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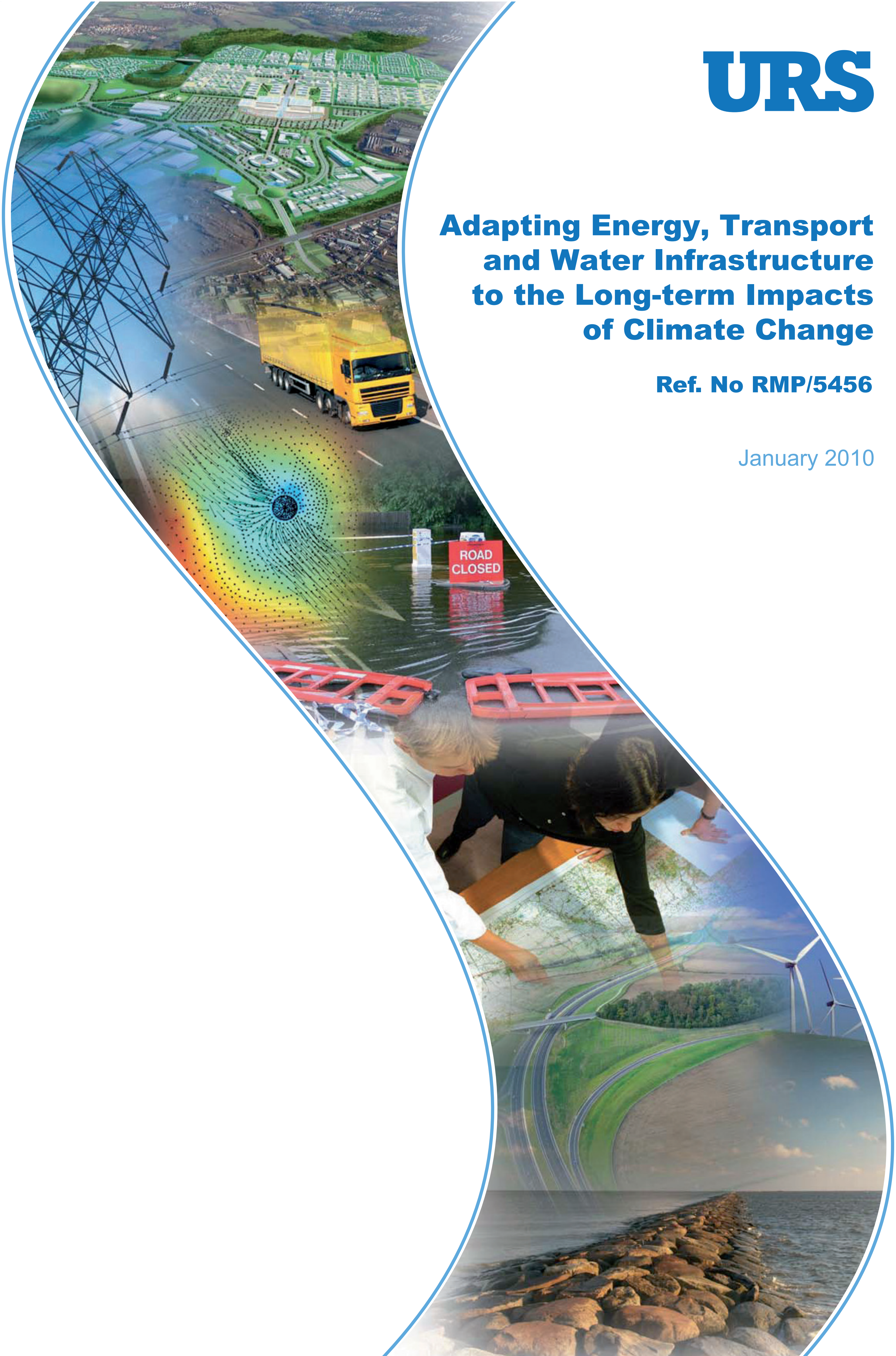

Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change

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Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change

Full Report

This is an independent report commissioned by the cross-departmental Infrastructure and Adaptation project.

Its findings, conclusions and recommendations are not endorsed by Government but will be considered by the project as part of its two year programme of work to identify and examine strategic solutions to improve the long-term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts.

Executive summary

This report sets out the case for adapting infrastructure in the energy, transport and water sectors so that new and existing infrastructure is able to operate effectively in a long-term changing climate.

The report focuses on the long-term impacts of climate change (2030s to 2100) to the infrastructure in the three sectors, setting out:

- **The long-term risks from climate to the infrastructure, both technically and operationally.**
- **The need to consider the interdependency risks of the infrastructure system and how this can be exacerbated by long-term climate change.**
- **The need for all infrastructure to consider the long-term impacts of climate change in its design, build and operation.**
- **The adaptation options available, as well as barriers possibly preventing action.**
- **Suggested recommendations to the Infrastructure and Adaptation project as part of its two year programme of work.**

This three month study provides a more thorough understanding of the above issues. It provides a robust starting point for more detailed work on infrastructure and adaptation to be taken forward by the Infrastructure and Adaptation project and others. For example, industry and academia might take forward possible work on understanding possible thresholds/trigger points that infrastructure might have to the impacts of climate change.

Given the long-term challenge of adaptation, it is an increasing concern for Government, business and infrastructure operators. This is underlined by new statutory adaptation provisions– the Adaptation Reporting Power and UK Climate Change Risk Assessment – within the Climate Change Act[1.]

This report focuses on long-term impacts of climate change (2030s to 2100) on the infrastructure in the energy, transport and water sectors.

[1] The Climate Change Act 2008. Available from: http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1].

This report is to the cross-departmental Infrastructure & Adaptation project[2] as part of the cross-Government Adapting to Climate Change (ACC) Programme. URS Corporation Limited (URS) was commissioned by the Department for Environment, Food and Rural Affairs (Defra) on 11 September 2009 to report to the Infrastructure and Adaptation steering group overseeing the project on the:

- Technical risks and operational implications of long-term climate change to infrastructure in the energy, transport and water sectors;
- Interdependency risks across the sectors from long-term climate change (and the role of Information and Communication Technology (ICT)); and
- Barriers to, and options for, increasing long-term adaptation action across the three sectors to improve the infrastructure's long-term resilience to climate change impacts.

The study comprised a number of joined up tasks: project planning, information assimilation (literature review and stakeholder consultation activities), analysis and assessment; and reporting. Stakeholder engagement within and across sectors has been invaluable to the study providing important technical and operational insights across the sectors. The consultation process covered a range of stakeholders including owners and operators of infrastructure assets, contractors, research institutions, policy makers and regulators. A key message from the stakeholders is that there is a reluctance to plan for the long-term impacts of climate change due to perceived uncertainty associated with the impacts and the financial risks involved. In addition, although UKCP09 is widely known, many companies are still finding it difficult to take on board its range of probabilities and uncertainties and to apply the projections to their own specific operations.

Key elements of infrastructure identified as vulnerable to long-term climate change impacts and associated technical risks are identified in relation to each of the three sectors overleaf.

[2] The two year Infrastructure and Adaptation project has been set up as part of the cross-Government Adapting to Climate Change Programme, to identify and examine strategic solutions to 'improve the long-term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts'.

