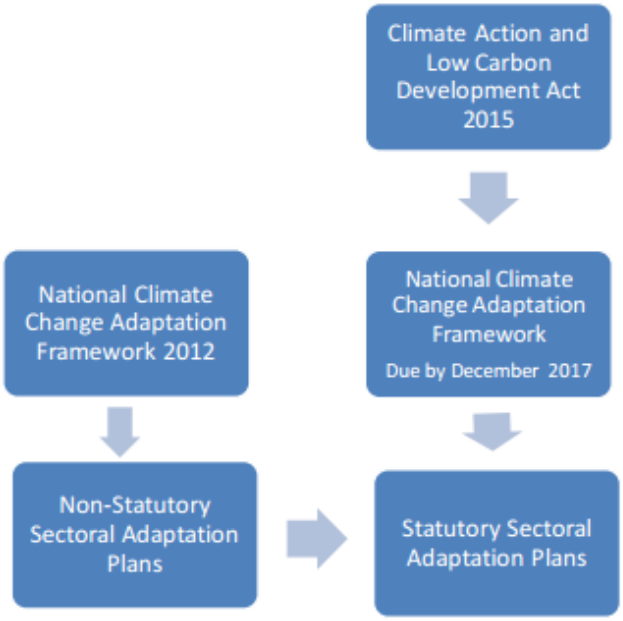


Figure 1.1 The Adaptation Plan within the national-level climate policy hierarchy

In a separate but complementary process under the *Climate Action and Low Carbon Development Act 2015*, future low-carbon measures for the transport sector are considered within the context of the *National Mitigation Plan*. This Plan, which was approved by Government in June 2017, sets a national pathway towards a transition to a competitive, low carbon, climate resilient and environmentally sustainable economy by 2050 through the reduction of non-ETS greenhouse gas (GHG) emissions across four main sectors: transport; agriculture; energy; and built environment. The transport contribution to the *National Mitigation Plan* highlights a wide-ranging number of measures which will serve to change Ireland's emissions profile for the positive, focusing primarily on promoting behavioural change and modal shift; further investment in public transport; increasing public transport capacity and movement to alternatively fuelled vehicles.

This Adaptation Plan also acknowledges the potential synergies associated with the implementation of adaptation measures in reducing the potential adverse impacts of climate change on public health and on the natural environment. It is envisaged that future iterations of this Plan will in due course take into account the provisions of the *National Clean Air Strategy*, currently being developed to comply with new and emerging EU clean air legislation.

DTTAS will also seek, when implementing the measures outlined in the recently published *National Policy Framework on Alternative Fuels Infrastructure for Transport in Ireland - 2017 to 2030*, to be sensible of the need for climate change adaptation. Similarly, the re-fuelling and recharging infrastructure which will be established as a result of the *Framework* will constitute a vital aspect of our transport network and will be considered accordingly in departmental and stakeholder adaptation policy.

It is important to acknowledge the synergies and co-benefits - not least when considering issues such as public health and air quality - that exist between 'mitigation' and 'adaptation' and to recognise that these are likely to become more pronounced in successive plans as progress on mitigation and adaptation planning becomes more developed in Ireland.

DTTAS acknowledges that adaptation planning will have tangible synergies with the spatial and land use planning at local and community, as well as at a national level, in the *National Planning Framework - Ireland 2040: Our Plan*, currently being developed by the Department of Housing, Planning and Local Government (DHPLG).

1.4 Co-Benefits

Adaptation planning for the Transport Sector will be updated on an ongoing basis to incorporate technological developments as climate research continues to progress.

In this context, it is important to acknowledge the synergies and co-benefits - not least when considering issues such as public health and air quality - that exist between 'mitigation' and 'adaptation' and to recognise that these are likely to become more pronounced in successive plans as progress on mitigation and adaptation planning becomes more developed in Ireland. Equally, it is important for decision-makers to be cognisant that the interaction between adaptation and mitigation measures, while conferring potential benefits, may also represent potential conflicts. To give an example of such a conflict, passenger heat stress on public transport caused by a rise in temperature may call for the installation of air conditioning systems as an adaptation measure. Such a measure would have the potential knock-on effect of increasing carbon emissions, however marginally, which would need to be strategically addressed by decision-makers.

DTTAS will be sensitive to the possibility of both complementary actions and potential conflicts of interest with existing policies (including but not limited to: the *National Planning Framework*; the *National Mitigation Plan*; the *National Clean Air Strategy*; and the *National Policy Framework on Alternative Fuels Infrastructure for Transport in Ireland*) and will seek to strike a sustainable and equitable balance when devising sectoral policy and recommendations.

2. Strategic Environmental Assessment and Appropriate Assessment

2.1 Strategic Environmental Assessment

Strategic Environmental Assessment (SEA) is the process by which environmental considerations are integrated into the preparation of plans and programmes.

The *European Communities Environmental Assessment of Certain Plans and Programmes Regulations* (S.I. 435 of 2004 as amended by S.I. 200 of 2011) stipulate that SEA is mandatory for certain plans/programmes which are prepared in a number of specified areas, including agriculture, energy and transport, and which set the framework for future development consent of projects listed in Annexes I and II to *Environmental Impact Assessment Directive* 85/337/EEC, or where it has been determined under the *Habitats Directive* that an assessment is required.

Following the screening process, where the context of the Plan has been assessed against the pre-screening check and the environmental significance criteria as set out in Schedule 1 of the SEA Regulations it is concluded that a full SEA is not required for the following reasons:

- The Plan does not provide a framework for development consent for projects listed in the *Environmental Impact Assessment Directive*.
- The purpose of the Plan is to outline transport policy on climate change adaptation in relation to the development of strategies and measures but the Plan will not consider specific locations nor propose projects or measures. This does not preclude the inclusion in later Adaptation Plans for the Transport Sector of more detailed adaptation approaches and measures should this be deemed necessary through the associated SEA and Appropriate Assessment (AA) process.

This Plan is not considered likely to have significant effects on the environment; therefore, an SEA is not required.

2.2 Appropriate Assessment

The EU Council Directive *92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora*, better known as the *Habitats Directive*, provides legal protection for habitats and species of European importance, through the establishment and conservation of an EU-wide network of sites known as the Natura 2000 Network. These are Special Areas of Conservation (SAC) designated under the *Habitats Directive*, and Special Protection Areas (SPAs) designated under the *Conservation of*

Wild Birds Directive (Directive 79/409/EEC as codified by Directive 2009/147/EC), collectively referred to as 'European Sites'. Article 6(3) establishes the requirement for an AA of plans and projects likely to affect European sites.

Section 4.3.2 of the European Commission document on managing Natura 2000 sites, The Provisions of Article 6 of the *Habitats Directive* 92/43/EEC, states that it does not seem appropriate to treat policy documents, which show the general political will or intention of a ministry or lower authority as 'plans' for the purpose of Article 6(3). The section further notes that this is particularly relevant if any initiatives deriving from such policy statements must pass through the intermediary of a land-use or sectoral plan.

It is concluded that a full AA of the Plan is not required because, as stated in section 5, it is not possible to carry out an assessment of the likely effects of the Plan on Natura 2000 sites as the purpose of the Plan is to outline DTTAS policy on adaptation to climate change within the transport sector, not to set out projects or propose specific measures.

3. Climatic Trends in Ireland

Observations show that Ireland's climate is changing and that the scale and rate of change are consistent with regional and global observations and trends (Dwyer, 2013). These changes are projected to continue and increase over the coming decades (Gleeson et al., 2013).

They include increases in average temperatures (surface air and sea surface), changes in precipitation patterns and ongoing sea level rise. Extreme weather events are projected to disrupt most natural and managed systems and regions. In particular, systemic risks due to extreme weather events leading to the breakdown of infrastructure networks and critical services such as electricity, water supply, transport and health and emergency services are expected.

Table 3.1:
Summary of the observed and projected impacts of climate variables for Ireland.
Source: EPA (2017).

	Observed Impacts	Projected Impacts
Temperature	Mean annual surface air temperatures have increased by about 0.8 ^{O}C over the period 1890–2012; an average of about 0.07 ^{O}C per decade.	Mean annual temperatures will rise by about 1 ^{O}C - 1.6^{O}C (RCP4.5 scenario*) by mid-century compared to the 1961–1990 average; highest increase in the east.
Precipitation	Average annual national precipitation over the period 1981–2010 has increased by 5% relative to the period 1961–1990.	Wetter winters (14% increase in precipitation for RCP8.5 scenario** by mid-century); drier summers (10 - 20% reduction for RCP8.5 by mid-century).
Extreme Events	There is no evidence of a sustained long-term trend but evidence exists of an increase in the frequency of days with heavy rain (10mm or more) over the period 1981–2010, relative to the period 1961–1990 (EPA, 2009).	Slightly fewer storms, but more intense ones. The tracks of intense storms are projected to extend further south.
Sea Levels	1993-2017 sea level rise of c. 35mm per decade (currently c. 3.4mm/year) has been observed. Tide gauge records pre-1990 show sea level rise of 1–2mm/year.	Rise of c. 550–600mm to 2100 [based on IPCC RCPs 2.6–4.5 and other medium-scale climate warming scenarios.
Environment	Trees and plants: evidence of change in timing of phenological phases such as bud burst, leaf unfolding, flowering, fruiting, leaf colouring and leaf fall in some trees and plants.	Projections suggest that bud burst of birch will continue to advance until 2100; rate of advance will vary with the north-east region showing the greatest advance.

* Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014. The pathways are used for climate modelling and research and describe four possible climate futures, dependent on the level of GHG emissions in the years to come. The RCP 4.5 scenario is a stabilisation model which assumes that international climate policies will set out and implement measures designed to limit greenhouse gas emissions and radiative forcing, resulting in climate stabilisation by the year 2100 (Thomson et al., 2011).

** The RCP 8.5 scenario corresponds to the pathway with the highest greenhouse gas emissions compared to the total set of RCPs. RCP 8.5 assumes the continuance of population increase, slower income growth and modest rates of technological advancements, leading to high energy demand and GHG emissions in absence of climate change policies (Riahi et al., 2011).

Other key results for the Irish climate, as set out in [1] *Ensemble of regional climate model projections for Ireland* (2015), [2] *A high-resolution, multi-model analysis of Irish temperatures for the mid-21st century* (2015) and [3] *Impacts of climate change on mid twenty-first century rainfall in Ireland: a high-resolution regional climate model ensemble approach* (2017) are as follows:

- Air temperatures will experience a general upward trend and are predicted to rise by 1-1.6°C between 2041-2060, relative to the average temperature of 1981-2000. The largest increases are projected in the east of the country which implies that regional variation in air temperature will become more pronounced [1, 2].
- Summer and winter temperatures will experience different patterns, with mean summer temperatures increasing from 0.9-1.1 degrees in the northwest to 1.3-1.7 degrees in the southeast; while mean winter temperatures are expected to increase from 1.0-1.2 degrees in the southwest and 1.3-1.7 degrees in the northeast (relative to mean temperatures for 1981–2000) [1,2].
- Warming is enhanced for the extremes (i.e. hot or cold days), with summer daytime temperatures projected to rise by approximately 0.7-1.3°C in the north and 2.0-2.6°C in the south. Winter night-time temperatures are projected to rise by 1.1-1.4°C in the south and 1.4-3.1°C in the north. Averaged over the whole country, the number of frost days (days when the minimum temperature is less than 0°C) is projected to decrease by over 50% [1, 2].
- Significant projected decreases in mean annual, spring and summer precipitation amounts are expected by mid-century. The projected decreases are largest for summer, with reductions ranging from 0 to 20% [1, 3].

Extreme weather events are projected to disrupt most natural and managed systems and regions. In particular, systemic risks due to extreme weather events leading to the breakdown of infrastructure networks and critical services such as electricity, water supply, transport and health and emergency services are expected.

- The frequencies of heavy precipitation events (with daily rainfall over 20mm) show notable increases of approximately 20% during the winter and autumn months. Regional variations could not be robustly evaluated [1, 3].
- The number of extended dry periods is projected to increase substantially by mid-century during autumn and summer. The projected increases in dry periods are largest for summer, with values ranging from 12% to 40% [1, 2].
- The energy content of the wind is projected to decrease during spring, summer and autumn. The projected decreases are largest for summer, with values ranging from 3% to 15% [1].

A sizeable amount of accurate and verified climate information is available to us from various universities, higher education institutions, private and semi-state bodies and agencies throughout Ireland. Unfortunately, the resolution of the information that is currently available to us in respect of climate trends is still at a high level and tells us little about low level projections, which are critical for determining risks for the transport sector. Future modelling for the transport sector in relation to climate risk will be vital to progress to more focused actions in subsequent adaptation plans. In this regard, the launch in May 2017 of *MÉRA*, the Met Éireann ReAnalysis Project of Ireland's climate data from 1981 to date, which provides historical high-resolution meteorological datasets for climate monitoring and use in predictive modelling and research, may in due course offer a valuable potential resource for a more nuanced understanding of our climate and its challenges.

Furthermore, researchers at the Irish Centre of High-End Computing (ICHEC), through an EPA-funded project, are currently working on updating and improving the high-resolution climate projection dataset for Ireland. This research involves utilising the most up-to-date climate models, coupled ocean-atmosphere-wave models and IPCC emission scenarios. The climate models are run at high spatial resolution (3.8km), allowing a better evaluation of the local effects of climate change in Ireland. To account for the uncertainty in future emissions, all IPCC RCP (2.6, 4.5, 6.0 & 8.5) emission scenarios are used to simulate the future climate of Ireland to 2100. It is expected that this research will reduce climate projection uncertainty and provide sharper estimates of expected climate change in the in the decades ahead.

4. Transport Sector Profile

4.1 Land Transport

4.1.1 Road Transport Infrastructure

Ireland's national road network totals 5,306km of road, comprising 2,739km designated as National Primary Road and 2,676km designated as National Secondary Road. These roads, which account for 94% of the country's roads network, carry around 55% of all road traffic.

Like the national network, the local and regional road network, which comprises approximately 93,000km and includes a network of bridges, is critical for the operation of local and regional economies, the transportation of goods to the marketplace, connectivity to the national road and rail network in addition to seaports and airports. This network is also vital to the operation of local communities, providing links to schools and community centres as well as providing support to the development of the tourism and agriculture sectors.

Transport Infrastructure Ireland (TII) operates, maintains and improves the national primary and secondary road network in the Republic of Ireland, with the local and regional road networks managed separately by 31 local authorities. Contained within the national road network are the Motorway/Dual Carriageway sections, totalling 1,224km of road. Approximately 328km of these sections are maintained under existing Public Private Partnerships and 744km are maintained directly by TII through Motorway Maintenance and Renewals Contracts, with the remaining 152km maintained through local authorities.

The national primary and secondary road network carries approximately 45% of the country's total road traffic, and most of Ireland's freight is distributed by road. TII is responsible for three tunnels as part of the National Motorway Network: the Dublin Tunnel (M50), the Jack Lynch tunnel (N40) and the Limerick Tunnel (N18). The tunnels are maintained through maintenance contracts.

The road network also supports, through high quality infrastructure, a national network of greenways and cycle lanes for active travel, in addition to the operation of public transport services, both State and private funded, including those bus services operated by Bus Éireann and Dublin Bus.

4.1.2 Bus Services

Buses are the backbone of the Irish public transport system. Bus travel in Ireland is far higher than the European average and increasing: data from the Central Statistics Office showed that the total number of passengers per annum increased from 210 million in 2011 to 224.1 million in 2015.