Sector	Vulnerable Infrastructure	Key Risks
Energy	Fuel processing facilities/ storage of fuel/ transport of fuel	• Flooding of fuel supply infrastructure due to increased storminess and sea level rises/ sea surges
	Power generation (fossil, nuclear and renewables) & pollution control and abatement	• Flooding of fossil fuel and nuclear power plants due to increased precipitation and sea level rise • Loss of efficiency of fossil fuel power plants due to increased temperatures • Loss of efficiency of, and storm damage to, renewable energy sources due to increased storminess
	Energy distribution systems	• Reduced capacity of distribution network due to increased temperatures and precipitation/ storminess.
Transport	Roads	• Flooding from increased precipitation and/or storminess • Scour of bridges due to increased precipitation and/ or storminess due to wetter winters and drier summers
	Rail	• Flooding (from increased precipitation and/or storminess) • Scour of bridges due to increased precipitation and/ or storminess • Moisture fluctuation in embankments in south east England due to wetter winters and drier summers • Overheating of underground trains due to increased temperatures
	Ports	• High tides/ storm surges causing increased sea level at ports • High winds at ports due to an increase in storminess
	Airports	• High winds at airports due to increased storminess
Water	Water supply, treatment and infrastructure	• Reduced security of supply due to changing precipitation patterns and periods of drought • Increased fluvial flooding due to increased precipitation and storm surges
	Wastewater collection, treatment and disposal	• Increased sewer (pluvial) flooding due to increased precipitation and storm surges • Increased fluvial flooding due to increased precipitation and storm surges • Increased pollution incidents due to changing precipitation patters and periods of drought

What is clear is that there are some significant long-term risks for infrastructure vulnerability both from extreme weather events and gradual climate change. We have already seen major disruption to infrastructure associated with climate events from extreme weather with significant economic consequences.

The impacts of climate change present a long-term problem and both our new and existing infrastructure will need to adapt to ensure that is it not adversely affected:

- Existing infrastructure in the UK has been engineered and built for our past or current climate and may not be resilient to continued climate change in the long-term.
- To ensure new infrastructure, often with a life-time of 50-100 years (or more), is resilient to long-term climate change, we need to ensure that when commissioning new infrastructure the long-term impacts are always considered in its design and build.

Effective planning and designing in long-term adaptation, particularly where we are predicting major investment in new infrastructure in the short term, such as the energy sector, will reduce the economic burden associated with some of the impacts.

An important finding of the study is that the infrastructure system is highly interconnected. There are interconnections between the infrastructure components within and between the three sectors and with the ICT sector. Where these interconnections are associated with the supply or receipt of a service on which the receiving sector is reliant these have been termed ‘interdependencies’.

The study identifies two specific types of interdependencies which could have far greater impacts on our infrastructure functionality than individual failures:

Cascade failures	referring to a series of linked impacts or failures.
Regional convergences	regional concentrations of infrastructure, which, if impacted by an extreme weather event, could have consequences on functionality at a national scale in one or more of the three sectors.

It is clear that in response to the long-term risk to infrastructure from the impacts of climate change, adaption options will be required. These need to include technical, operational, cultural, financial, regulatory, repair, retrofit and replacement options as well as wider cultural, financial and regulatory options. Given the time constraints on the project the net benefit of each option was qualitatively assessed considering the possible benefits versus the main potential barriers or challenges. A systematic review of the adaptation options resulted in identification of a number of common barriers and constraints that will require national, cross sector action. These include:

- Currently investment in new infrastructure does not adequately consider long-term impacts of climate change. Consequently, we need to ensure that investment decisions consider how long-term climate change might affect investment.
- Often significant upgrades/maintenance projects consider the current or historic climate. There is a need to ensure that all new/existing infrastructure projects consider the climate over their estimated lifetime to ensure their long-term resilience.

- Consideration of long-term climate change impacts and the need for adaptation is not typically part of day to day business planning and operation. There is a need to ensure that consideration of these issues is integrated into business practices across all business functions and not necessarily left to a singe environmental or climate change team,

- These sectors are highly interconnected, relying on each other for delivery of their service and function. Currently cross sector engagement does not systematically occur as part of business planning and risk assessment. There is a need to ensure that the interdependences are understood and effectively considered in business planning.

- Whilst it is clear that there is increasing understanding of the need to adapt to climate change, better understanding of long-term climate change impacts and the range of probabilities and uncertainties in UKCP09 is required to enable effective application to specific operations.

- Even with many changes, current levels of supply and infrastructure functionality may not be possible at a reasonable cost. We need to ensure that the general public understands the constraints and challenges.

A discussion of options to address the above issues is presented and recommendations made to progress actions in each area. The recommendations focus on national, cross sector actions that are key for the orchestrated approach that is required to long term climate adaptation. Infrastructure has already been challenged by severe weather events. Increasing intensity of such events, combined with gradual changes in our climate will present significant long term risks. For continued reliance on performance of the infrastructure in the energy, transport and water sectors there is a clear need for technical and operational change supported by robust financial, regulatory and policy frameworks. Early identification of the actions will enable decisions to be made proactively considering overall net benefits and not as an urgent reaction to disasters.

A key recommendation is for the establishment of a cross sector group, with a broad cross section of representatives endorsed by Government and chaired in a leading person in industry. This forum is needed to increase information sharing, in particular of technical and operational risks and appropriate adaptation measures; as well as ensuring continued development of the understanding of interdependencies. The cross sector workshop held in November as part of this project demonstrated the imperative and appetite for such working group.

Contents

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Section 1
Introduction

Introduction

This report is to the cross-departmental Infrastructure & Adaptation project[3] as part of the cross-Government Adapting to Climate Change Programme.

URS Corporation Limited (URS) was commissioned by the Department for Environment, Food and Rural Affairs (Defra) on 11 September 2009 to report to the Infrastructure and Adaptation project on the:

- Risks and operational implications of long-term climate change to infrastructure in the energy, transport and water sectors;
- Interdependency risks across the sectors from long-term climate change (and ICT); and,
- Barriers to, and options for, increasing long-term adaptation action across the three sectors to improve the infrastructure's long-term resilience to climate change impacts.

Context

While it is essential to reduce greenhouse gas emissions (climate change mitigation), due to past and current emissions, we are also committed to continued climate change for decades to come. What is done to assess the risks from climate change and how we take action in response to those risks is climate change adaptation.

This report focuses on long-term impacts of climate change (2030s to 2100) on infrastructure in the energy, transport and water sectors.

The impacts of climate change in the UK to the end of this century are shown by the UK Climate Projections (UKCP09) published in June 2009[4]. UKCP09 shows that the main trends will be hotter and drier summers, warmer and wetter winters, rising sea levels and more severe and frequent extreme weather events such as floods, storms and heat waves.

Consequently, climate change is an increasing concern for Government, business and infrastructure operators. This is underlined by new statutory adaptation provisions – the Adaptation Reporting Power and UK Climate Change Risk Assessment – within the Climate Change Act[5].

Defra is the lead department for domestic climate change adaptation and has set up the cross-Government Adapting to Climate Change (ACC) Programme for England.

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[3] The two year Infrastructure and Adaption project has been set up as part of the cross-Government Adapting to Climate Change Programme, to identify and examine strategic solutions to 'improve the long-term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts'.

[4] UK Climate Projections, the climate of the UK and recent trends, January 2009.
http://ukclimateprojections.defra.gov.uk/content/view/816/9/

[5] The Climate Change Act 2008. Available from: http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1.

As the country's infrastructure is already, and will be increasingly, affected by the impacts of climate change, long-term responses will be needed to ensure more resilient and robust infrastructure. The Domestic Adaptation Programme Board, which oversees the ACC programme, has prioritised 'infrastructure' as a cross-departmental priority. It is also recognised that effective adaptation of infrastructure will minimise potential long-term disruption and costs to the UK economy.

As a result, in April 2009, a cross departmental project was set up to examine and identify strategic solutions to "improve the long term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts". This also encompasses the role of Information and Communication Technologies (ICT) in the sectors and the interdependency risks between and within the sectors. The project takes a 20-90 year time frame (i.e. from the 2030s through to 2100) and its overall objectives and aims are outlined in Box 1. Further information can be found on the Defra website (www.defra.gov.uk/adaptation).

Box 1
Infrastructure and adaptation project

Overall aim: implement a programme of work to improve the resilience of new and existing infrastructure in the energy, transport and water sectors to the long term impacts of climate change

Overall objective: the infrastructure in the energy, transport and water sectors are able to adapt to long-term climate change by overcoming "adaptation barriers" and policy is in place to support this.

Study objectives

There are a number of objectives for this study which include:

1. Examining the long-term impacts of climate change on the infrastructure within the three sectors (energy, transport and water) with respect to:
   - The technical implications, i.e. how climate change impacts (including both extreme events and long-term climatic changes) are likely to affect physical assets and the ongoing function of the infrastructure.
   - What this means operationally – how climate change is likely to affect the operation and national infrastructure.
   - The interdependencies between and within the infrastructure in the three sectors and the role of ICT in each.
   - Possible new, or modified, future infrastructure (considering where innovation may be needed) that may be required in the UK due to climate change.
2. Identifying possible sector wide and/or strategic changes that will be required, in particular:
   - What adaptation measures are needed to minimise the long-term impact of climate change.
   - When changes might be needed.

- What the barriers to adaptation are

The project does not seek to provide a general narrative on the vulnerabilities of organisations within each sector from long-term climate change nor replicate short-term resilience planning or possible resilience standards, which is being taken forward by the Cabinet Office's National Hazards Team.

Study approach

The study comprised a series of steps including project planning, information assimilation, analysis, assessment and reporting. Further detail on each of these steps is provided in the relevant sections of this report. An integral part of the study has been stakeholder engagement within and across sectors: both one to one interviews as well as a cross sector workshop. The views and experiences of stakeholders have been invaluable, providing important insights across various aspects of the sectors. Stakeholders that have been involved in this report are identified in Box 2.

Box 2
Organisations contributing to project engagement

Anglian Water plc
Association of British Ports
Association of Electricity Producers
Automobile Association
Birmingham International Airport
British Airports Authority
British Dam Society
British Energy
BP
Carbon Disclosure Project (CDP)
Centrica
Chartered Institute of Water and Environmental Management (CIWEM)
Consumer Council for Water
Dorset County Council
Dover Harbour Board
Drax Group plc
E.ON
EDF Energy
Energy Networks Association
Environment Agency
Health and Safety Executive (HSE)
Highways Agency
Institution of Highways & Transportation
International Power
Leeds University Climate Change Centre
Manchester Airport
National Grid
Network Rail
Office of the Gas and Electricity Markets (Ofgem)
Powerfuel
RAC Foundation
Renewable Energy Association
Road Haulage Association
RWE npower
Scottish Power
Skanska
Southern Energy
Sellafield Ltd
Severn Trent plc
Society for Motor Manufacturers and Traders
Stagecoach
Surrey County Council
Thames Water Utilities Ltd
Transport for London
UKCIP
UK Energy Research Partnership
UK Water Industry Research (UKWIR)
United Utilities plc
Water Service Regulation Authority (Ofwat)
Water UK Climate Change Focus Group (CCFG)
Waterwise
Warwickshire County Council

The study has also benefited from participation of the project steering group which comprised representatives across Government departments[6]. The input of this steering group has been critical throughout not least in identifying existing studies and providing guidance on the areas for focus.

Report structure

This report presents the findings of this study and is structured as follows:

Section 1 this introduction.

Section 2 presents key elements of background information and context for the study both in terms of climate change and the infrastructure being examined.

Section 3 outlines the approach taken to meet the above objectives.

Section 4 details the key outcomes from engagement with stakeholders.

Section 5 presents the findings of the sector specific vulnerability assessment and evaluates a series of key technical risks for the sectors.

Section 6 discusses interdependencies between the infrastructure and operation of each of the sectors and discusses the relationship of the sectors with ICT.

Section 7 discusses the potential implications of climate change adaptation on new infrastructure in each of the three sectors

Section 8 discusses various adaptation options for the technical risks discussed and evaluated in Section 5. Potential barriers for these options are also considered.

Section 9 identifies a number of high level actions which would, if addressed, reduce the constraints to change.

Sections 10 & 11 present the study conclusions and recommendations.

This report is completed by a series of **appendices** including a Glossary as Appendix A.

In addition, a separate high-level **Summary Report** has also been produced.

6 Departments involved in the steering group were: Defra (ACC and Water & Floods), DfT, Highways Agency, Cabinet Office, BIS, DECC, Environment Agency and CLG

Section 2
Background

Background

How is our climate changing?

Due to past and current global greenhouse gas emissions we are committed to decades of climate change. Consequently, we not only need to reduce our global greenhouse gas emissions to minimise the risk of the most severe impacts from occurring, but we now also need to put in place effective long-term adaptation measures.

Beyond the 2040s, the severity of climate change will depend on how successful global action to reduce global greenhouse gas emissions is. Nevertheless, it is clear that adaptation will present a long-term challenge to the country and its infrastructure.

The UK has experience of the sorts of extreme weather events we might expect more of in the future. In August 2003 the highest daily temperature for England of 38.5ºC was recorded by the Met Office[7] whilst in the summer of 2007, severe floods affected the country; in particular Yorkshire and Humber and the South West of England.

The general trend shows the climate getting hotter, with temperatures rising by up to 1ºC across the UK since the 1970s[8]. Sea level has also risen by about 1mm/yr in the 20th century, with higher rates for the 1990s and 2000s[8]. Before 2001, the Thames Barrier was raised on average three times per year, compared with an average of six times per year between 2001 and 2008[9]. It is likely that the rise in sea level has contributed to this increase.

The latest set of UK Climate Projections (UKCP09) were published in summer 2009, which show how the UK's climate might change under different emissions scenarios. Covering a range of climatic variables including temperature, rainfall, air pressure, cloud, humidity and sea level rise, these projections are designed to enable organisations to plan more effectively for the long term impacts of climate change and to further integrate 'climate risk' into their decision making.

UKCP09 provides the following central estimate (50% probability level[10]) projections for the UK for the 2080s (2070-2099) assuming a medium emissions scenario[11].

- An increase in mean daily maximum temperatures across the UK, with an increase in the summer average of up to 5.4 ºC in parts of southern England and 2.8 ºC in parts of northern areas of the UK.
- Changes in the warmest day of summer ranging from +2.4 ºC to +4.8 ºC depending on location, but with no simple geographical pattern (See Figure 1).

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7 Met Office, Weather Extremes. http://www.metoffice.gov.uk/climate/uk/extremes/

8 UK Climate Projections, the climate of the UK and recent trends, January 2009. http://ukclimateprojections.defra.gov.uk/content/view/816/9/

9 Environment Agency. http://www.environment- agency.gov.uk/research/library/data/58613.aspx

10 UKCIP recognises the uncertainty associated with climate data and therefore assign probability estimates for different possible climate change outcomes. Climate change at the 50% probability level is that which is as likely as not to be exceeded; it is more commonly referred to as the central estimate in UKCP09.

11 UKCP09 includes probabilistic projections for three emissions scenarios: low, medium and high. These comprise different assumptions on future socioeconomic changes as defined in the IPCC Special Report on Emissions Scenarios.