Bus services throughout the country consist of a combination of Public Service Obligation (PSO) routes which are contracted by the National Transport Authority (NTA) and commercial routes which are licensed by the NTA.

PSO routes are services that receive State funding to ensure that socially beneficial but financially unviable transport services are provided. In the Greater Dublin Area, Dublin Bus carried 128 million passengers on PSO routes in 2016. Bus Éireann also carried 32 million passengers on PSO routes throughout the country in 2016.

Commercial services receive no State funding and are operated on a 'for-profit' basis by a variety of operators across the country. In 2016 a total of over 25 million passengers travelled on a commercial bus service.

In addition to PSO and commercial licensed services, there are also a variety of other bus services, including tourist transport provision and school transport. In 2016 Bus Éireann and over 1500 subcontractors carried just over 40 million passengers through the school transport system.

4.1.3 Rail Infrastructure and Services

Ireland has a network of rail lines that have been in place for almost 150 years over which a significant number of public transport rail services are provided. The network supports the economic and social development of the state in providing accessible transport to many key destinations. Approximately 42 million passenger journeys were completed on the network in 2016, which is returning to the levels achieved at the height of the boom in 2007. However, Ireland remains significantly below the EU average for number of passengers completing journeys by rail transport.

4.1.3.1 Heavy Rail

The heavy rail network, operated by Iarnród Éireann, currently extends to approximately 2,400km of track, 5,100 bridges, 1,240 level crossings, 147 stations, 4,900 cuttings and embankments, 330 coastal/estuarial defences, 372 platforms and 14 tunnels. Within this figure, the heavy rail passenger network consists of 1,679km of line tracks linking areas and regions, with 144 passenger stations in total; however,

the comprehensive network includes main line, Dublin suburban and commuter passenger routes, together with freight-only routes. There is a cross-border connection to the railway system in Northern Ireland between Dundalk and Newry. Part of the Dublin suburban railway network (DART) is electrified, with the remainder of the network continuing to operate with diesel traction.

Iarnród Éireann also owns and operates Rosslare EuroPort, the second biggest port in the Irish State.

Figure 4.1: Iarnród Éireann intercity routes

4.1.3.2 Light Rail

The light rail system is operated by Transdev Dublin Light Rail Ltd. under contract to TII and the National Transport Authority (NTA). The existing light rail network, known as the Luas, comprises two lines: the Red Line and the Green Line. The Luas Red Line runs from termini at Saggart and Tallaght to Connolly Station and The Point. The Luas Green Line runs from Bride's Glen to Sandyford, Dundrum and St.

Stephen's Green. In total, Luas infrastructure on the Red and Green lines comprises over 37km of twin track, serving 54 operational Luas stops. There are also two tram maintenance depots and 20 electrical sub-stations, in addition to seven Park & Ride sites. The Luas fleet consists of 66 Alstom Citadis trams.

Luas Cross City, currently under construction, is the next phase of Dublin's integrated light rail network. It will provide an interchange between the existing Red and Green Lines in the City Centre and will serve the new Dublin Institute of Technology campus at Grangegorman, with 13 stops along its route. The Luas Cross City will commence operation before the end of 2017 and will provide for an estimated 10 million additional journeys per annum on the Luas network.

4.2.1 Airports

Ireland has 5 international airports, of which Dublin, Cork and Shannon handle the greatest number of passengers. In 2016, almost 33 million passengers (32.8m) passed through Irish airports. Dublin Airport is the largest, serving an average of 25 million passengers per annum and over 180 destinations. Cork Airport is the country's second busiest airport, flying to over 50 destinations across the UK and continental Europe. More than 2.2 million passengers travelled through the airport in 2016. Shannon Airport is the third busiest airport after Dublin and Cork, serving 1.67 million passengers in 2016.

There are also a number of regional airports supported by Exchequer funding operating in Ireland. The principal ones are located in Donegal, Knock, Kerry and Waterford. In 2016 these four airports handled over 1 million passengers – 13,511 from Waterford, 44,156 from Donegal, 325,670 from Kerry and 735,869 from Knock.

4.2.2 Aviation Services

The Irish Aviation Authority (IAA) is responsible for the management of Irish controlled airspace as well as the safety regulation and security oversight of Irish civil aviation. The IAA ensures that Irish civil aviation operates to safety standards set internationally by the International Civil Aviation Organisation (ICAO), the European Civil Aviation Conference, the European Aviation Safety Agency, the European Joint Aviation Authorities, Eurocontrol and the EU.

Air traffic management includes the provision of operational services, engineering and communications in airspace controlled by Ireland and the provision of the related air traffic technological infrastructure. The IAA provides air traffic management services in the 451,000km^2 of airspace controlled by Ireland and to all aircraft arriving and departing from three State airports of Dublin, Shannon and Cork.

4.3 Ports

As a trade-dependent island economy without a land connection with continental Europe, Ireland's network of 25 ports constitutes infrastructure of strategic economic importance to the State. This significance may potentially be heightened in the context of Brexit, as Ireland will no longer share a contiguous border with any EU Member State.

Irish ports differ greatly in size and the 2013 National Ports Policy classifies three ports as 'Tier 1 Ports of National Significance': Dublin Port, Port of Cork and Shannon Foynes. There are two ports classified as 'Tier 2 Ports of National Significance': the Port of Waterford and Rosslare EuroPort. The remaining commercial ports are classified as 'Ports of Regional Significance' with the largest in freight terms (based on 2015 data) being Drogheda, Bantry Bay, Greenore and Galway. There are a further 12 regional ports, including the Port of Galway and Dún Laoghaire Harbour Port.

According to the Central Statistics Office, in 2015 alone Irish ports handled 50.6 million tonnes of cargo. Dublin Port accounted for 43.8% of all freight handled in 2015 (22.2 million tonnes). Shannon Foynes and Port of Cork handled 21.5% and 19.2% (10.8 and 9.7 million tonnes) respectively. A further 2.1 million tonnes was handled in Rosslare EuroPort and 1.5 million tonnes in Waterford Port.

In addition to freight cargoes, Ireland's ports facilitate a range of maritime activities including pilotage, channel dredging, land and property rental, port training, towage, mooring boats, storage and repairs.

Ports also represent key gateways for international tourism, with 2.75 million maritime passengers handled in Irish ports in 2015. Dublin Port, the Port of Cork, Rosslare EuroPort, the Port of Cork and Dun Laoghaire Harbour Port, amongst others, provide ferry, marine, cruise, events and leisure services. Ferry connections to the UK are particularly important in Dublin with up to 16 sailings daily. The cruise ship sector is also significant to national port activity, with 193 visits from cruise liners and over 241,872 cruise ship passengers in 2015. 50% of all cruise ship visits in 2015 were to Dublin Port (93 visits, up from 86 in 2014). The Port of Cork had the next highest share at 31% (57 visits, up from 52), while 10% of cruise ship visits were to Waterford Port.

Figure 4.2: Ireland's principal roads, airports and ports

4.4 Cross-services Interdependencies

DTTAS recognises that transport is central to the overall resilience of many sectors. Changes in climatic trends and weather events are unlikely to affect one sector in isolation of another so it is important that we understand the interdependencies between the sectors and address risks in a co-ordinated manner.

Critical infrastructure is often located in clusters or involves development of inter-modal junctions to generate the greatest benefits to passengers. However, this can also concentrate impacts and create challenges in terms of scaling of contingency plans and responses to extreme events. Much greater consideration of the inherent capacity within and between networks, to allow for switching between modes to take place, could improve overall resilience to severe weather. DTTAS needs to ensure that present and future policies recognise these interdependencies and consider those risks that may be exacerbated by climate change.

The opportunities for adaptation of the various networks will need a well-researched mix of technological development and improved long-term spatial planning, where the integrated nature of the different transport networks is given greater recognition and importance in the planning and decision making process with the consequential cost implications incorporated from the beginning.

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5. Methodology I: Determining the Vulnerability of the Transport Sector to Impacts of Climate Change

Climate change impacts will vary between transport modes and their associated infrastructure, and will also vary widely between regions. While it may be difficult to determine the extent to which climate change will impact on the transport system in the coming years, the sector is actively developing its understanding of the implications of our changing climate through the collation of baseline data in relation to the impacts of severe weather events on transport infrastructure and services, particularly since 2009.

Following the methodology advocated by the EPA and described in Section 1.2, DTTAS identified the scope of works represented by this Plan and the critical transport stakeholders to which these works pertain (Step 1). A climate impact and vulnerability screening exercise was then conducted through literature review and stakeholder consultation (Step 2).

Within the transport sector, five subsectors - road, bus, rail (heavy rail and light rail), aviation and ports - were selected for assessment. Potential vulnerabilities for these five subsectors were identified on the basis of: infrastructure; modes; staff; and passengers.

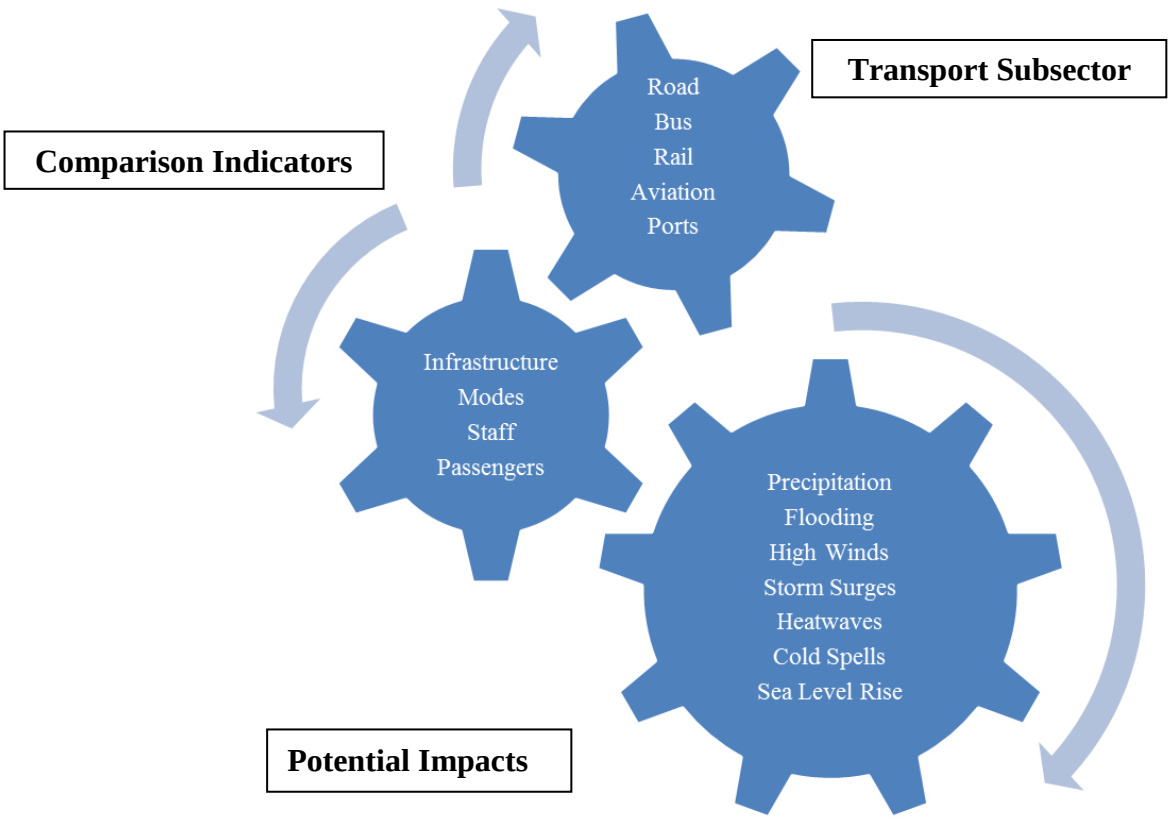

Figure 5.1. Process of Determining Vulnerability

The potential climate change vulnerabilities to these five subsectors were identified as precipitation; flooding; high winds; storm surges; heatwaves; cold spells; and sea level rise. This dynamic is reflected in Figure 5.1 overleaf.

In the development of this paper, these vulnerabilities were categorised by:

a) changes (both observed changes and projected changes) in climate variables e.g. increasing temperatures; and
b) extreme weather event type e.g. cold snap.

The initial focus of this analysis was on impacts which have occurred due to observed changes in Ireland's climate and recent extreme weather-related events that had affected the transport sector.

Table 5.1 provides an overview of high and medium priority impacts. While low priority impacts are not included, it should not be assumed that these have been excluded from further consideration.

A more detailed table of impacts is contained in Annex I of this document.

Table 5.1: An overview of high and medium priority impacts		
Area	**High Priority Impacts**	**Medium Priority Impacts**
Road	• Increase in fluvial flood risk • Ice damage • Increased risk of road infrastructure risk from coastal flooding and erosion	• Degradation/ Disintegration of road surfaces
Bus	• Disruption of services due to flooding • Extreme levels of snow can impact garages and stations • Dangerous road conditions resulting in increased journey times	• Passenger and staff comfort
Rail	• Failure of overhead electrification systems during freezing events • Braking performance on trains affected • Damage to stations and infrastructure from storm events • Increased risk of scour damage at bridges from fluvial flood events. • Increasing risk for rail infrastructure from coastal erosion and flood risk	• Degradation of track • Passenger and staff comfort
Aviation	• Challenges for storm-water management • Increased requirement for de-icing facilities • Coastal flood risk (Shannon Airport)	• Damages to airport buildings and aircraft due to storm conditions • Disruption of services due to extreme weather events
Ports	• Sea level rise and increased occurrence of coastal storms will put port infrastructure at risk • Damages to port infrastructure from freezing weather events • Service disruption • Changing patterns of siltation	• Passenger and staff comfort

6. Methodology II: Examining the Impact of Severe Weather Events and Climate Change on the Transport Sector

Following the identification and prioritisation of the wide range of known climate and weather-related vulnerabilities for the transport sector in Ireland, this section will examine in greater detail the potential impacts of climate change considered of particular significance to the transport sector, in line with Step 3 of the approach to adaptation planning guided by the EPA. These were considered significant on the basis of on-going and potential future level of loss/consequence for the sector in terms of economic consideration and/or service delivery. Priority impacts were identified through an extensive process of climate literature review and consultation with key transport stakeholders.

Projected changes in levels of impact were also considered, drawing from climate projection information and international evidence, e.g. impact analysis such as the UK Climate Change Risk Assessment, with particular reference to the Transport Sector and Northern Ireland. Potential future climate changes, such as heat as an emerging impact, were included as part of these considerations.

As demonstrated through recent extreme precipitation events, flooding (fluvial and pluvial) due to periods of extreme rainfall has significant and detrimental impacts on the transport sector.

The priority climate changes with impacts for Transport identified are:

1. projected increase in the frequency of extreme precipitation events and the associated risk of high river flows;
2. ongoing and projected changes in sea level and projected changes in the occurrence and intensity of storm surge; and
3. projected increase in average temperature and projected increases in frequency and duration of heatwaves (temperature extremes).

6.1 Extreme Precipitation Events and Associated Risk of High River Flows, Fluvial Flooding and Erosion

The frequency of extreme precipitation events across Ireland is expected to increase in the coming years as a result of climate change. As demonstrated through recent extreme precipitation events, flooding (fluvial and pluvial) due to periods of extreme rainfall can have significant and detrimental impacts on the transport sector, including damage to infrastructure, disruption to services and significant financial costs. Higher flood frequencies and intensities can lead to increased localised riverbank erosion, undermining the structural integrity of road and rail bridges. The projected changes in

precipitation indicate that these flooding risks, particularly for pluvial (rain-generated) local flooding, will most likely increase in the future.

6.1.1 Projected Changes to Extreme Precipitation and Risk of High River Flows - Pluvial and Fluvial Flooding

As global temperatures increase, the hydrological cycle is expected to become more intense and will result in more extreme precipitation events and flooding.

For Ireland, projections indicate a marked increase in heavy precipitation events, which will have implications for flooding (fluvial and pluvial), stream-flow and load.

As global temperatures increase, the hydrological cycle is expected to become more intense and will result in more extreme precipitation events and flooding.

The relevant projections for Ireland for 2041–2060 (Nolan, 2015 and Nolan; O'Sullivan; and McGrath, 2017) are outlined below:

- The frequency of heavy rainfall events is expected to increase (approximately 20%) during the autumn and winter months.
- Increase in stream-flow and loads are expected during winter and autumn.
- The number of extended dry periods is also projected to increase substantially by mid-century. Projected increases in dry periods are largest for summer ('likely' values ranging from 12 to 40%).

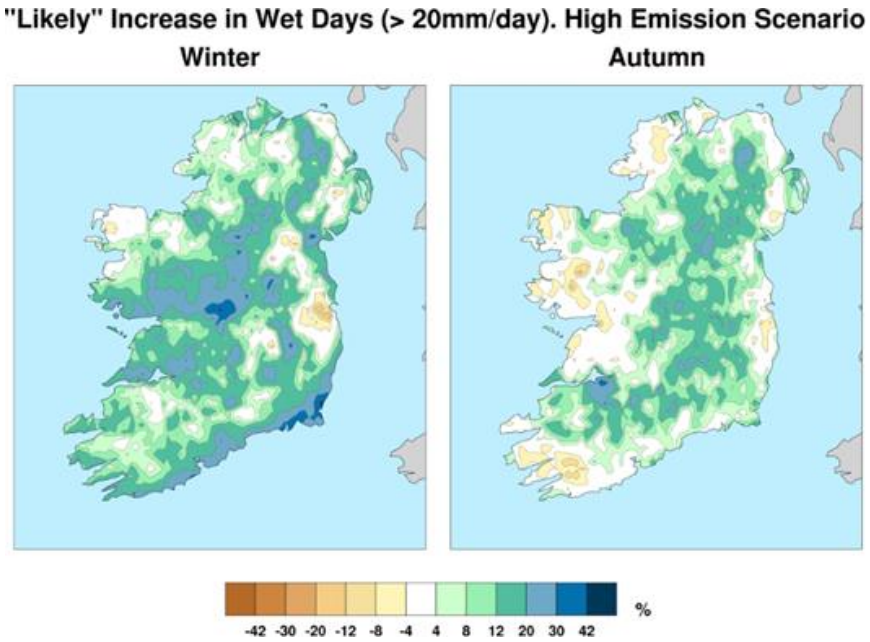

Figure 6.1: The "likely" increase for 2041 – 2060 in number of winter and autumn wet days (rainfall > 20 mm) for the high emission ensemble scenario (RCP 8.5), in relation to number of winter and autumn wet days 1981 – 2000.

Experience has demonstrated the wide-ranging consequences of extreme precipitation and associated flooding (pluvial and fluvial) events on the transport sector. Increased precipitation in winter and autumn and more occurrences of extreme precipitation will put the transport sector at higher risk from flooding (both pluvial and fluvial).

Fluvial flooding occurs when excessive rainfall over an extended period of time causes a river to exceed its capacity. The damage from a river flood can be widespread as the overflow affects smaller rivers downstream, often causing dams and dykes to break and flood nearby areas. Fluvial flooding is also associated with flash floods - characterized by an intense, high velocity torrent of water that occurs in an existing river channel with little to no notice. Flash floods are destructive both due to the force of the water and the debris that is often swept up in the flow. Heavy precipitation following long periods of dryness can exacerbate the problem, causing flash floods to occur.

Rivers are a dominant and enduring feature of Irish topography. Numerous major towns and cities, such as Dublin, Cork, Limerick, Galway, Waterford, Kilkenny and Athlone, are situated on river plains. With many of Ireland's major transport links running in close proximity to rivers, fluvial flooding poses a significant threat to key transport infrastructure and can result in service disruptions and substantial financial costs.

Case Study 1 – Unprecedented Rainfall in October and November 2009

Overview

Unprecedented rainfall in late October and early November 2009 resulted in severe and prolonged flooding in many river catchments in Ireland. The event was truly exceptional with total recorded rainfall for November being the highest on record for most stations. Many rivers across the country reached record high levels, including the River Shannon which significantly exceeded the highest levels previously recorded over a period of 100 years.

Meteorological Conditions

The period 18th–31st October saw a series of Atlantic depressions and their associated fronts move across Ireland. The heaviest rainfalls were measured on the 19th, 20th, 24th and 30th October. There were also widespread heavy showers on the 21st and 22nd. In November 2009, a series of fast-moving Atlantic depressions brought a series of active frontal systems across Ireland, bringing very wet and windy conditions. In this month, more than twice the average rainfall amounts were measured at almost all stations and over three times the normal amounts at some stations. Rain and showers were recorded on almost every day while the frequency of heavy precipitation days was also well above normal.

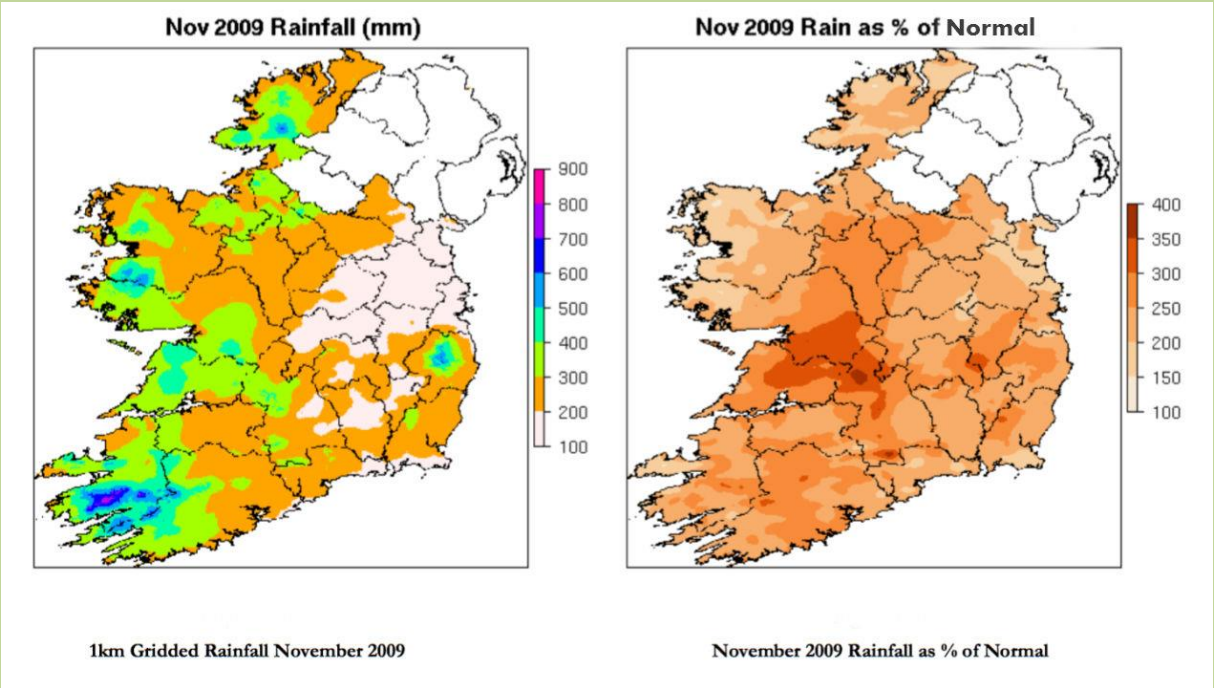

Figure 6.2: (left) 1km gridded rainfall for November 2009, (right) November 2009 rainfall as % of normal (1961–1990)

Key Impacts for the Transport Sector:

- The unprecedented rainfall led to the closure of a number of roads to traffic for a significant period and the disruption of numerous public transport services. The most severely disrupted national roads were the N6, N17, N18, N63, N65, N67 and N7. Regional and local roads in the affected areas were either impassable, or only passable with difficulty.
- The flooding at this time, followed by a spell of severely cold weather, is estimated to have cost in excess of €225 million for repairs to national, regional and local roads.
- Bus and rail services were widely affected during November. Closures due to flooding were recorded on the following heavy rail lines: Dublin to Sligo (flooding at Longford, Carrick-on-Shannon and Sligo); Dublin to Cork (flooding at Hazelhatch and Ballybrophy); Dublin to Galway and Dublin to Mayo (flooding at Athlone); and on the DART line between Dún Laoghaire and Bray (flooding at Sandycove).
- Flooding also closed the line between Waterford and Tipperary at Carrick-on-Suir and caused delays to services between Banteer and Millstreet on the Mallow to Tralee line.

Figure 6.3: Flooding causing significant disruption to roads

Figure 6.4: Train derailed at Wicklow, November 2009

Figure 6.5: Floods in Roscommon

Case Study 2 – Widespread Flooding Following Storm Desmond and Storm Frank, December 2015 to January 2016

Overview

In December 2015 the country was hit by two major storms, Storm Desmond and Storm Frank which resulted in widespread flooding. Following Storm Frank, the main areas affected were along the south coast and in the catchments of the Blackwater, Suir, Slaney and Shannon rivers. Storm Desmond mainly affected the western coastal counties, in particular, the Moy, Clare and Shannon catchments. While Storm Desmond was considered a 1-in-100 year event, a near-real time attribution analysis found that such extreme rainfall was up to 40% more likely due to the effects of human induced climate change experienced to date, making similar events now a 1-in-72 year event (van Oldenborgh et al. 2015). The widespread flooding in some parts of the country was exacerbated by already saturated ground following the normal rainfall in November.

Meteorological Conditions

Jet streams play a key role in determining weather and the period December 2015 was exemplified by a pattern of continuous troughs and ridges across the North Atlantic and Ireland. This resulted in a predominant south-west to south-westerly airflow over Ireland and a spell of very mild and wet weather during which record temperatures and rainfall occurred.

Key Impacts for the Transport Sector:

- As a result of the damage caused to transport infrastructure, €106 million was allocated for repairs €8 million for rail network, €90 million for regional and local roads and €8 million for national roads.
- Throughout the country, Iarnród Éireann experienced serious incidents. Speed restrictions were imposed and in some places rail lines were closed due to flooding. For instance, the Cobh/Midleton line, the Mallow line and at Gorey and Wexford. There were instances of fallen trees and debris blocking railway tracks and high winds caused problems with automatic level crossings barriers.
- A significant number of national, regional and local roads were closed. National roads included the N25 Cork/ Waterford Rd (between Killeagh and Castlemartyr), N65 (between Portumna and Borrisokane) and the N4 (at Shannonside Retail Park). Cavan County Council reported in the region of 50 roads as impassable, many submerged under 1m of water. In East Cork, the County and City Managers Association reported that 20 roads were closed, many due to the disintegration of the roads. It was also noted that Bus Éireann had a diversion in Wicklow from the R752 regional road due to road subsidence.
- Notably, there were few impacts on the Strategic Motorway Network, potentially reflecting the considerable efforts since the commencement of the Motorway Maintenance and Renewals Contracts to undertake preventative maintenance on sections of the network previously negatively affected through flooding.
- Drogheda Port closed to commercial traffic due to sediment accretion within the

approach channel: it took 5 weeks and extensive dredging to restore the Port to full operational capacity.

Figure 6.6: Road disintegration in County Cavan, January 2016

Figure 6.7: Floods in Mallow County Cork, December 2015

Figure 6.8: Road damage in Waterford, 2016

Figure 6.9: Coole area Galway, after Storm Desmond in 2015

6.1.2 Bridge Scour and Landslide Risk

River bridges represent critical components of the transport infrastructure and carry services as well as people and traffic. As a result, the loss of a bridge can have multiple and wide-ranging impacts.

River bridges represent critical components of the transport infrastructure and carry services as well as people and traffic. As a result, the loss of a bridge can have multiple and wide-ranging impacts.

Bridge scour relates to the process by which material from around bridge piers and abutments is removed by swiftly moving water, typically in a flood situation. Bridge scour can result in structural failure as removal of material can undercut the foundations, resulting in instability and eventual collapse of the bridge. The problem is exacerbated for many older masonry bridges (pre-20th century) because they typically have shallow foundations. Across the UK, bridge scour causes on average one bridge failure per year.

Iarnród Éireann currently manages 475 bridges that span water courses, many with fast-moving water that have the potential to remove structural material. The bridges vary widely in size, type and date with many bridge assets being up to 150 years old.

In addition, it has been estimated that the foundation material for railway bridges over water is known for less than 10% of existing bridges.

A considerable proportion of the estimated 25,000 bridges carrying Irish roads are over watercourses. In addition to basic maintenance requirements, road bridges which span watercourses are liable to the same problems with scour damage as rail bridges. The risk of scour damage is increased when bridge piers or abutments are subject to fast moving or tidal water.

Landslides can occur when ground on a slope saturated with rain cannot support the extra weight. The soil and rock eventually gives way to come tumbling down the slope. Landslides can damage roads, railways, canal embankments, and cause dams to fail. Rivers can be blocked or diverted by sediment or rock displaced by landslides. Relatively small landslides in terms of the volume of material displaced can damage bridges and roads, and also cause injury and death. Landslides are relatively rare in Ireland; however, in recent years occurrences have been notably preceded by periods of heavy rainfall which may have triggered ground failure. The vast bulk of earthworks, bridges and tunnels date from their original construction and are considerably more than 100 years old. The effect of climate change and the changing weather patterns means that wetter winters and extreme rainfall events will become more frequent. Inevitably, the rate of required renewal and major refurbishment of assets will have to increase in order to improve resilience to extreme weather events and ensure the reliability and safety of the assets.

Case Study 3 – Bridge Scour Incident during Flood Event Following Extreme Rainfall, October 2011

Overview

On 24th October 2011 following a period of extreme rainfall and during a serious flooding event in the Ballsbridge area of Dublin, the railway bridge UBR63 which spans the River Dodder at Lansdowne Road DART station suffered a significant scour incident in which the pier and abutment at the southern end were undermined to such an extent that the structure was near to collapse. A cavity 2.5m deep, between 4m and 5m horizontal dimension, perpendicular to the line of the abutment was created. This cavity extended a total length of 30m from upstream of the abutment to a location approximately 10m downstream. The cavity developed over a short time due to the high velocity of the flow passing through the bridge, and because of constriction caused both by the bridge and by a significant amount of flood debris trapped at the bridge, which directed the flow down towards the channel bed from where it scoured material. Urban landscape particularly assists rapid run-off rainwater which means that the rivers in urban areas are particularly susceptible to flash flooding during periods of intense rainfall.

Figure 6.10: Photo of debris trapped at UBR63 on 25/10/2011 as flood water recedes. The quay wall on the right hand side of the picture was completely overtopped at the peak of the event which caused major flooding of housing and cars in the Ballsbridge area

Meteorological Conditions

On 24th October, Ireland was at the centre of a slow-moving frontal depression which stretched from western France to south of Iceland, causing excessive rainfall over eastern

and northern parts of Ireland, the greater Dublin Area and Wicklow. This heavy rainfall combined with high rainfall totals the previous day, lead to a saturation of soils and flooding occurred in some eastern areas.