- Changes in winter precipitation with the biggest changes predicted along the western side of the UK with increases of up to +33% (See Figure 1).
- The biggest changes in precipitation in the summer are seen in parts of the south of England with decreases as much as -40%. Changes seen over parts of northern Scotland are projected to be close to zero.
- Absolute sea level is projected to rise by up to 39cm by the 2080s. Sea level rise is expected to be greater in the south of the UK than the north.

Although we cannot definitively attribute single episodes of extreme weather to climate change, we do know that more frequent and more severe extreme weather events are expected due to climate change. This might mean:

- Increased number of hotter summers, such as the heatwave which killed thousands of people across northern Europe (and up to 2,000 in the UK) in 2003[12].
- Increased number of flooding incidents caused by a greater frequency and intensity of rainfall.
- Increased number of droughts especially during the summer months due to higher temperatures and reduced rainfall.
- Increased occurrence and severity of storms.

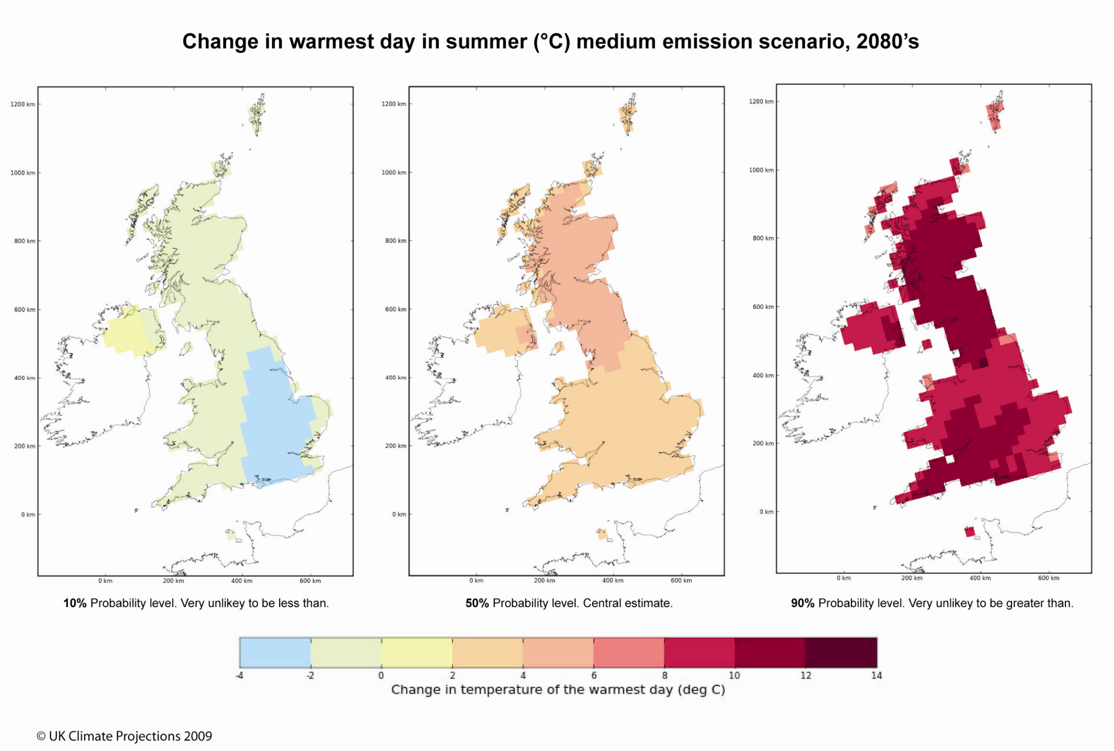
The impacts of climate change present a long-term problem and both our new and existing infrastructure will need to adapt to ensure that is it not adversely affected:

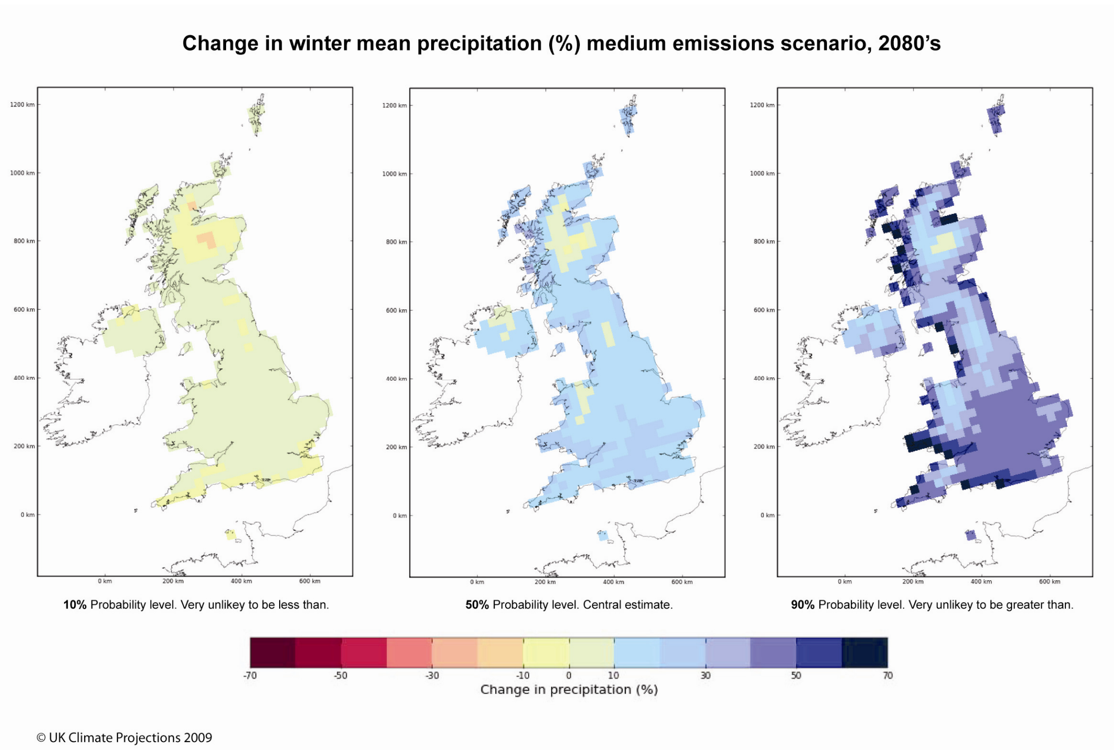
- Existing infrastructure in the UK has been engineered and built for our past or current climate and may not be resilient to continued climate change in the long-term.
- To ensure new infrastructure, often with a life-time of 50-100 years (or more), is resilient to long-term climate change, we need to ensure that when commissioning new infrastructure the long-term impacts are always considered in its design and build.

To improve our understanding of the types of risks new and existing infrastructure face from a long-term changing climate, this report examines technical and operational risks. It aims to make the case that existing infrastructure when upgraded, and new infrastructure, when commissioned, needs to consider the future climate not just the current or historic climate.

[12] New Scientist, "European heat wave caused 35,000 deaths", 10th December 2003.: http://www.newscientist.com/article/dn4259.

Figure 1: Maps extracted from UKCP09: showing projected summer temperature and winter precipitation changes





Box 3
How infrastructure can be affected by climate change

- In November 2009 severe flooding in Cumbria resulted in a number of road bridges collapsing leaving utility cables visible and without support and a community split in two. The same flooding also impacted the West Cumbria Railway Line[13].

- During the summer of 2007, a series of severe floods occurred across the UK including Gloucestershire, Worcestershire and East Yorkshire. The severity of these floods was attributed to the intensity of rainfall which followed an unusually dry period. Impacts included the evacuation of a large number of people from their homes; interruptions to electricity and water supply; and significant disruptions to the road and rail networks. In Gloucestershire the loss of the Mythe water treatment works left 140,000 houses without mains water supply for up to two weeks, while up to 10,000 people were left trapped on the M5, and commuters were left stranded on the rail network[14].

- Many regions in the UK including the Lake District, Hertfordshire and Bedfordshire, experienced power cuts and road and rail closures caused by storms and high force winds in January 2007. Road and port closure during this time included a number of junctions on the M25 and M1; the M48 Severn Bridge, and the port of Dover.

- In the summer of 2006, road surfaces in regions including Cumbria and Durham softened due to a heat wave[15].

- Hose pipe bans were implemented by water companies across the south-east during 2006 after a long period of dry weather.

- During the heat wave of 2003, many of France's nuclear power stations were unable to operate at their design capacity due to a change in temperature of the river water used for cooling, which resulted in some being shut down entirely. This occurred at a time when electricity demand was particularly high due to an increase in the use of air conditioning. Consequently a large part of continental Europe suffered blackouts[16]

[13] Cumbria County Council website, Latest Flood Updates on News in Cumbria. http://www.cumbria.gov.uk/floods/floodsnews.asp.
[14] Environment Agency, Review of 2007 Summer Floods, December 2007. Available from: http://publications.environment-agency.gov.uk/pdf/GEHO1107BNMI-e-e.pdf
[15] Local Government Association (LGA), "Winter gritting lorries placed on summer standby", 18th July 2006. http://www.lga.gov.uk/lga/core/page.do?pageId=45277.
[16] G.Thuma (GRS) et al, Experience with the influence of both high summer air cooling water temperature and low river levels on the safety and availabilty of German and French NPP. Available from: http://www.eurosafe-forum.org/files/pe_76_24_1_1_01_paper_weatherconditions_en_thu_big_final_031104.pdf

Climate change adaptation policy

The 'Stern Review on the economics of climate change'[17] presents an authoritative report on the economic consequences of climate change and the need for adaptation. In particular it states:

"climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen…Based on simple extrapolations, costs of extreme weather alone could reach 0.5-1% of world GDP [Gross Domestic Product] per annum by the middle of the century, and will keep rising if the world continues to warm…in the UK, annual flood losses alone could increase from 0.1% of GDP today to 0.2-0.4% of GDP once the increase in global average temperatures reaches 3 or 4°C [degrees Celsius]…heat waves like that experienced in 2003 in Europe, when 35,000 peoples died and agricultural losses reached $15 billion, will be commonplace by the middle of the century."

The Climate Change Act 2008 establishes a statutory framework for adaptation, enhancing the UK's ability to adapt to climate change impacts. Specific adaptation provisions include establishing that:

- A UK Climate Change Assessment must take place every five years - the first UK Climate Change Risk Assessment will be published in 2012.
- A national adaptation programme for England must be put in place and reviewed every five years to address the most pressing climate change risks to England – the first national adaptation programme must be in place by 2012.
- The Government has the power to require public authorities and statutory undertakers (e.g. water and energy utilities) to report on how they have assessed the risks of climate change to their work and what they are doing to address these risks. In November, the Government published a strategy outlining how this new power will be used, and identifying the priority organisations that will be covered by it
- The Government is to provide statutory guidance on how to undertake a climate risk assessment and draw up an adaptation action plan. This was completed in November 2009.

The independent Adaptation Sub-Committee of the Committee on Climate Change has been set up to report on progress in connection with adaptation, and advise on the UK Climate Change Risk Assessment. In addition, in June 2009, all Government Departments agreed to produce a Departmental Adaptation Plan by spring 2010.

[17] Cabinet Office - HM Treasury. 2006. Stern Review on the economics of climate change

Infrastructure in the energy, transport and water sectors

Each of the three sectors that form the subject of this study are complex in terms of their various infrastructure components, the various parties involved (e.g. owners, operators, investors) and interdependencies across the sectors and with the ICT sector. For the purposes of this study we have focused on major national infrastructure as relevant to these three sectors.

Energy

The energy sector comprises a number of infrastructure components and has been divided below into electricity, gas, oil, renewable and nuclear. Across this sector significant investment in new infrastructure, as well as maintenance of existing, is expected in the next decades to ensure long term security of supply and the move to a low carbon economy.

Electricity

The key elements for electricity are generation, transmission, distribution and supply to customers. Each of these requires different types of assets, organisations and regulatory frameworks. A key issue is the size and shape of future generation. Major investment in new generation capacity is required in the next 20 years to replace existing power stations, meet rising demand and achieve the transition to a low carbon economy. Generation is considered a competitive market and each generator makes its own investment decisions. Currently there are over 2,500 generating stations in the UK. The majority of the generating capacity is fuelled by coal, gas and nuclear energy. Electricity is the main means for accessing low carbon energy sources such as renewables, nuclear and carbon capture. For this reason these are likely to see significant growth to enable the UK to succeed in reducing carbon emissions in line with Government targets.[18]

Transmission is the transfer of electricity from individual generation sites to distribution networks (or a few major energy users). Across the UK it comprises over 7,000 kilometres (km) of overhead and over 650 km of underground lines and some 340 substations. The UK has a number of electricity distribution networks supplying industrial, commercial and domestic users. A key issue is the future shape of the transmission and distribution network as growth in renewable and distributed generation increases. Companies in this part of the sector are subject to price regulation by Ofgem and decisions on investments are highly influenced by the regulator's approach to service requirements and allowable investments.

Gas

The key elements of the gas sector are production and processing, transmission and distribution, storage and shipping and supply.

Production and processing is associated with exploration, extraction and processing from primarily offshore gas fields. The UK also imports gas via pipelines from continental Europe. As with electricity, the UK has a transmission network and a series of regional distribution networks

[18] The UK Climate Change Act, 2008 created a legal framework for the UK achieving, through domestic and international action, at least an 80% reduction in GHG (i.e. equivalent CO2) emissions by 2050 against a 1990 baseline

transferring the gas to the end user. Storage facilities support these transfer networks including large partially depleted gas fields, underground salt cavities and LNG storage. Key issues include increased reliance on imports and a need for a progressive switch from North Sea gas to other sources. Significant investment will be necessary to make this change. As with electricity, gas distribution and transmission are subject to economic regulation by Ofgem; investment is therefore subject to similar reviews and challenges. Gas storage is not licensed nor subject to economic regulation.

Oil

Oil is often divided into upstream (exploration and production) and downstream (refining, distribution and supply of products). Downstream comprises reception terminals, refineries, distribution terminals and filling stations with distribution occurring through pipelines and tanker. No element of the downstream industry is subject to economic regulation, and each company is responsible for its own investment decisions. Downstream decline will see further dependence on imports from the EU and further afield.

Renewable energy

Renewable energy is primarily used for electricity production with onshore wind, hydro generation and offshore wind being the three largest components. Substantial growth in this sector is required to meet the Government's target for 15% of the UK energy to be from renewable sources by 2020[19]. Investment in the transmission and distribution network is required in the short to medium term to provide appropriate grid connections for these new electricity generation facilities. The renewable industry is privately financed and not subject to economic regulation, however, the Government plays an important role in providing support mechanisms for investment.