The heaviest rainfall occurred during the afternoon and early evening, with Dublin Airport reporting a maximum 9-hour rainfall of 66.8 mm, the daily totals at the Dublin stations would represent approximately 1 in 20 to 1 in 25 year events.

Key Impacts for the Transport Sector

- Iarnród Éireann monitored the flood event and imposed a speed restriction on the railway line until it was safe for divers to enter the water and inspect the structure. At that stage the seriousness of the scour incident was identified and the line closed.
- Dublin City Council activated an emergency plan to deal with the floods.
- Damage to transport infrastructure in the Greater Dublin Area estimated to be worth millions of Euro.

Case Study 4 – Landslide Following Intense Rainfall, December 2015 to January 2016

Overview

On the 29th of December 2015, during Storm Frank, which was the strongest storm of the 2015–16 windstorm season, a localised landslide developed on the Irish Rail network halfway between Farranfore and Killarney. The steep inclination of both slopes leading down to the track exacerbated the issue and the debris covered the track resulting in track closure.

Figure: 6.11: Landslide 29th December 2015, County Kerry

Meteorological Conditions

Met Éireann's nearest weather station is located on Valentia Island approximately 55km from the failure site. During December 2015, 339mm of rainfall fell in Valentia which equates to 206% of the long-term average for December in the area and is the highest December rainfall since 1934 at the site. Approximately 10% of that total (31.5mm) fell on the 29th of December, the day of the first failure event.

January 2016 was the wettest January on record in Valentia Observatory since 1974 with 293.8mm of rainfall. This equates to 169% of the long-term average for January at the observatory. Between the 5th and 7th of February, 13.8mm, 16.6mm and 13.5mm of rainfall respectively fell per day. It was during this period that the second failure event occurred.

Key Impacts for the Transport Sector

- Rail services were suspended for two days following the first failure event, with bus transfers put in place between Tralee and Killarney stations.
- During a planned closure of the line on the 6th and 7th February 2016 a further landslip occurred. This landslip event was attributed to the rainfall that had occurred in the preceding days and months.

6.1.3 Summary of Projected Consequences of Extreme Precipitation in the Transport Sector.

- **Vehicles:** Cars, trucks, buses and trains can all be damaged by driving through floods while extreme precipitation events can also result in dangerous driving conditions, particularly in areas where the capacity of existing drainage networks is overwhelmed.
- **Services:** High level of disruption to services which will impact on the safety and comfort of passengers with an associated cost to the economy.
- **Increase in fluvial and pluvial flooding:** Significant increase in the frequency and duration of road and railway flooding events. This is particularly the case for those areas located at the confluence of major rivers or those areas located around estuaries where projected rises in sea level in combination with increased river outflow may cause extensive flooding. The frequency of flooding for infrastructure located in floodplains (and in areas already considered at risk) is projected to increase.
- **Airports:** With the exception of Shannon Airport, Ireland's airports are not located on river channels and as a result are not expected to be impacted directly by increased fluvial flood risk. However, increases in the occurrence and magnitude of extreme precipitation events and associated pluvial flooding will put existing storm-water drainage systems under stress with implications for airport operations.
- **Increase in bridge scour events:** The vast bulk of earthworks, bridges and tunnels date from their original construction and are considerably more than 100 years old. The effect of climate change and the changing weather patterns means that wetter winters and extreme rainfall events will become more frequent. Inevitably, the rate of required renewal and major refurbishment of assets will have to increase in order to improve resilience to extreme weather events and ensure the reliability and safety of the assets. Projected increases in river/stream-flow will augment the potential for the fast-moving water to remove material from the bridge piers and abutments. Brick and masonry arches which are considered to be particularly vulnerable to scour (because of shallow foundations) are at an increased risk. Also, climate changes may mean that bridges which are currently classed as being adequately protected against scour risk may not be under future climate conditions.
- **Heightened landslide risk:** This higher risk applies not only to railways and roads situated in cuttings or cut into hillsides but also to railways and roads situated on top of embankments. Extreme precipitation, leading to an accumulation of water and saturation of a slope, adversely affects the stability of the slope and increases the potential of a landslide. Many of Iarnród Éireann's cuttings and embankments were constructed 100–150 years ago and have steeper slopes (and therefore greater likelihood of landslips) than would be permitted with modern design standards. Iarnród Éireann's ongoing earthwork improvement programme, which operates on a prioritised basis, is

unlikely to achieve modern design standards in the foreseeable future. Those areas already considered at risk of landslide will probably be at increased risk.

6.2 Sea Level Rise and Storm Surge

According to the Central Statistics Office, in 2016 over 2 million people lived within 5km of the sea. Due to the location of key transport infrastructure on the coast, sea level rise and storm surges pose a significant risk for the transport sector. Coastal erosion and flooding already constitute a serious risk for coastal transport infrastructure and result in damage to infrastructure, service disruption and significant financial costs. Climate projections indicate that this risk is likely to increase in the future and in particular when considered in the context of the projected rise in sea level and increasing intensities of extreme weather events.

The relevant projection information for Ireland (Nolan, 2015) is:

- Global mean sea levels are projected to rise by up to 0.98m by the end of the century (IPCC, 2013). For Ireland, the greatest increases are expected in the south and west.
- The number of very intense storms e.g. winter 2012/2013, is expected to increase.
- Projections indicate that the winter tracks of these very intense storms may extend further south than the current situation, which means more of these storms will reach Ireland.

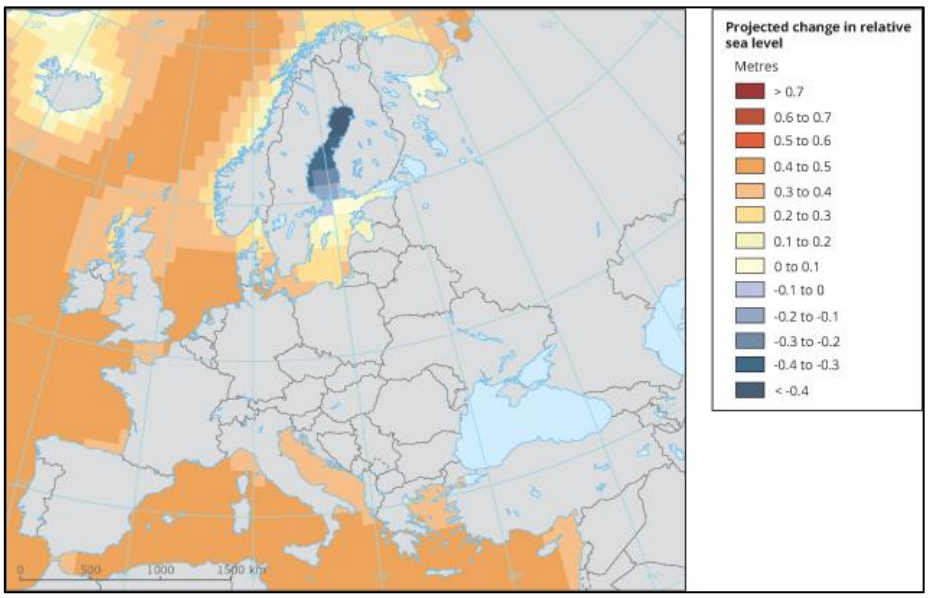

Figure 6.12: Projected change in relative sea level in 2081–2100 compared to 1986–2005 for the IPCC Fifth Assessment Report medium-low emission scenario (RCP 4.5) (EEA 2014)

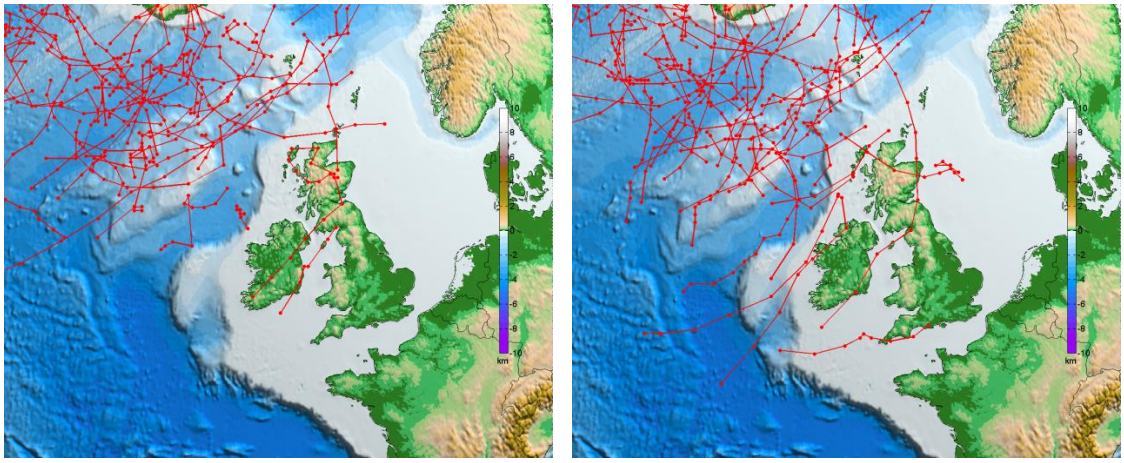

Figure 6.13: Tracks of storms with a core MSLP (mean sea level pressure) of less than 940 hPa (hectopascals) and with a lifetime of at least 12 hours. (left) Past RCM (regional climate model) simulations for1981–2000; (right) climate prediction simulations for 2041-2060, based on IPCC Fifth Assessment Report RCP 8.5 scenario. (Nolan, 2015)

Due to the location of key transport infrastructure on the coast, sea level rise and storm surges pose a significant risk for the transport sector.

In Ireland, observed sea level trends are broadly consistent with the global average. A rise of at least 50cm to 2100 is projected for Ireland, consistent with projections from regional and global models (Olbert et al., 2012). However, levels of sea level rise will vary and are based on local conditions e.g. vertical land movements after the last ice age will augment this trend in the south of Ireland and reduce it in the north. As a result, areas of the south will be the first to feel the effects of sea level rise which will magnify the effects of storm surge. At particular risk are low-lying areas e.g. areas on the eastern coast, and those already situated on eroding shorelines (south and east coast in particular). In conjunction with these are areas located on estuaries where higher sea level and changes in the incidence of high river flow events interact and can result in a volumetric combination of storm surge and peak river flows that can drastically increase flood hazard.

6.2.1 Coastal Erosion

Ireland has a coastline of approximately 6000km, half of which is categorised as soft coastline (non-rocky), and it is estimated that up to 500km is actively eroding and considered to be at risk. Currently, the coasts most susceptible to erosion are those composed of unconsolidated (soft) sediment and are most common on Ireland's eastern and southern coastline and in estuaries. A number of primary transport routes are located in these areas and are potentially susceptible to both gradual changes in rates of coastal erosion and the impacts of increasing coastal storms.

Case Study 5 – Ongoing and Gradual Erosion of the Eastern Rail Corridor

Overview

The Dublin to Rosslare railway represents the main rail route between Dublin Connolly Station and Rosslare EuroPort where it connects with ferry services to the UK and mainland Europe. Services provided on the line include DART and Intercity services. A significant length of the line lies close to the shoreline which is subject to erosion, with incidents of annualised erosion rates of up to 3m per year recorded. However, at most places, erosion rates were less than 0.5m per year, reflecting the variability of erosion rates and the significance of localised conditions.

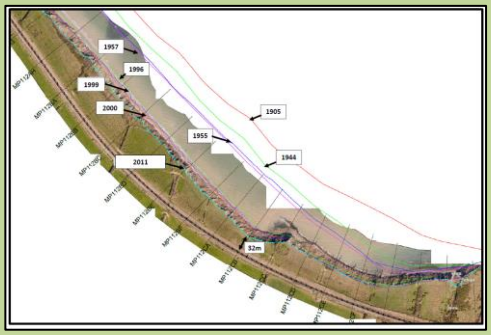

Figure 6.14: Cliff erosion rate on railway line near Rosslare Harbour

Meteorological Conditions

The Wexford coast is composed of bands of soft sedimentary rock, (carboniferous limestone and old red sandstone) overlain with sandy soil which are vulnerable to coastal erosion over time by wind, rain and sea level rise (Sistermans, Nieuwenhuis et. al, 2014). For the 30 year period 1961-1990, mean monthly wind speeds (January – December) at Rosslare were 11.5 knots; average daily temperatures between 7.6 and 12.6 degrees; and mean monthly total precipitation was 877.2 mm (Met Éireann).

Key Impacts for the Transport Sector

- A sea cliff supporting the railway at Ballygerry near Rosslare Harbour is being eroded by storm events. The area that threatens the railway is on the approach to Rosslare EuroPort. The coastline along this stretch is unprotected, allowing continuous erosion of the 11m high soft cliffs.
- Between 1905 and 1999, the coastline receded approximately 135m at an average of 1.4m per year, with acceleration in the rate of average erosion of approximately 2m per year from 1999 - 2015.
- Critically, from the survey data gathered to date and erosion modelling by the OPW, it is estimated that the coastline will continue to recede, and could potentially undermine the existing rail corridor before the year 2030.

Case Study 6 –Erosion Resulting from Extreme Weather, Storm Frank (December 2015)

Overview

Immediately north of Wicklow town and in close proximity to the Murrough nature reserve, the Dublin to Rosslare railway line runs along the coastline. On the 29th and 30th December 2015, a clay cliff supporting the railway line collapsed into the sea, leaving the railway line within 2m of the sea. The collapse took place immediately north of an area where Wicklow County Council had already placed 'rock armour' as part of a coastal erosion prevention scheme in 2009.

Meteorological Conditions

On the 29th and 30th of December 2015, Storm Frank, the third of three named winter storms (Desmond, Eva and Frank) set new records for high seas with a 6.2m wave height observed at the M2 marine weather buoy, which is situated off the east coast.

A Status Yellow wind warning was issued for the same period, with mean wind speeds measuring between 50 and 65 km/h, rising to 95 to 110 km/h at times. Heavy rain and high winds caused large waves to blow ashore from the Irish Sea, collapsing the soft clay banks along the Wicklow coast.

Key Impacts for the Transport Sector

- The Dublin-Rosslare rail line was briefly forced to close to allow emergency response works on New Year's Day to be carried out.
- Iarnród Éireann added to and extended the area's rock armour defences by placing nearly 2,500 tonnes of boulders in a 185m-long barrier to protect the worst affected areas at a cost of €150,000.

Figure 6.15: Rate of erosion from Nov 2014 to Dec 2015, Murragh, Wicklow.

6.2.2 Coastal Flooding (Storm Surge)

Coastal flooding poses a significant risk to associated transport infrastructure. Key transport networks are increasingly vulnerable due to amplified warming of the Atlantic, sea level rise and a predicted increase in frequency of extreme weather events such as major storms and surges.

Key transport networks are increasingly vulnerable due to amplified warming of the Atlantic, sea level rise and a predicted increase in frequency of extreme weather events such as major storms and surges.

Case Study 7 – A Series of Unprecedented Storms, December 2013 to February 2014

Overview

During the period from 13th December 2013 to 6th January 2014 there were storms in or around Ireland roughly every three days. These storms coincided with high tides and created severe conditions in a number of coastal areas, causing disruption across a range of transport services. A study by the National University of Ireland, Maynooth, found that the winter of 2013/14 was the stormiest for at least 143 years, when storm frequency and intensity are considered together. Significant damage was caused to roads particularly along the western seaboard counties and the safety of road users was a major concern due to the stormy conditions and damage caused. In certain areas of the country, prolonged flooding led to significant disintegration of road surfaces.

Meteorological Conditions

The winter of 2013/2014 was severely affected by a series of exceptional winter storms. These were a result of the extension of the polar jet stream across the North Atlantic and directly over Ireland. Storm force winds occurred on 12 different days and precipitation amounts were between one and two times above normal and fell on saturated or waterlogged ground throughout the country.