Nuclear

Nuclear currently provides around 15% of the UK's electricity. Many of the nuclear power stations are coming to the end of life, and without the planned new nuclear power station build, by 2025 only Sizewell B will remain generating electricity. The draft National Policy Statement for Nuclear Power Generation outlines that a significant proportion of the anticipated additional 25GW of new non-renewable capacity required in the UK by 2050 will be filled by nuclear power. In the NPS 10 sites are identified as being potentially suitable for the deployment of new nuclear power stations by 2025 - Bradwell; Braystones; Hartlepool; Heysham; Hinckley Point; Kirksanton; Oldbury; Sizewell; Sellafield; and Wylfa. Development of single reactors at each of these sites would result in approximately 12-17 GW of nuclear capacity[20].

The safe and cost effective decommissioning and clean-up of the industry's power stations and fuel processing facilities, which are being progressively shut down, are providing future technical and engineering challenges for the industry. The decommissioning of the UK's civil nuclear facilities and the clean-up of the sites has been the responsibility of the Nuclear Decommissioning Authority since 1st April 2005.

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[19] HM Government, The UK Renewable Energy Strategy, July 2009
[20] draft National Policy Statement for Nuclear Power Generation (EN-6) published by DECC in November 2009.

Transport

The transport sector includes road, rail, airports and ports. Challenges already faced by the sector include rising fuel prices, increased traffic congestion and passenger congestion on busy commuter rail routes. Climate change impacts are likely to further increase these challenges.

Road

The road network consists of over 8,000 km of motorways and trunk roads (known as the 'strategic road network') and over 250,000 km of other public roads (the 'local road network'). The Highways Agency, an Executive Agency of the Department for Transport, is responsible for managing the strategic road network including responsibility for traffic, tackling congestion, informing road users, improving safety and minimising adverse impacts on the environment on England's strategic road network. The Highways Agency also develops and implements road improvements and schemes approved by the Secretary of State for Transport.

Rail

Rail infrastructure, including over 20,000 km of rail track is owned and operated by Network Rail, who runs, maintains and develops Britain's tracks, signalling system, rail bridges, tunnels, level crossings, viaducts and key stations. While managing the existing fabric of the network, and ensuring its safe use, it also supports and implements new initiatives and upgrades and oversees investment. The Office of Rail Regulation (ORR) ensures that Network Rail operates and plans the future use and development of the network and maintains and enhances its assets in such a way that meets the reasonable requirements of its customers and investors.

Passenger trains are operated by Train Operating Companies (TOCs), who apply to the Department for Transport for franchises to run specific routes. Freight trains are run by Freight Operating Companies. Rolling Stock Companies (ROSCOs) own and lease the actual trains that run on the rails. They work with the train operating and freight companies to determine the sorts of engines, carriages and trucks required to deliver the services. ROSCOs also have a responsibility to develop services by phasing out old and aged rolling stock.

Ports

The country's 120 commercial ports remain important trade and travel gateways. While individual ports vary widely, the majority of ports in Britain now fall into one of three categories of governance: private ownership, municipal control, or run by a trust. Twenty one UK ports, for example, are privately owned by Associated British Ports. As a competitive sector, ports are not subject to regulation.

Aviation

The aviation industry in the UK includes 36 commercial airports and consists of a network of airport operators each funding and operating its own infrastructure working with partners including air traffic control services. Airport operators are regulated by the Civil Aviation Authority, the Competition Commission and the UK Government. The Civil Aviation Authority controls all flight paths and aircraft routes at UK airports, and regulates airlines, airports and NATS air traffic control services.

Water

The water sector can be divided into water supply and wastewater removal and treatment. The industry in England is made up of 9 water and sewerage service providers and 14 water suppliers.

Challenges faced by the sector for both water supply and wastewater removal and treatment include rising population and demand, supply issues associated with water quality and availability of water. Climate change impacts are expected to compound these challenges.

Water supply, treatment and distribution

Freshwater supply comprises abstraction of groundwater from aquifers and surface water from rivers and reservoirs, treatment of the water in a local treatment works and delivery to customers. Infrastructure comprises pumping stations, reservoirs, treatment works and pipeline networks. Across the whole of the UK the water industry collects, treats an suppliers more than 17 billion litres of water to domestic and commercial customers.

Wastewater collection, treatment and disposal

Waste water collection, treatment and disposal comprises operation of sewerage systems and treatment plants and relies on infrastructure such as sewers, surface water drainage, pumping stations and treatment plants. Every day the wastewater industry across the UK collects and treats over 16 billion litres of wastewaters.

The water industry is subject to extensive economic, environmental and water quality regulation. Ofwat is responsible for economic regulation, Government for policy and legislation and, in England, the focus of this study, the Environment Agency for licensing of abstraction and discharges to water reserves. Ofwat sets price limits for water supply and sewerage services following price reviews which occur on a five year cycle. Price reviews primarily consider operational expenditure, capital investment programmes and return on investor capital. A performance level for reliability of service is defined which could be related to resilience, however, consideration of climate change adaptation is not explicit in this assessment.

Future investment in this sector is largely expected to be refurbishment and upgrading of existing assets (such as the mains removal of London's Victorian pipes). However, there might need to be investment associated with more extensive water supply networks and new water sources (e.g. desalination and reservoirs).

Interdependencies

There are many interconnections between the infrastructure components within and between the three sectors and with the ICT sector. Where these interconnections are associated with the supply or receipt of a service on which the receiving sector is reliant and an impact on this supply could be critical, these have been termed 'interdependencies'.

The study identifies two specific types of interdependencies which could have far greater impacts on our infrastructure functionality than individual failures:

Cascade failures referring to a series of linked impacts or failures.

Regional convergences regional concentrations of infrastructure, which, if impacted by an extreme weather event, could have consequences on functionality at a national scale in one or more of the three sectors.

Further discussion on these and the technical issues from long-term climate change is in Section 6.

Section 3
Study methodology

Study methodology

The study methodology comprised a four-stage approach of project planning, information assimilation (literature review and stakeholder engagement activities), analysis, assessment and reporting. The following sections outline the key elements of the study.

Project planning

Infrastructure in each sector examined

The type of infrastructure considered for each of the three sectors, energy, transport and water, is shown in Table 1. This list was agreed in consultation with the project steering group. Assessment of the infrastructure against climate change impacts included consideration of operational activities, processes, systems and supply chains.

Table 1: Types of infrastructure examined

Energy	Transport	Water
Fuel Processing Facilities, Storage and Transport of Fuel *Fuel Processing Facilities* Refineries / biomass processing / coal handling *Storage of Fuel* Oil and gas storage *Transport of Fuel* Gas and oil pipelines **Power Generation, Pollution Control and Abatement** *Power Generation* Fossil, nuclear and renewable – wind; photovoltaics; solar; biomass; wave and tidal *Pollution control & abatement* Carbon capture including cooling water, wastewater treatment, and stacks / precipitators / Flue gas desulphurisation (FGD) **Energy Distribution** *Energy Distribution Systems* Substations, transmission lines – overhead and underground, pylons and storage e.g. for hydro and fuel cell *Energy flow management* Computer systems & ICT networks	**Road** Strategic road network Service stations Vehicles (Cars, lorries, buses) New technology – electric vehicles/charging points Communications systems including those that regulate traffic **Rail** Over-ground /high speed rail/Channel tunnel Underground rail, tramways / light rail Stations & trains – passenger / freight Freight terminals / interchanges Communications and power systems **Ports** Dock facilities, ships, ferries Communications systems **Airports** Aircraft, terminal buildings, runways, communications systems	**Water Supply, Treatment & Distribution** *Water Resources* Storage reservoirs, aqueducts and aquifers, boreholes/ source pumping stations, raw water supply pipelines, intake pumping stations *Water Treatment* Treatment works: service reservoirs & water towers, treated water pipelines & pumping stations *Water Network* Distribution networks, distribution pumping stations & storage **Wastewater Collection, Treatment & Disposal** *Wastewater Networks* Sewer networks including trunk sewers, pumping stations & rising mains, combined sewer overflows (CSO) & other overflows *Wastewater Treatment* Pumping stations, treatment works & outfalls *Sludge Disposal* Sludge treatment (including CHP & incineration) Sludge disposal or recycling

Key technical assumptions

Climate change assumptions

UKCP09 is based on probabilistic climate change projections for a number of climate variables, averaged over seven overlapping 30-year time periods across different geographical areas (e.g. 25 km resolution, administrative regions and river basins). For this project, UK figures from the central estimate for the medium emissions scenario have been used. Similar projections are also given for a smaller number of variables averaged over marine regions around the UK.