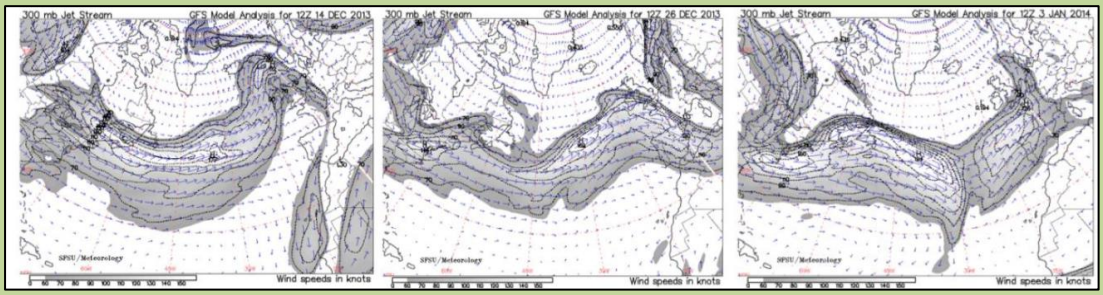

Figure 6.16: Position of the Polar Jet Stream over the North Atlantic on December 14th, 26th 2013 and 3rd January 2014

Key Impacts for the Transport Sector:

- Ferries (particularly the swift services) were cancelled on numerous occasions across the period to the New Year. Likewise, some cruise ferries were also

affected. A number of lighthouses were also damaged and the frequency and strength of the storms also had implications for the services of the Coast Guard.

- Storms, during the period in question, caused significant damage to Shannon Airport flood defence embankments (31st January/early morning of 1st February) along the Shannon Estuary resulting in severe flooding on airport property. Further storms, and Storm Darwin in particular (12th February 2014), also caused structural damage to buildings in the area and a regional aircraft (ATR42) was tipped on its side resulting in an undercarriage failure. The cause was a combination of a very high tide, a significant tidal surge, heavy rain and the prevailing wind direction on the dates in question.
- This short-lived storm in December 2013 is estimated to have cost the State in the region of €70 million. In terms of direct damage to the transport sector, the cost of repair to the road network was estimated at €16.6 million with a further €6.95 million needed to repair other transport infrastructure including rail, airports and Irish Coast Guard facilities.
- The severe weather during the later period of January to February 2014 caused further damage to roads and to other transport infrastructure with an associated repair cost of €13.5 million. It is clear that storm events can have significant implications for the Exchequer. Notwithstanding the stress and reduced safety caused to transport users, the fallout from the event can resonate over a much longer period particularly where severe damage has been caused to the transport infrastructure.

Figure 6.17: Storm causing flooding in Carrigaholt, County Clare, February 2014

Figure 6.18: Damage to the roadway at Silver Strand, County Galway, February 2014

6.2.3 Summary of Projected Consequences of Sea Level Rise and Storm Surge for the Transport Sector

Projected increases in inundation extents and duration and levels of coastal erosion will have wide-ranging impacts for transport:

- Transport infrastructure currently considered at risk of coastal inundation and erosion will be at increased risk while areas currently not considered at risk may also be threatened. This is particularly the case for transport infrastructure located in low-lying coastal areas, on eroding coastlines and on estuaries.
- Port infrastructure will be at particular risk under projected changes in sea level and storm surge. The key impacts identified include: damages to port infrastructure, navigations and safety equipment; damages to vessels while in port and impacts on safety of passengers while embarking, in transit, and disembarking. Storm activity can also cause issues in relation to the channels leading into ports becoming blocked with large amounts of sand silt and other materials driven by storm activity. In addition, changes in sea level will have impacts on dredging requirements at ports, positive or negative depending on local circumstances, and implications for natural scouring capability at estuarial ports.
- In general, aviation infrastructure is situated away from the coast. However, Shannon Airport is located on the estuary and will be at increased risk from estuarine flooding.
- Increased floodwaters will make travelling conditions more dangerous and mean transport modes (bus, rail) will be at greater risk.
- Damages to infrastructure will result in higher levels of disruption to services (delays/cancellations/diversions) and a requirement for emergency planning to facilitate the transport of passengers from affected areas.

6.3 Extreme Temperatures

Extreme temperatures (heat and cold) can have a wide range of impacts for the transport sector and result in significant costs. Extreme cold temperatures have previously resulted in significant impacts for all transport modes in Ireland. In contrast and to date, episodes of extreme heat e.g. the summer of 1995, which was the warmest summer on record for Ireland, have not resulted in adverse impacts on transport infrastructure and modes, demonstrating the resilience of transport to current temperature conditions.

Although transport has demonstrated resilience to extreme heat episodes, the projected rise in temperature for Ireland has the potential to increase risk of adverse heat related impacts for transport. In contrast, projected occurrences of extreme cold days are expected to decrease. Nonetheless, due to the significant and adverse impacts of previous extreme cold weather events and the level of disruption and financial

costs associated with these events, transport must ensure adequate provision for periods of extreme cold temperatures. Two of the six coldest spells in the recent weather history of Ireland occurred in the same calendar year and that they were preceded by an exceptional flooding event in November 2009; demonstrating the unpredictability of weather patterns which affect the country. It is essential to ensure that preparedness actions remain in place.

The relevant climate projection data for Ireland are:

- Average temperatures are expected to increase across all seasons and by up to 1.7°C by mid-century (Nolan, 2015).
- The warmest days are expected to be warmer by 0.7–2.6°C by mid-century (Nolan, 2015).
- With increasing air temperatures an increase in the intensity and duration of heatwaves is expected (Nolan, 2015). For the most severe climate change projections, Matthews et al. (2016) suggest that summer conditions as warm as 1995, the warmest summer on record for Ireland, will occur once in seven years by the end of the century.
- The number of frost days is expected to decrease by 50-62%, while the number of ice days is expected to decrease by 73-82% (Nolan, 2015).

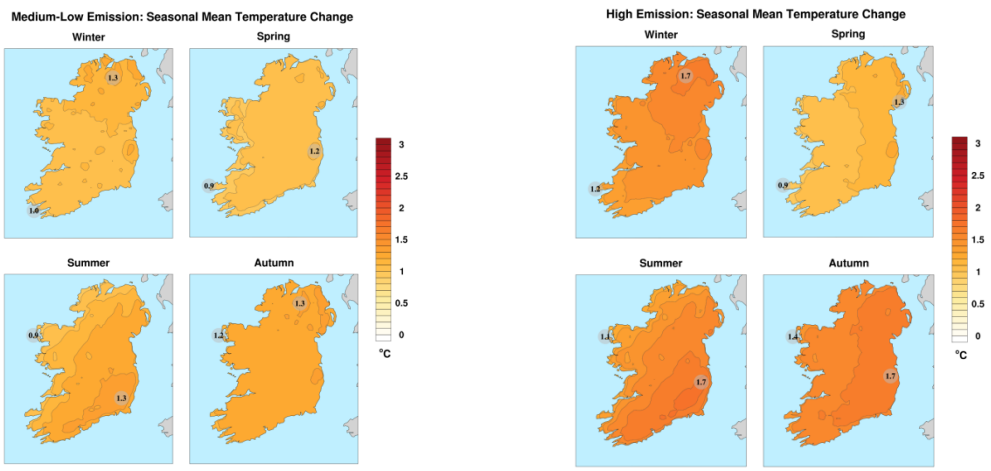

Figure 6.19: Projected change in seasonal mean temperature for 2041-2060 in relation to the period 1981-2000; (left) - IPCC Fifth Assessment Report's medium to low emission scenario (RCP4.5); (right) IPCC Fifth Assessment Report high emission scenario (RCP 8.5).

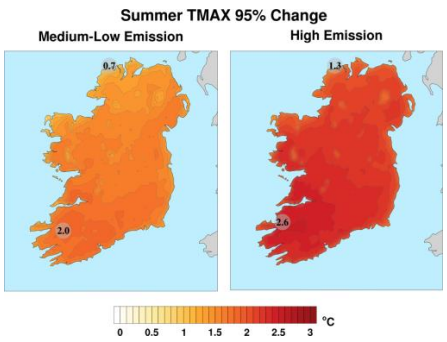

Figure 6.20: Projected change in the top 5% of maximum daytime summer temperatures 2041-2060 in relation to the period 1981 – 2000, for the medium to low emission (RCP4.5) and high emission (RCP8.5) scenarios.

Figures refer to the minimum and maximum increases displayed at their locations.

Case Study 8 – Extreme Cold Experience, Winter 2010

Overview

The cold spell that began on the 27th November 2010 was one of the most severe and prolonged cold spells recorded in recent Irish weather history and continued for 30 days. Extreme cold temperatures were accompanied by heavy snowfalls across many parts of the country, and extremely low temperatures were recorded – as low as minus 10 ºC and well below normal winter ranges. Temperatures remained below freezing for prolonged periods, with a maximum daytime temperature of minus 9.1 ºC recorded at one weather station. In terms of the impact on our transport system, most people continued to be able to travel, although with greater care than normal and at reduced speeds on the roads. National primary roads were generally kept open for traffic and public transport routes were largely able to operate throughout the period. Heavy snowfalls in the week before Christmas 2010, in association with closures throughout Europe, caused severe hardship for air travellers during the critical pre-Christmas travel period.

Meteorological Conditions

A cold north-easterly arctic airstream caused low temperatures, severe frost, freezing fog and snow across the country. Exceptionally low air and ground temperatures were measured in Leinster on the 28th and 29th November.

In December, cold northerly winds brought snow showers in many areas, most frequently along Atlantic and Irish Sea coasts, causing considerable disruption of road and air travel. Both Dublin Airport and Valentia Observatory had their driest winters since 2005/06. The precipitation during most of December was in the form of snow, with over 20cm of snow at some eastern stations. Freezing conditions persisted for long periods, with the temperature remaining below 0°C for 9 consecutive days in some inland areas. December was the coldest month ever recorded in over 50 years at Dublin Airport, Casement Aerodrome and Mullingar stations. The lowest December air temperature ever measured in Ireland, -17.5°C, was recorded at Straide, Co. Mayo on 25th December.

Key Impacts for the Transport Sector

- Transport links were severely affected by the adverse weather conditions, with icy conditions and compacted snow on roads causing congestion, slow speeds and traffic accidents. Despite gritting major routes, a number of national roads, including motorways, became impassable.
- Dublin Airport was closed on 6 occasions over the 30 days of severe weather, Cork and Shannon Airports also suffered some disruptions.
- Overall, 90% of Dublin Bus route network was serviced during the period. Dublin Bus ceased operations after peak time on 4 evenings while, during this

period, Nitelink services did not operate on 3 nights.

- Almost 95% of Bus Éireann routes continued to operate during the severe weather.
- Dublin Swift ferry sailings between Holyhead and Dublin Port were cancelled on the 1st December.
- Commuters experienced delays on intercity trains, Dart and commuter services throughout December, although the Luas Red and Green lines operated as normal with the exception of a period of six hours on December 2nd.
- One of the issues identified after the January 2010 cold weather was the need to align local authority salting routed with public transport routes. This alignment work took place over the summer of 2010, and when the spell of cold weather emerged in November 2010, the public transport companies were included as part of both national and local co-ordination groups.
- The National Directorate for Fire and Emergency Management Report made a series of recommendations to improve the State's response to extreme cold/heavy snowfall conditions.

Figure 6.21: Heavy snowfall can disrupt travel (Image courtesy of Iarnród Éireann)

Figure 6.22: Snow disrupts bus services (Image courtesy of Bus Éireann)

6.3.2 Summary of Projected Consequences of Extreme Temperatures for the Transport Sector

- The effects of temperature extremes on the rail track range from buckling of rails in hot weather to freezing of points and broken rails in cold weather. As summer temperatures are projected to rise, so are rail temperatures and the thermally induced forces in the steel rail. Whilst buckling of rails is a rare occurrence in Ireland (less than one per year on average) the probability of it happening will be increased if extreme high temperature events occur. There will therefore be more requirements for trackside monitoring and more likelihood of blanket network-wide speed restrictions. A network-wide speed restriction is a precautionary measure to reduce the consequences should a buckle occur. There were network-wide speed restrictions in the south of England during the summer of 2016 which heavily impacted on train services .

Figure 6.23: Rail buckling incident

- High temperatures may cause road surfaces to deform. This may be a particular problem on secondary roads as these have lower surface specifications than motorways. In relation to public transport, over-heating of trains, trams and buses can greatly discommode passengers.
- In ports, extreme heat can reduce the life of felt-type roofing products and cause degradation of road surfaces. Also, port workers may not be able to work in glass boxes on cranes. Drought may impact on natural scouring leading to increased siltation.
- Increased temperatures can cause aircraft climb problems and increase the need for air-conditioning in airport buildings.
- With fewer cold snaps expected as a result of climate change, the capacity to learn from such experiences may be diminished resulting in greater disruption to services and safety practices when such events do occur.

7. Categories of Adaptation Options

Adaptation can be defined as the ability of a system to adjust to climate change (including climate variability and extremes), to minimise potential damage, to take advantage of opportunities, and to cope with the consequences. The following represents a widely accepted suite of general adaptation options available to the transport sector:

7.1 Policy/Government Options

Targeted policy development and government support can be instrumental in effecting long-term change. Examples of policy and government support that can promote effective adaptation measures include:

- strategic land use and effective integration with other sectors in planning and development;
- collaborative research and co-operation between stakeholder bodies;
- green public procurement; and
- national transport infrastructure investment addressing the scale of potential risks associated with climate change

7.2 Infrastructural Options

Infrastructural options are technological or engineering solutions to address existing or future climate impacts e.g. the construction of sea walls or tidal barrages in response to sea level rise. Actions of this nature are easy to quantify but can be very costly. The following represents an example of the types of infrastructural options available to the transport sector:

- new transport infrastructure to be positioned in areas less likely to be affected by climate change;
- transport infrastructure planners/designers to take climate change projections and impacts into account during the design and upgrade phases;
- transport infrastructure contracts to have climate change adaptation clauses;
- climate change to be incorporated into engineering management practices; and
- auditing transport infrastructure to identify vulnerabilities and implement optimum adaptation measures.

7.3 Green Options

There are also measures of an ecological nature that can be deployed to lessen the impact of climate change; e.g. efforts to reinstate dune systems to act as buffers against coastal storm damage. However, these actions can have very long lead-in times.

8. Current Measures that Assist in Adaptation Planning

In assessing the adaptive capacity of the transport sector, it is clear that existing planning systems already provide for some degree of resilience to the impacts of climate change, forming a foundation from which to develop future adaptation plans.

8.1 Central Measures

8.1.1 Planning Law

The *Planning and Development Act 2000* sets out the detail for regional planning guidelines, development plans and local area plans as well as the basic framework for the development management and consent system. Among other things, it provides the statutory basis for protecting our natural and architectural heritage and carrying out Environmental Impact Assessments (EIA).

EIA is the process by which the anticipated effects on the environment of a proposed development or project are measured. If the likely effects are unacceptable, design measures and/or other relevant mitigation measures can be taken to reduce or avoid those effects. In recent years, measures have been taken to integrate climate change, including adaptation, into the EIA. The EU Commission issued the guidelines *Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment*, which aims to help Member States improve how climate change, both mitigation and adaptation, are integrated in EIAs.

The NTA has a remit in the Greater Dublin Area to publish a transport strategy that refers to the issues of Climate Change as well as an Integrated Implementation Plan. Nationally, the NTA produces policy and technical guidance to aid local authorities which must consult the NTA when drawing up their Regional Planning Guidelines. The NTA has the role of sanctioning authority for the financing and construction of most public transport infrastructure projects. With regards to mainline railway projects, this work is undertaken by Iarnród Éireann due to the specialist nature of the works.

8.1.2 Flood Management

The Office of Public Works (OPW) have produced guidelines for relevant authorities on flood risk management entitled *The Planning System and Flood Risk Management – Guidelines for Planning Authorities* (OPW-DEHLG, 2009). In addition, the Office for Public Works commenced the *Catchment Flood Risk Assessment and Management* (CFRAM) programme in 2011, which comprises three phases: Preliminary Flood Risk Assessment (2011); CFRAM Studies (2011–2015); and Implementation and Review (2016 onwards). The programme also provided for three

main consultative stages, namely *Preliminary Flood Risk Assessment* in 2011, the *Flood Hazard Mapping Process* in 2014 and the *Flood Risk Management Plans* in 2015 for specific geographical locations. It is worth noting that, during this process, Shannon Airport was identified as an area for further assessment.

Flood Risk Management Plans for the specific catchment regions, arising from the Catchment Flood Risk Assessment, have now been developed. Indeed, flood defence recommendations have been made on the type of adaptation measures e.g. raising in height of river embankments, required specifically to protect Shannon Airport from the possibility of experiencing flood events. (www.opw.ie/FloodPlans)

8.1.3 Emergency Planning

In 2001, a range of government structures was put in place to support emergency planning in Ireland. A key objective was to improve co-ordination across the various existing national emergency plans. The Government Task Force on Emergency Planning directs and oversees the emergency planning activities of all government departments and public authorities in Ireland. The most common emergencies that arise are unexpected events which require a rapid response from the emergency services, particularly fire services and the Garda Síochána. In the context of adaptation, severe weather and flooding could be constituted as an 'emergency' depending on the scale of the event and the associated impacts.

Under the *Emergency Planning Framework*, DTTAS is the lead department for a range of transport-related emergencies such as air and maritime major incidents) and supports other lead departments for emergencies which affect travel and transport e.g. severe weather. The role of DTTAS in these situations is to oversee and co-ordinate a national level emergency response, where a national response is required.

The National Emergency Coordination Group (NECG) is activated in the event of a national emergency or a crisis. In terms of recent events, DTTAS had lead responsibility for the State's co-ordinated response to the disruptions caused by volcanic ash in April/May 2010 and again in May 2011, and had a significant support role during the severe weather events including those of winter 2009/2010, the prolonged snow event of November/December 2010, and the series of high winds, high seas and flooding events of December 2013 to February 2014.

The future impacts on the transport sector from climate change will most likely arise from disruptions to services or damage to transport infrastructure caused by more frequent storm events, rising sea levels and increased incidents of flooding. The State transport operators and agencies have built on the experience of the severe weather events since 2009 and have adapted and updated their mitigation and response plans to minimise the impact of both current and future weather-related events. Co-benefits with emergency planning will be a complementary outcome of this Plan.

8.2 Transport Service Providers Measures

8.2.1 Roads Infrastructure/Services

- Local authorities play a critical role in responding to the impacts of flooding, coastal erosion and landslides on national, regional and local roads and are responsible for the salting and gritting of the road network during periods of sub-zero temperatures.
- The local authority sector also provides significant expertise in forward planning as well as being first responders to the impacts of disruptive weather events through a range of services (e.g. engineering, fire, civil defence and the operation of road crews). Each local authority is developing its own *Climate Change Sectoral Adaptation Plan* and the sector is actively involved in the Government's National Steering Group on Emergency Planning.

> ***As part of climate change initiatives, TII has prepared the Strategy for Adapting to Climate Change on Ireland's Light Rail and National Road Network.***

- TII is a longstanding member of the Conference of European Directors of Roads. Through this, a number of key strategies for adapting to climate change have been developed and are being implemented in a number of European countries, especially those facing more profound climatic impacts.
- As part of climate change initiatives, TII has prepared the *Strategy for Adapting to Climate Change on Ireland's Light Rail and National Road Network*.
- Areas vulnerable to climatic impacts are identified early in the planning process for all new road projects.
- TII has developed a modelled strategic flood map for the national road network that identifies likely vulnerable road sections which require further detailed assessment.
- In addition, TII has developed a comprehensive flood management protocol for addressing flooding risks on the national road network.
- Where flood events lead to road closures, the event is analysed to investigate the cause of the flooding and explore what adaptation measures are required to reduce the risks of a future event. In the undertaking of any analysis of flood events and the implementation of adaptation measures, TII recognises the importance of co-ordinating such activities with relevant authorities, such as the local authorities and the OPW.
- In addition, the TII road design standards *TII Publication (Standards)* http://www.tiipublications.ie/ have been amended to include climate change adaptation; rainfall intensities are increased by 20% to allow for climate change in the design of drainage systems.
- Standards are kept under regular review; drainage standards have recently been extensively modified to allow for the construction of more sustainable

solutions to road run-off such as the use of constructed wetlands and grassed channels.

- Pre-planned diversions, call-out services, road user information and speedy clear ups are among the range of measures implemented by road authorities and public service transport providers when dealing with an extreme weather-related event. In addition, Intelligent Transport Systems continue to be planned on national routes in order to keep road users informed.

Bus Services

- In addition to having emergency response and environmental policies in place, Bus Éireann is guided by the key document *Providing Transport Services Resilient to Extreme Weather***.** Bus Éireann's emergency plan caters for immediate response from all levels of management and staff and also for liaising with other stakeholders.
- Severe weather management plans are in place to provide co-ordinated response including arrangements for staff training and storage of supplies and equipment for use during major weather events. Priorities and approach on key routes have been agreed with local authorities. Route review and alternative route planning is in place.
- Roadside real-time passenger information signs are used to provide information on service curtailments and diversions and the internet and social media are used to provide communication and information.
- Bus Éireann can engage private contractors at short notice in case of capacity issues.
- Internal reviews are conducted to ensure that systems are maintained successfully.

- Dublin Bus is a member of the Sustainable Energy Authority of Ireland's (SEAI) Public Sector Energy Partnership Programme, which offers support in energy planning, including guidance on future-proofing operations to minimise the impacts of climate change and promote sustainable practices.
- Dublin Bus currently has a severe weather plan in place, which covers severe winds, thunderstorms, heavy flooding, heavy frost or ice on the roads and heat waves.
- A Severe Weather Review Group has been established which ensures the identification of critical route network areas, passenger safety at bus stops, provision of hardware for Depot locations, staff cover for the Emergency Panel, the development of plans with Dublin City Council and other local authorities and communication protocols (Real Time Passenger Information etc.)

- Dublin Bus is also a member of the Government's Emergency Response Task Force.
- During the course of a severe weather event, Dublin Bus will also provide additional information through social media. The Dublin Bus Media and Communications Manager will provide regular updates on request from local radio stations and other media outlets.

8.2.2 Rail

Heavy Rail

- The cornerstone of arrangements for responding to extreme weather events and service recovery in the Heavy Rail sector is the Iarnród Éireann weather management protocol. This is a series of protocols developed to assist local managers to plan a response to a period of severe, possibly service-affecting weather. The document addresses the response to conditions of flooding, snowfall, ice, high winds and heat.

Iarnród Éireann has spent approximately €2.5 million in active monitoring for scour at these bridges since 2009 and has undertaken scour countermeasure works at 12 bridges in the last three years.

- In addition, there are further specific Technical Standards and Bulletins developed to address other engineering aspects which are a consequence of climatic conditions:
    - Flood and Scour Management Standard
    - Prevention of Track Buckling
    - Guidance on Alerts and Service Restrictions during Severe Weather Alerts
    - Work Limitations during Warm Weather
    - Six Day Weather Forecast Meteograms from Met Éireann
    - Tamping and Welding in Cold Weather Conditions.
- In order to address and manage the risk of bridge scour Iarnród Éireann undergoes active monitoring of bridges over watercourses. This monitoring consists of bridges being inspected by divers every one, three or six years depending on their risk condition rating. Iarnród Éireann has spent approximately €2.5 million in active monitoring for scour at these bridges since 2009 and has undertaken scour countermeasure works at 12 bridges in the last three years. Iarnród Éireann has identified a further 80 scour countermeasure projects and will implement these on a prioritised basis dictated by the results of active monitoring. In addition, there is a programme to investigate unknown foundations to determine their depth and material. Over the last three years, 32 investigations of this nature have been completed.

- Of the major impacts already identified for heavy rail, the existing trigger level for intervention in respect of track buckling and the existing trigger level for maintenance intervention/adjustment of the overhead line equipment will remain the same. As it is forecast that climate change will increase the frequency at which these trigger levels are exceeded (in the medium and long term), there is no requirement to adjust existing arrangements.

Light Rail

- TII has developed a severe weather management plan which provides a framework for managing responses to any weather event that has the potential to seriously disrupt Luas services.
- In the short term and as a continuation of current practice, TII will continue to plan and design new public transport infrastructure projects by implementing The *Planning System and Flood Risk Management Guidelines for Planning Authorities* (DHPLG and OPW). In particular, the feasibility of projects and route options will continue to be evaluated and assessed with reference to the Office of Public Works National Flood Hazard Mapping (www.floodmaps.ie) and with Flood Risk Assessment and Management Studies that are available (e.g. the Fingal-East Meath study).

8.2.3 Airports

- A key consideration in airport infrastructure development is the ability to accommodate growth in passenger numbers and also to facilitate technological change, both in the air and on the ground. Environmental aspects are considered, encompassing key climate change impacts, insofar as possible at the time. From a cost and sustainability perspective, airports seek to ensure new developments deliver increased resource efficiency.
- Planning applications submitted by Dublin Airport Authority are subject to rigorous flood risk assessment by the local authority planning department prior to being approved or otherwise.
- Dublin Airport Authority uses standard drainage models for predicted peak flows, surcharges and average flows in the drainage network. These models include a climate change factor in all calculations.
- There will be continued use of detailed weather forecasting services provided by Met Éireann. Shannon Airport is the location for a weather forecasting station that specialises in aviation forecasting. Dublin Airport Authority and Shannon Airport Authority utilise a wide range of sources for day-to-day operations. These include weather data from Met Éireann and the UK Met Office. These data sources are used for near term weather to enable efficient

airport operations. Historic climate data such as 30-year averages are used in some cases for studies relating to drainage or environmental impacts.

- The airport authorities prepare plans to deal with various emergency response scenarios, as required, including terminal building evacuation, snow and ice plan, aircraft emergency and crash procedures. The airport authorities regularly conduct reviews of operating and contingency procedures to ensure that they are consistent with aviation best practice.
- The airport authorities source data reports for information on climate change from the EPA, Directorate General for Climate Action, IPCC, the European Aviation Safety Agency, ICAO, the IAA, the Airports Council International and the International Air Transport Association.
- The airport authorities engage with representative organisations such as the Airports Council International and IBEC for up-to-date information on climate studies relevant to industry. Specific climate risk assessments from peer airports are also publicly available e.g. Heathrow Climate Change Adaptation and Resilience Progress Report.
- Numerous other commercial meteorological service providers are available e.g. Open Runway. These can supply forecast data on a contract basis at a price.
- Shannon Airport Authority's Aerodrome Manual which contains the airport's standard operating procedures outlines detailed procedures to be followed by employees to ensure the ongoing provision of a safe aerodrome during adverse weather events e.g. snow and ice plans.
- For drainage projects, a climate change factor is included in the design specification and/or modelling exercises.
- Ireland West Airport Knock is developing a drainage plan based on information received from Met Éireann which is located in the airport.

Airport Services

- In relation to airport services, the IAA has a National Operational Contingency Plan which is periodically updated to account for changes in any relevant circumstances.
- The IAA utilises relevant information from Eurocontrol, the European Aviation Safety Agency, the ICAO and the International Air Transport Association with regards to climate change.
- Stakeholder engagement is conducted to ensure environmental efficiency in Irish airspace.
- The impact of climatic conditions is taken into account in any infrastructural developments undertaken by the IAA.

8.2.4 Ports

- Dublin Port Company publishes an annual sustainability report to track and record progress on the port's economic, environmental and social responsibilities. Dublin Port Company is certified in Port Environmental Review System and ISO 14001 Environmental Management System and is a member of the Dublin Bay Biosphere Partnership.
- Rising sea level and fluvial flooding are priority issues for Port of Cork and the City of Cork. Infrastructure planning and design is based on risk assessment and strategic planning. Special attention is paid to maintaining the road access to the port under extreme weather conditions. Emergency planning procedures are in place, including monitoring of ship movements and crane operations in extreme conditions.
- In relation to dealing with impending weather events, Shannon Foynes Port Company recently developed a co-operative and combined approach with Limerick Combined Authority and the OPW. It also engaged with the local communities, including initiating a text alert messaging system to advise of future events.
- Drogheda Port is currently involved in developing a project focused on small to medium sized Atlantic ports in Europe, the lead partner being the Association des Ports Locaux de la Manche. The project is designed to identify the impact on the existing infrastructure of ports and identify future infrastructural requirements to protect port operations.

Drogheda Port is currently involved in developing a project focused on small to medium sized Atlantic ports in Europe, the lead partner being the Association des Ports Locaux de la Manche. The project is designed to identify the impact on the existing infrastructure of ports and identify future infrastructural requirements to protect port operations.

9. Next Steps to Enable Climate Change Adaptation Progress in the Transport Sector

> ***This sector's adaptation to the impacts of climate change will require collective effort and co-operation between all stakeholders.***

Work on adapting to our changing climate is already underway - either through a process of specific adaptation or through strengthening and maintenance works carried which are not necessarily identified under the banner of adaptation. The challenge is now to ensure that these actions are identified, co-ordinated and complementary; forming part of a considered and cohesive approach guided by international scientific evidence from the IPCC and that provided through national research bodies such as the EPA. Such an approach will be vital to ensure that Ireland is as prepared as possible to manage the impacts of climate change and maximise potential opportunities as they arise.

This sector's adaptation to the impacts of climate change will require collective effort and co-operation between all stakeholders. In the long term, the need for targeted investment in the transport system will increase as the sector seeks to respond to the impacts of climate change, particularly those impacts that could be exacerbated by any existing vulnerabilities in our road and rail infrastructure. However, costs associated with such measures are high and it is possible that a funding model may need to be considered in the context of addressing such vulnerabilities as part of a long-term adaptive strategy for transport in Ireland.

9.1.1. Policy Integration Measures

Policy development must occur, of course, in tandem with climate research as it is through scientifically supported climate impact and vulnerability screening that adaptation measures for our transport infrastructure and services are optimised.

Mainstreaming climate change adaptation into general policy and strategic objectives is a priority. This process has already commenced at a departmental level; e.g. the impacts of climate change both in terms of mitigation and adaptation have been referenced in DTTAS' 2015 aviation strategy *A National Aviation Policy for Ireland*.

In conjunction with DCCAE, DTTAS assisted in the production of a sectoral guidance document that will provide a valuable template for other departments in the development of their respective adaptation plans. DTTAS will continue to participate in a cross-sectoral adaptation governance group to co-ordinate the implementation of various sectoral adaptation plans at a national level. This governance group will work to ensure greater coordination between the various sectors affected by climate change, as well as between these sectors and local government.