Due to the project's timetable and budget a number of assumptions were applied with regard to UKCP09 (see Box 4). Data extracted from UKCP09 applying these assumptions is shown in Table 2.

Box 4
Climate change assumptions[21]

Time Period: the study uses data for the 2030s (2020-2049), 2050s (2040-2069) and 2080s (2070-2099)

Emissions scenarios: the study uses the medium emissions scenario in UKCP09

Probability: the study extracts data for UKCP09 from three different probability levels: 10%, 50% and 90%. This approach enables both lower and higher limits in terms of probability to be considered alongside the central estimate.

Temporal averaging: the study uses the winter and summer average, as well as key seasonal extremes e.g. precipitation on the wettest day in the winter and warmest day in the summer.

Geographical locations: the study uses data that represents the highest and lowest regional change in the UK. Absolute sea level projections have been extracted from UKCP09 (see discussion below) and indicate future changes in the mean level of seas around the UK as a whole.

Wind/storm intensity: as the available wind data projections are inconsistent and UKCP09 does not include models for the UK, we have identified where wind strength, direction and storm intensity are a significant potential concern but the lack of meaningful data has limited the extent of evaluation.

[21] The UKCP09 data with respect to changes in temperature, precipitation and sea level rise have been used to qualitatively assess the risk associated with the infrastructure in the three different sectors. Derived/ secondary data on peak flood flows or future low flows have not been considered in this assessment.

Table 2: UK Climate Projections, highest and lowest change in the UK for selected climatic variables (central estimate, assuming medium emissions scenario)[22]

	Time Period	Specific variable	Projected change compared to a baseline period 1961-1990 (lowest – highest change in the UK)
Temperature	2030s (2020 - 2049)	Mean winter	1.0 - 2.0℃
		Mean summer	1.0 - 3.0℃
		Mean daily minimum winter	1.0 - 2.0℃
		Mean daily maximum summer	1.0 - 3.0℃
		Warmest day in summer	0 - 4.0℃
	2050s (2040 - 2069)	Mean winter	1.0 - 3.0℃
		Mean summer	1.0 - 3.0℃
		Mean daily minimum winter	1.0 - 3.0℃
		Mean daily maximum summer	1.0 - 3.0℃
		Warmest day in summer	0 - 4.0℃
	2080s (2070 - 2099)	Mean winter	1.8 - 3.1℃
		Mean summer	2.5 - 4.2˚C
		Mean daily minimum winter	2.1 - 3.5 ℃
		Mean daily maximum summer	2.8 - 5.4 ℃
		Warmest day in summer	2.0 - 6.0 ℃
Precipitation	2030s (2020 - 2049)	Mean winter	(-10%) - (+20%)
		Mean summer	(0%) - (-20%)
		Wettest day of the winter	(-10%) - (+20%)
	2050s (2040 - 2069)	Mean winter	(-10%) - (+30%)
		Mean summer	(-20%) - (0%)
		Wettest day of the winter	(-10%) - (+20%)
	2080s (2070 - 2099)	Mean winter	(-2%) -(+ 33%)
		Mean summer	(-40%) -(+1%)
		Wettest day of the winter	(0%) - (+25%)
Sea Level Rise	2030s (2020 - 2049)	Absolute Sea Level Rise	0.076 - 0.171 meters
	2050s (2040 - 2069)	Absolute Sea Level Rise	0.139 - 0.25 meters
	2080s (2070 - 2099)	Absolute Sea Level Rise	0.255 - 0.394 meters

[22] All data except 2080s temperature and precipitation projections, has been estimated based on the UKCP09 maps for the UK. : http://ukcp09.defra.gov.uk/content/view/16/6/. 2080s temperature and precipitation data has been extracted directly from UKCP09 Science report.

Socio-economic assumptions

Given the time period that this study is considering, reference to the predicted changes in population is required to consider potential future impacts on demand and supply elements. Population projection estimates as published by the Office of National Statistics (ONS) Population Estimates Unit, which extend to 2083, have been used in this study. Population changes against a 2009 baseline with ranges have been generated for each of the three periods covered by the study (with the 2080s only covering 2070 to 2083).

Table 3: Population assumptions – upper and lower estimates[23], [24]

Year	Total UK Population		Percentage change from 2009	
	Lower	Upper	Lower	Upper
2020-2051	66,522,000	77,073,000	7.65%	24.73%
2041-2071	74,165,000	82,341,000	20.02%	33.25%
2071-2083	82,341,000	85,684,000	33.25%	38.66%

Forecasts of housing growth have also been considered as part of the estimation of future demands for water and energy. Forecasts of housing statistics are available only to 2031 through the ONS and the Department of Communities and Local Government (DCLG). In the absence of longer term projections it has been assumed that the correlation between housing growth and population change (from 2009 to 2031) will be maintained for the period of 2031 onwards.

Table 4: Household assumptions[25], [26]

Year	Number of households		Percentage change from 2009	
	Lower	Upper	Lower	Upper
2020-2051	25,028,000	31,886,672	12.46%	43.27%
2041-2071	29,951,160	35,392,957	34.58%	59.03%
2071-2083	35,392,957	37,617,997	59.03%	69.02%

Forecasts of future transport levels (including road, air, rail and maritime traffic) are available through the Department for Transport (DfT) up to 2030. As we anticipate some considerable change in transport behaviours over the study period, we have applied the same method for extrapolation to that used for the housing data to generate estimates for the first and last years in the date ranges (i.e. 2020 and 2051 etc). The first and last years in each of the date ranges are referred to as ‘lower’ and ‘upper’ in the following tables (i.e. lower = 2020, 2041 and 2071 and upper = 2051, 2071 and 2083).

[23] Office of National Statistics 2008-based National Population Projections 21 October 2009
[24] Data is only provided by ONS till 2083.
[25] Communities and Local Government, Household projections to 2031, England.: http://www.communities.gov.uk/publications/corporate/statistics/2031households0309.
[26] These projections have been extrapolated based on population growth. Population projections only extend to 2083.

When considering the transport assumptions, it should be noted that there are many other factors that should be taken into account when projecting growth in the transport sector. These include household income and economic growth; age of population, price of fuel; planning and regulations. Accurate projections on these variables are not available, hence for these purposes only population growth has been factored into the extrapolation.

Table 5: Transport assumptions – road[27]

Year	Percentage change from 2009	
	Lower	Upper
2020-2051	8%	25%
2041-2071	20%	33%
2071-2083	33%	39%

Table 6: Transport assumptions – air (constrained growth)[28]

Year	Percentage change from 2009	
	Lower	Upper
2020-2051	38%	156%
2041-2071	112%	211%
2071-2083	211%	251%

Table 7: Transport assumptions – rail[29]

Year	Percentage change from 2009	
	Lower	Upper
2020-2051	14%	47%
2041-2071	38%	63%
2071-2083	63%	73%

[27] According to DfT Road Transport Forecasts for vehicle kms up to 2025; road transport approximately follows the same trend as population growth projections.