DTTAS has had a valuable engagement with the Climate Change Advisory Council, an independent statutory body which advises on climate policy, through the development of this Plan. The CCAC was established under the *Climate Action and Low Carbon Development Act*, 2015, with the objective of supporting Ireland's national transition to a low carbon economy. The Adaptation Plan will be updated continuously to reflect our changing climate needs and DTTAS will continue its relationship with the CCAC and to action their advice through future iterations of the Plan. In addition, DTTAS is cognisant of the potential co-benefits between adaptation and mitigation measures which the CCAC will be aptly positioned to highlight.

The *Programme for Partnership Government* includes a commitment to establish a National Dialogue on Climate Change (NDCC). The NDCC will include a wider consideration of issues relevant to how we transition to a low carbon, climate resilient society and its broad engagement will raise public awareness of climate change risks. The Transport Sector will participate fully in the dialogue addressing mitigation and adaptation challenges.

DTTAS is currently drafting a comprehensive national strategy on Intelligent Transport Systems (ITS). One of the key advantages of ITS is the ability to enhance the efficiency of transport infrastructure, traffic management and mobility. DTTAS will consider potential for, and costs of, the capacity and potential of ITS to improve user information, early warning systems and public awareness elements of adaptation for inclusion in the upcoming strategy.

Furthermore, a number of key transport stakeholders are currently in the process of adaptation policy development. TII intends publishing its *Strategy for Adapting to Climate Change on Irelands' Light Rails and National Roads Network* by end 2017.

DTTAS also supports the development of freight driver education policy which incorporates awareness of adaptation needs as part of the Road Safety Authority's (RSA) educational *Driver Certificate of Professional Competence* (CPC) training. DTTAS will examine the potential for incorporating climate adaptation awareness in the driver theory testing process, specifically in relation to the area of how to drive in extreme weather conditions.

The Government is currently preparing a new *National Planning Framework* to provide a framework for future development and investment in Ireland over the next twenty years: *Ireland 2040 – Our Plan.* This plan will have statutory backing and will provide a framework from which other, more detailed plans, including city and county development plans and regional strategies, will take their lead. The development of this new national planning framework provides a timely opportunity to ensure that the climate implications of our spatial choices are fully considered and addressed to ensure that our national planning system supports, and is aligned with, our national transition objective to transition to a low carbon economy.

Summary of Policy Integration Measures
Immediate Actions • Publish this Adaptation Plan under the provisions of the *National Climate Change Adaptation Framework 2012*. • Participate and engage with the cross-sectoral Adaptation Governance group. • Continue to engage with the Climate Change Advisory Council and consider their findings and recommendations in relation to adaptation. • Participate in National Dialogue on Climate Change. • Contribute to the development of sectoral adaptation planning guidelines by the EPA. • Consider potential opportunities and costs for adaptation mechanisms in the development of the national strategy on Intelligent Transport Systems (ITS). • TII to publish its *Strategy for Adapting to Climate Change on Irelands' Light Rails and National Roads Network*. • Support the RSA educational policy for freight drivers in extreme conditions.
Short-Medium Term Actions • Ensure that climate change is mainstreamed in general policy and strategic objectives to 2050. • Ensure climate considerations are fully addressed in the new *National Planning Framework* (NPF). • Support actions highlighted in the sectoral contribution to the *National Mitigation Plan* (NMP) which carry co-benefits for adaptation. • Examine the potential for incorporating climate adaptation awareness in the general driver theory testing process.

9.1.2 Research and Collaboration Measures

DTTAS considers engagement in sharing experience and knowledge to be a vital component in increasing our understanding and improving the effectiveness of our efforts to adapt. DTTAS will support collaborative and sector-specific research across the stakeholders' group by engaging expert speakers, disseminating information on new technologies etc.

Whilst there will always be a degree of uncertainty to adaptation planning and decision-making, it is essential that adaptation planning is supported by authoritative and relevant information. While a sizeable amount of climate information currently exists for Ireland, much of this is spread out among a number of institutions and agencies. In order to satisfy these objectives, the development of a collaborative

platform could act as a centralised information resource for transport stakeholders to address shared adaptation priorities. It is anticipated that such a repository could be facilitated and maintained through the expansion of the *Climate Ireland* platform, allowing government departments, public authorities and transport sector stakeholders access to the relevant evidence-based climate data and tools necessary to build capacity for adaptation in their strategies and planning. DTTAS' work on the cross-sectoral adaptation governance group will assist in the further development of this information platform. It is important that the level of certainty or uncertainty in the accuracy of scientific data and the validity of the climate predictions be clearly demarcated to allow the relevant bodies a degree of confidence in assessing the probability of future climate change impacts on the transport network.

Several programmes, set out in an annex to this document (Annex II), are expected to deliver information on climate change impacts for adaptation which will inform future planning. With the view that a collaborative climate data repository may serve the interests of multiple departments, DTTAS has made reference to a wide range of studies which will produce valuable data for adaptation across a wide range of sectors, including transport.

DTTAS will continue to cultivate productive working relationships with other sectors, local authorities, industry stakeholders and academic experts currently involved in developing climate adaptation measures. DTTAS is participating on a steering group for the EPA-funded *Critical Infrastructure Vulnerability to Climate Change* (CIVIC) project which seeks to consolidate Ireland's existing understanding of infrastructural vulnerability. This project aims to map critical infrastructure assets across transport, energy water and telecoms, together with predicted future changes in environment and hazards which will assist in informing climate change adaptation policy at national level. DTTAS will also continue to keep informed of developments in other EU countries.

The Local Government sector, in particular, will have a key role in adaptation planning given its role as a front line responder to the impacts of severe weather and climate change related events. The proposed establishment of regional offices to coordinate the local authority response to climate action will be a positive step in terms of developing specific climate change adaptation and mitigation measures. This would allow DTTAS to ensure that local authority adaptation planning is properly reflected in sectoral adaptation plans. Equally, the development through the EPA-funded *Climate Information Platform for Ireland* (ICIP) project of the online *Local Authority Adaptation Support Wizard*, scheduled to become operational in 2017, will be a valuable tool to coordinate adaptation efforts at Local Government level.

Summary of Research and Collaboration Measures
Immediate Actions • DTTAS will support collaborative and sector specific research among its stakeholders by engaging expert speakers, disseminating information on new technologies etc. • DTTAS will continue to keep informed of developments in other EU countries. • DTTAS will, through the cross-sectoral adaptation governance group, assist in the further development of *Climate Ireland*.
Short-Medium Term Actions • Identify likely vulnerabilities for the transport network through inter-alia, continued participation in the CIVIC steering group. • Support the proposed establishment of regional offices to coordinate the local authority response to climate action. • Support the use by Local Government of the forthcoming *Local Authority Adaptation Support Wizard* in the development of coordinated local and regional-level adaptation strategy.

9.1.3 Investment and Development Measures

The question of funding climate change adaptation is both complex and challenging. While the identification and implementation of adaptation measures will undoubtedly require funding, the extent of public vs. private expenditure and the benefits accruing from same will vary within the transport sector. Opportunities exist for stronger and more consistent co-operation with the private sector for public/private partnerships in relation to shared financing and adaptation investment. The public expenditure implications will become clearer with time as adaptation priorities and the measures required are identified. Future requests for funding for repair of infrastructure will also need to specifically identify the cost of installing preventative measures.

The extent to which the final *EU Multi-Annual Financial Framework*, 2014 – 2020, provides for the integration and mainstreaming of climate action across key funding programmes may also provide opportunities to access funding for certain climate adaptation actions. Further opportunities to source potential EU funding to advance adaptation projects will be explored through the Adaptation Steering Group.

DTTAS will appraise and consider potential for adaptation mechanisms such as improvements to user information, early warning systems and public awareness elements of adaptation, through the development of an Intelligent Transport System (ITS) strategy.

Summary of Investment and Development Measures
Immediate Actions • Through the Adaptation Steering group investigate potential EU funding sources to advance adaptation projects.
Short-Medium Term Actions • Future requests for funding for repair of infrastructure will also need to identify the cost of installing preventative measures.

9.1.4 Risk Assessment Measures

Risk assessment will be a vital part of planning for adaptation. Integrating climate change risks will involve legal, institutional and policy changes which, as such, will require a flexible, preventative and forward-looking approach. It will be important to critically consider the appropriate mechanisms by which to identify vulnerable areas and key transport assets.

Detailed information and data collection is needed to design any future adaptation actions. An initial step towards this would be the establishment of a central data collection system for periodically collating information in relation to climate incidents.

A key element of the CIVIC project consists of a high-level analysis of climate change and extreme weather risk across Ireland's critical infrastructure. A key component of this analysis will be engagement with stakeholders to assess existing work done in an Irish context.

DTTAS will engage with the EPA-funded C-RISK Project (*National Risk Assessment of Impacts of Climate Change*) which seeks to develop an initial national-level risk assessment by examining the potential social, environmental and economic consequences from the impacts and risks posed by climate change.

Private owners and operators of critical infrastructure also need to carry out assessments on the risks posed by climate change and develop strategies to respond to these risks. Detailed risk assessments for individual transport networks have already been undertaken by key transport stakeholders e.g.TII is completing a detailed flood risk assessment of the national road and light rail network. It is also implementing and further developing a flood protocol to manage flood events and remediate identified vulnerable sections.

Similarly, Iarnród Éireann is currently in the process of developing a Coastal Vulnerability Index (CVI) model in order to pinpoint areas of extreme vulnerability. The pilot area is from Bray Head to Wicklow Town, with the expectation of extending the model to other coastal sections of the rail network. The model also takes into consideration the presence of conservation designated sites along the route. The presence of these designations increases the vulnerability of the route as it is an important influencing factor on the type of adaptation measures which can be employed to limit the effect of climate-related events on any particular route.

As part of the Alexandra Basin Redevelopment project, in Dublin Port, new quay walls will be higher and hinterlands will be significantly raised to future-proof against long-term increased sea-level rise.

Summary of Risk Assessment Measures

Immediate Actions

- Establish a data collection system, in tandem with stakeholders, for periodically collating information in relation to climate incident impacts on transport stakeholders.
- TII to complete a detailed flood risk assessment of the national road and light rail network.
- TII to implement and further develop a flood protocol to manage flood events and remediate identified vulnerable sections.
- Iarnród Éireann is currently developing a Coastal Vulnerability Index (CVI) model in order to pinpoint areas of extreme vulnerability.
- As part of the Alexandra Basin Redevelopment project, in Dublin Port, new quay walls to be built higher and hinterlands will be significantly raised to future-proof against long-term increased sea-level rise.

Short-Medium Term Actions

- Consider appropriate mechanisms by which to identify vulnerable areas and critical transport assets as part of a detailed risk assessment across the entire transport system:
  - CIVIC project to conduct a high level national risk and climate change adaptation assessment across Ireland's critical infrastructure.
  - CIVIC project will use probabilistic analysis to examine climate change vulnerability of one element of Irish critical infrastructure. This pilot is to showcase the usefulness of detailed probabilistic assessment in informing infrastructure asset management decisions in a climate change context.
  - C-RISK Project (National Risk Assessment of Impacts of Climate Change) to develop a *National Risk Assessment* to examine potential consequences of climate risk for national policy and planning.

10. Monitoring and Reviewing

As part of the process to establish a robust plan for adaptation in transport, it will be vital to establish a system for monitoring and evaluating measures identified in the Plan. Performance indicators will be used to establish whether adaptation measures are being achieved and considered to have value in terms of improving the future outcomes of an adaptation action. Future modelling for the transport sector in relation to climate risk will be vital as we progress to more focused actions in subsequent adaptation plans.

This Plan represents a very early stage in adaptation planning and in understanding how best to adapt to climate variability. Consequently, a monitoring system will help to support communication and learning and to indicate progress towards the goals of adaptation.

This Plan represents a very early stage in transport adaptation planning and in understanding how best to adapt to climate variability. Consequently, a monitoring system will help to support communication and learning and to indicate progress towards the goals of adaptation.

Measures identified will be considered in the context of effectiveness, efficiency, equitability and social, economic and environmental criteria. The monitoring system put in place for transport will be part of a larger system to monitor progress at local authority level as well as MMR reporting at national level to the EC and UNFCCC.

Over the period of this Plan, the following indicators will help to demonstrate progress towards an ultimate goal of building resilience into the transport system against the impacts of climate change:

- baseline monitoring;
- recognition of adaptation needs within sectoral work programmes (mainstreaming);
- level of adaptation research;
- launch of adaptation measures/level of spending collected;
- co-operation with other sectors/sub-national levels is planned/happening; and
- periodic reviews /evaluations are planned.

Longer term, there will be recurring *National Adaptation Frameworks* and sectoral plans as provided for by the *Climate Action and Low Carbon Development Act*, 2015.

A sub-group has been established under the aegis of DCCAE to coordinate the implementation of the various measures to incorporate adaptation into policy at a national level. This will facilitate a coordinated and consistent approach to assessing, prioritising, implementing, monitoring and reporting on the various aspects of these sectoral adaptation plans.

11. Conclusion

This first Adaptation Plan has examined the impacts of climate change and weather related events, both those impacts that have been observed and those projected for the future, on key transport services and infrastructure within the Irish Transport Sector.

As these changes to our climate continue, and potentially increase, over the years to come, Transport must now begin to prepare for Ireland's new climate reality. It is clear that knowledge of likely climate change impacts and of options to respond, taking into account climate variability, will be fundamental to building capacity for adaptation policy and implementation. Further research and modelling to address knowledge gaps, particularly in relation to cross-cutting issues, will lead to better and more targeted adaptation as adaptation planning progresses following the publication of the forthcoming *National Adaptation Framework*, anticipated later this year.

However, by identifying current and potential vulnerabilities within the sector, key transport stakeholders are now in a position to continue putting in place appropriate measures to reduce potential adverse impacts to our vital transport networks, exploit any opportunities that arise and enable our transition towards a low-carbon, environmentally sustainable and climate-resilient Transport Sector by 2050.

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13. Annex I: Detailed Table of Impacts

Climate Impact – Precipitation				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Bus Services	Disruption; overcrowding; delays etc.	Low	Disruption; overcrowding; delays etc. Increase in flash flood risk	Low to medium
Light Rail	Disruption; overcrowding; delays etc.	Low	Disruption; overcrowding; delays etc. Increase in flash flood risk	Low to medium
Heavy Rail	Reduction in slope stability and increase in land slides Drainage systems unable to cope Service disruption due to line closures Passengers discommoded	Low	Disruption; overcrowding; delays etc. Increase in flash flood risk	Low to medium
Aviation	Pressure on building rainfall run-off systems Pressure on airport drainage systems e.g. rain event 15th Aug'16 Shannon.	Low	Challenges to storm-water management	Medium
Ports	Radar ability compromised during heavy precipitation	Low	Challenges to storm-water management	

Climate Impact – Flooding				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Heavy Rail	Sea level rises require increased railway flood defences Scour damage at bridges Damage to track Depots flooded	Medium	Disruption; overcrowding; delays, etc. Increase in scour damage at bridges Increase in damage to track	Medium to high
Light Rail	Closure of depot e.g. Dundrum for 26 months	Low	Risk to low-lying junctions and sub-stations	Low
Aviation	Runway drainage systems Pressure on flood defence embankments (Shannon)	Low to Medium Medium	Danger of estuarine flooding from River Shannon Emergency planning requirements for staff/passengers from flooded areas	Medium
Ports			Pollution risk where draining services exceed capacity Risk to storage facilities Impact on dredging requirements – positive or negative depending the location Gradual impact on natural scouring capability of estuarial ports	Low
Roads	Damage to pavements, road washout, road submersion, underpass flooding, overstrained drainage systems, risk of landslides, instability of embankments	Medium	Damage to paving from pluvial flooding	Medium

Bus Services	Heavy rainfall and tidal river surplus caused Drogheda depot to flood at high tide resulting in limited access to the depot for passengers, with unpleasant conditions underfoot.		Disruption due to overcrowding; Diversions; delays etc. Possible damage to bus depots Damage to vehicles caused by driving through floods	Medium

Climate Impact – Storms/High Winds and Storm Surge				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Road Infrastructure	Western seaboard prolonged flooding leading to disintegration of road surfaces (€16.6m December/Jan 2013/14) Roadside tree/vegetation can block roads	Medium to High	Increased coastal flood risk of roads (western coast routes)	Medium to high
Ports	Damage to port infrastructure and damage to vessels in ports Challenging equipment's ability to discharge at high water	Low to medium	Damage to port infrastructure, navigational aid and safety equipment Damage to vessels in ports Impact on safety of passengers while in transit/embarking/ disembarking	Medium
Heavy Rail	Interruption in operation of automatic level crossing barriers due to high winds Damage to signalling and power equipment due to falling trees etc. Damage and/or blockage of track due to fallen debris and rock falls Trees and leaves on railway lines Structural damage to stations etc.	Low	Disruption, overcrowding, delays etc.	Low

Light Rail	Difficulty operating Luas, danger from overhead contact wires in high winds Speed restrictions due to high winds	Low		
Aviation	Damage to Shannon Airport due to river over-topping during Storm Darwin Jan/Feb 2014 Damage to Shannon Airport building from high winds Storm Darwin Jan/Feb 2014, €700k for one-off event	Low	Landing and take-off issues Damage to buildings and facilities Protection of aircraft on the ground Disruption of services to the public Damage to flood defence embankments	Low
Bus Services	Can cause vehicles to be diverted, curtailed and cancelled	Low	Possible disruption of services caused by fallen trees, debris	Low

Climate Impact – Heat-waves				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Bus Services	Over-heating on buses	Medium	Air quality problems Increased over-heating on buses	Low to Medium
Aviation			Aircraft climb problems Increased need for air-conditioning	Low
Heavy Rail	Increase risk of rail buckling/misalignment of track Increase in network-wide speed restrictions due to risk of rail buckling Over-heating of equipment	Low	Disruption, overcrowding, delays etc.	Low
Road Infrastructure	Melting tarmac	Low to medium	Reduced life of asphalt roads	Low
Ports			Extreme heat can reduce life of felt type roofing products and cause degradation of road surfaces Workers may not be able to work in glass boxes on cranes Drought may impact on natural scouring leading to increased siltation	Low

Climate Impact – Cold Spells				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Bus Services			Heavy levels of snow and ice and cold, can delay buses leaving depots Passengers at risk of accidents during snow/ice Staff unable to get to work, staff fatigue Can cause black ice and consequently reduce vehicle speeds and increase journey times	Low to medium
Ports			Potential increased damage to roads, walls, paving, water pipes and storage tanks Operational fuel can freeze	Low to medium
Heavy Rail	Failure of overhead electrification systems Braking performance of trains affected Passenger falls on icy platforms, station entrances and exits, depot access, walkways and roads Increase risk of rail breaks and damage to overhead catenary system due to extreme cold weather	Low	Disruption, overcrowding, delays etc.	Low

Light Rail	Failure of overhead electrification systems Braking performance of trains affected Falls on icy platforms, station entrances and exits, depot access, walkways and roads. Ice and snow damage to overhead catenary systems and rail joints	Low		
Airports			Degradation of runways/tarmac from freezing temperatures Aircraft landing problems on damaged surfaces	Low

Climate Impact – Sea level Rise				
Sector impacted	**Observed impacts**	**Level of impact**	**Projected impacts**	**Change in level of impact**
Airports	Pressure on flood defence embankments Shannon Airport (Feb 2014)	Low	Estimated figure is in excess of €100m for operation disruption costs to Shannon airport	Low
Heavy Rail	Flooding and erosion resulting in damage and loss of coastal rail infrastructure	High	Disruption, overcrowding, delays, etc. In the long-term it may be viable to realign the railway inland	High
Ports			Will impact on existing infrastructure, including existing equipment capabilities, i.e. ability to discharge at the top of high water etc.	Low
Bus Services			Possible disruption of services caused by coastal flooding	Low

14. Annex II: Ongoing Adaptation Research

DTTAS has identified a number of on-going and future studies which could provide valuable insights to climate change adaptation policymaking for multiple actors, with potential for significant collaboration and co-benefits as sectoral planning evolves.

While research to date has allowed key transport stakeholders to identify and develop initial adaptive mechanisms, this is anticipated to be an intrinsically iterative process. It is important to identify gaps in existing research programmes, with especial reference to climate monitoring, modelling and predictive capacities, in order to provide the scientific evidence and socio-economic assessments needed to continuously adapt our critical transport infrastructure and services. The climate data arising from these studies will be inherently interdisciplinary and will have cross-cutting benefits across a number of sectors; with insights from data arising from other sector-specific studies, as outlined in the sectoral plans, offering potential applications for Transport in turn.

II: 1 Report 159 and the Met Éireann ReAnalysis Project (MÉRA)

Dr. Paul Nolan of the Irish Centre for High-End Computing (ICHEC) has conducted a climate prediction project, culminating in a definitive collection of regional modelling projections for Ireland laid out in the EPA's 2015 *Report 159 - Ensemble of regional climate model projections for Ireland*. Together with Met Éireann and the EPA, Dr. Nolan will seek to update this research by incorporating the high-resolution historic climate data from the Met Éireann Reanalysis project (MÉRA) to update the validation results laid out in this report, as well as using more up-to-date climate models and greenhouse gas scenarios. The data from the MÉRA project will potentially provide a greater degree of accuracy for transport stakeholders in identifying future areas of vulnerability within key transport infrastructure. A Climate Information Portal will be established through which the updated climate insights will be made available for wider research and to the general public. It is anticipated that the portal will be facilitated by *Climate Ireland*.

Under *Horizon 2020*, the EU Framework Programme for Research and Innovation running from 2014-2020, Irish climate researchers have secured competitive funding of €16.9 million from the Climate Action, Environment, Resource Efficiency and Raw Materials (Climate Action) sub-programme. Two of the projects which have secured funding, namely *iSCAPE* and *CONNECTING Nature*, will study Dublin as a hub for various aspects of environmental focus.

II: 2 iSCAPE

In the context of climate change adaptation, air quality impacts will be studied through the iSCAPE project (*Improving the Smart Control of Air Pollution in Europe*) led by Francesco Pilla from University College Dublin. The project is being conducted across Europe on a number of test cities using a Living Lab approach in order to co-design interventions with relevant local stakeholders.

While air quality is more thoroughly addressed in the *National Clean Air Strategy*, currently in the process of being established by DCCAE, cognisance of air quality concerns will inform the development of climate change adaptation policy and best practice for the transport sector. Additionally, the project will seek to develop an advanced integrated air quality modelling tool for the assessment of air pollution and associated control strategies, which will allow transport stakeholders to foster sustainable behaviours towards air pollution when developing action plans.

II: 3 CONNECTING Nature

The *Connecting Nature* project is an international collaboration, represented in Ireland by Dr. Marcus Collier with Trinity College Dublin. The project proposes nature-based solutions for adaptation in urban areas. Ireland has become increasingly urbanised, with almost two-thirds of the population now living in cities, towns and suburbs according to the Census conducted in April 2016. As transport is a derived demand, transport services and infrastructure are highly concentrated in urban areas.

A focus of study in the project is the creation of 'living' buildings, including urban transport hubs such as train stations and bus depots, by incorporating plant life into building design, which increases the rate of evapotranspiration (evaporation of moisture from leaves into the atmosphere). This would serve to regulate temperature, providing a cooling effect on warm days and also a layer of insulation from cold temperatures in winter. This will serve to mitigate heat stress, an impact of climate change identified in this Plan. Due to the tendency of urban area microclimates to retain heat, the impacts of heat stress will be exacerbated in Irish cities and towns. While the findings of the study will be of primary interest to multiple sectors and local authorities, from a transport perspective it could also consider the development of living bus shelters, which would additionally provide shading for public transport passengers waiting for buses.

II: 4 Urb-ADAPT

The EPA funded *Urb-ADAPT* project (2016-2018), which seeks to identify the impact of climate change on Dublin city and surrounding towns across the Eastern and

Midlands Region up to the middle of this century (as far as 2060), will continue its work in climate modelling for temperature, coastal inundation and flash flooding. The project is coordinated by the Marine and Renewable Energy Institute (MaREI), Environmental Research Institute, UCC and conducted in partnership with the Eastern and Midlands Regional Assembly (EMRA). Data from the project will be made available through Ireland's Climate Information Platform (ICIP), facilitated by *Climate Ireland* www.climateireland.ie in addition to a dedicated project website www.urbadapt.com .

In the context of transport, the findings of this research will be of greatest benefit in the development of adaptation measures concerning identifying flood risk, the risk to transport infrastructure in close proximity to coastlines and the impact of changing temperatures on population health and behaviour. Projected increase in rainfall intensity in Ireland and rise in sea levels will undoubtedly pose dangers to critical transport infrastructure in the years to come. The study will support decision-makers within the transport sector by providing enhanced accuracy in discerning likely areas of vulnerability to pluvial events and coastal flooding, and to outline their response capacity accordingly.

Equally, as this Plan has identified, temperature rise (and the associated health impacts for public transport network employees and passengers) is an area which may merit further attention. Transport providers may draw valuable insights in relation to the likelihood of increased incidents of temperature extremes and potential mechanisms to mitigate their impacts (through installation of air conditioning technologies etc.), with especial sensitivity to the 'urban heat island' effect in urban centres and their hinterlands.

In addition, the project will seek to develop a standardised system of identifying future vulnerabilities or Climate Vulnerability Indicators to determine climate sensitivities and potential responses. While the results of the project will be geographically focused on the EMRA, the development of standardised neighbourhood templates, outlining climate change impacts on a range on built topographies, may offer broadly applicable data for consideration on a national level.

II: 5 INTACT

The *INTACT* project aims to draw together knowledge from stakeholders and experts, analyses and assessments, to help and make critical infrastructure more resilient to extreme weather. As such the potential benefit of the project for European infrastructure is self-evident. In order to make the results of this complicated undertaking usable and accessible, the findings will be brought together in the *INTACT* Wiki. This wiki provides a platform for users to search for expertise, research, results and outcomes across the range of subject areas examined for this project, including different geographical areas, climate conditions, particular forms of

extreme weather events, or the merits of different strategies and approaches compared to others. The *INTACT* Wiki will be designed to be an easy to use tool for decision makers, stakeholders involved in the development process of critical infrastructure, or those involved in operational management of infrastructure or crisis response. It will feature a number of convenient entrance points catering to specific informational needs, including information for specific geographical areas, governmental bodies, CI operators, specific CI sectors, best practices and experiences, and a reference guide.

II: 6 Irish National Tide Gauge Network

The Marine Institute, together with the OPW and public and private organisations, are leading the ongoing development of centrally managed national tidal monitoring infrastructure, the National Irish Tide Gauge Network. The network will ultimately be comprised of 20-25 permanent stations providing high accuracy water level time series including at least two Irish tide gauges at Global Sea Level Observing System (GLOSS) monitoring standards, the global quality standard for sea level monitoring, bringing Ireland in line with the rest of the developed world. This will allow for the determination of baselines, then in time deviation from these baselines as a result of combined natural cycles and anthropologic climate change. Such data will inform local and regional level adaptation planning, particularly civil engineering, in relation to long-term sea level rise and also assist emergency planning and response structures by its contribution to flood and storm surge warning systems. The project is co-funded under the Marine RTDI Measure of the *National Development Plan*, 2000-2006 and the European Regional Development Fund (ERDF).

II: 7 EcoStructure project

Dublin Port is currently involved with an international working group which aims to conduct climate research with a view to developing predictive models, synthesising relevant research and disseminating the data to coastal stakeholders to encourage climate adaptation measures in coastal infrastructure development. The working group has representatives from Irish and Welsh universities, including University College Dublin (UCD), University College Cork (UCC), Aberystwyth University (AU), Bangor University (BU) and Swansea University (SU).

Cognisant of potential impacts to the coastal environment associated with the implementation of adaptation measures, a key focus of the working group will be to develop practical strategies (including development of blue/green infrastructure) to minimise negative impacts and enhance the ecological and societal value of artificial coastal structures in the Irish Sea. Works will include mapping and imaging coastal structures, trialling new concrete engineering materials and designs, use of wave dynamics modelling to assess impacts, synthesising relevant global literature,

developing a stakeholder network and a GIS-based online mechanism for stakeholder interactions.

Identifying a balance between environmental concerns and the necessity of hard coastal defences to protect key transport assets will be a consideration in the development of climate change adaptation policy. It is foreseen that data from this project will inform future iterations of this Plan.

The *Ecostructure* project is part-funded by the European Regional Development Fund (ERDF) through the Ireland Wales Cooperation Programme 2014-2020. www.ecostructureproject.eu http://www.irelandwales.eu/projects?priority=37#projects

15. Annex III: Glossary

Term	Definition
Adaptation	Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organisation. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.
Climate Change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods
Extreme Weather Event	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.

	When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme e.g. drought or heavy rainfall over a season.
Mitigation	Mitigation (of climate change) is a human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Sustainable Development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
United Nations Framework Convention on Climate Change (UNFCCC)	The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It contains commitments for all Parties. The convention entered in force in March 1994. In 1997, the UNFCCC adopted the Kyoto Protocol

Source: Intergovernmental Panel on Climate Change (2014), WG2, *Climate Change 2014, Impacts, Adaptation and Vulnerability*.

16. Annex IV: Acronyms

AA	Appropriate Assessment
CCAC	Climate Change Advisory Council
CFRAM	Catchment Flood Risk Assessment and Management
CIVIC	Critical Infrastructure Vulnerability to Climate Change
CPC	(Driver) Certificate of Professional Competence
CVI	Coastal Vulnerability Index
DAA	Dublin Airport Authority
DAFM	Department of Agriculture, Forestry and the Marine
DART	Dublin Area Rapid Transit
DCCAE	Department of Communications, Climate Action and the Environment
DELCG	Department of the Environment, Community and Local Government
DHPLG	Department of Housing, Planning and Local Government
DTTAS	Department of Transport, Tourism and Sport
EEA	European Environment Agency
EC	European Commission
EU	European Union
EIA	Environmental Impact Assessment
EMRA	Eastern and Midlands Regional Assembly
EPA	Environment Protection Agency
ERDF	European Regional Development Fund
GDA	Greater Dublin Area
HSE	Health Service Executive
IAA	Irish Aviation Authority
IBEC	Irish Business and Employers' Confederation

ICAO	International Civil Aviation Organisation
ICIP	Climate Information Platform for Ireland
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
ITS	Intelligent Transport Systems
MÉRA	Met Éireann ReAnalysis (Climate Reanalysis Project)
NAF	National Adaptation Framework
NDCC	National Dialogue on Climate Change
NECG	National Emergency Coordination Group
NTA	National Transport Authority
NMP	National Mitigation Plan
NPF	National Planning Framework
OPW	Office of Public Works
PSO	Public Service Obligation
RCP	Representative Concentration Pathways
RSA	Road Safety Authority
SAA	Shannon Airport Authority
SAC	Special Areas of Conservation
SEA	Strategic Environmental Assessment
SEAI	Sustainable Energy Authority of Ireland
SPA	Special Protection Areas
TII	Transport Infrastructure Ireland
UCC	University College Cork
UNFCCC	United Nations Framework Convention on Climate Change