[28] Projections have been extrapolated based on population growth and projection data published by the DfT: Air passenger demand and CO2 forecasts 2009, central estimate for constrained demand. This accounts for airport capacity constraints under the central s12s2 scenario (i.e. extra runway at Stansted in 2015 and at Heathrow in 2020).

[29] According to DfT The future of Transport: Modelling Analysis rail passenger km growth is expected to increase annually by around 1.3% between 2010 and 2025. Extrapolation for rail transport is based on this figure and population projections.

Stakeholder engagement and information review

In gathering information and evidence for this study, a range of information sources have been used. These include:

- A literature review.
- Consultation within the three infrastructure sectors and consultation with URS experts both in the UK and abroad.
- Stakeholder consultation focused on engaging technical professionals with close to 100 individuals contacted. The consultation process followed a systematic set of questions designed to explore understanding of climate change projections, impact on their organisation (including the infrastructure) and current business practices for assessing the significance of impacts and planning adaptation actions.
- The organisations contacted as part of the study are identified in Box 2 with the specific questions posed during the process in Appendix B.
- In addition, a cross sector workshop was held on 4 November 2009 bringing together industry, Government representatives and URS to discuss the project. The workshop presented an opportunity to test findings emerging from the study and get views on barriers and possible options for overcoming these. The workshop report is at Appendix E.

Analysis and assessment

The analysis and assessment process used comprised a staged process which is described in more detail in the relevant sections of this report but can be summarised as follows:

- Assessing the vulnerability of infrastructure to the predicted change associated with the climate variables in the three time periods of 2030s, 2050s and 2080s;
- Evaluating the nature and significance of the key technical risks associated with high vulnerability; and
- Identifying possible responses or interventions and evaluating the likely net benefits of these and the barriers for their implementation.

A systematic review of the identified responses and barriers enabled the identification of a series of cross sector actions which will, if implemented, support long-term adaptation.

Appendix C contains the detailed outputs of the assessment and analysis which is then summarised in later sections of this report.

Section 4

Findings from stakeholder engagement

Findings from stakeholder engagement

The consultation process covered a range of stakeholders including owners and operators of infrastructure assets, contractors, research institutions, policy makers and regulators. (Box 2 contains a list of the organisations consulted and Appendix B the questions asked).

There is an increasing awareness of the need to adapt to for climate change within each of the three sectors. However, it was clear that this awareness has generally not to date led to concerted and focused action for adaptation, with climate change mitigation taking a higher priority. This is not unexpected as much of the focus on policy and financial incentives for action on climate change to date has been around carbon reduction and energy efficiency actions. In addition, the cost savings that can be realised through energy efficiency measures and through, for example, the EU Emissions Trading Scheme, enable the case for return on investment to be readily made.

Where adaptation actions are being implemented, these generally focus on short-term climate change impacts or civil contingency work rather than the longer time periods which are the focus of this study. In addition, the majority of actions are focused on risks from extreme weather events such as flooding and storms rather than the incremental change, for example in temperature, that are also projected. This is also not unexpected as there is already clear evidence of the economic impacts associated with the extreme weather events that we have experienced in the UK.

Whilst the majority of the focus across the sectors has been on planning for extreme events in the short term, this does not mean that longer term assessments have been neglected. For instance, water companies are required to make Water Resources Management Plans with a 25 year projection and for those companies interviewed these plans have considered the impacts of climate change. The Environment Agency has published guidance for the development of these Water Resources Management Plans, with section 8 specifically covering climate change and greenhouse gas impacts.[30] In addition, asset owners in the road and rail sectors have also conducted assessments of longer term climate change impacts due to the predicted and design life of new and existing structures such as bridges. For example, much of the infrastructure in the rail network is over 75 years old and is currently anticipated to be in use for a further 100 years, whilst the design life of road bridges is 120 years.

Box 5 identifies examples of adaptation action already underway.

Box 5
Examples of some adaptation actions already underway

Flood risk and coastal erosion

- Government has more than doubled spending on flood and coastal erosion risk management in real terms since 1997, reaching a total of £2.15 billion over the three years

[30] Water resources planning guidance, November 2008, Environment Agency (http://publications.environment-agency.gov.uk/pdf/GEHO1208BPDC-E-E.pdf)

Box 5
Examples of some adaptation actions already underway

of this Spending Review (to 2011).

- The Environment Agency has published a long-term investment strategy looking at flood and coastal erosion risk management over the next 25 years using UKCP09.
- The Environment Agency has published the Thames Estuary 2100 Project for consultation; which aims to develop a tidal flood risk management plan for the Thames Estuary through to the end of this century based on the latest climate change projections and potential future sea level rise.
- Defra and the Environment Agency, working with the Centre for Ecology and Hydrology, are looking at the relationship between catchment characteristics and climate change impacts on peak flows for 155 river catchments. The UK Climate Projections will help Defra and the Environment Agency to identify which river catchments are most vulnerable to the future river flooding we anticipate from a changing climate, allowing decisions to be made about where additional work will be required.

Energy & flood risk

The utility companies have:

- Carried out a major review of substation resilience to flooding and development of investment plans for the economic regulator (Ofgem) to consider during the companies' current price review; and
- Purchased relocateable flood defence barriers, improved business continuity planning and constructed new substations designed to sit above the level of potential flood waters.

Transport

New road surface specifications, similar to those applied in the south of France, have been introduced and improved drainage standards for new works and renewals are also being implemented. These will improve drainage allowing for increases in rainfall intensity of 20% – 30%, and will mean a road network that is more resilient in the face of climate change

Droughts & water supply

Government has:

- Placed a requirement on water companies to explicitly consider the impacts of climate change on supply and demand in their 25-year water resources management plans;
- Placed a requirement on water companies to prepare, consult upon and maintain plans for the impacts of drought.
- Published Future Water a water strategy for England; which sets out the Government's long-term plans for water including how the sector should adapt to a changing climate through increased metering and a much greater emphasis on water efficiency.

There was clear feedback from interviews across all three sectors that there is a reluctance to plan for the long term (50-80 years) due to the perceived uncertainty associated with the impacts of climate change.

Although UKCP09 is widely known, some companies are still finding it difficult to take on board its range of probabilities and uncertainties and to apply the projections to their own specific operations. In addition, there are only very few instances where trigger points for impacts being observed.

One of the key points raised during the consultation was that often companies' interpretation of UKCP09 is too simplistic. Rather than using a multi-variable approach, investment decisions are based on headline figures from the report. In many cases, the lack of consideration of long-term impacts of climate change in relevant regulatory frameworks means that businesses find it difficult to justify the financial investment considering the uncertainty and possible long payback periods.

Section 5

Vulnerability of infrastructure to climate change in the energy, transport and water sectors

Introduction

This section focuses on the assessment of infrastructure vulnerability to predicted climate change and the evaluation of key technical risks. Section 8 sets out suggested adaptation measures to address these risks.

For each sector an assessment has been made of how the predicted changes in certain climate variables could impact infrastructure, using a graded *classification* system ranging from low to high impact.

To maximise consistency of the assessments across the three sectors, definitions of low, medium and high impact were developed using the following criteria and the matrix shown below:

- Impact on infrastructure functionality; and,
- The likely geographical or spatial scale of the impact (i.e. local, regional or national).

Impact on infrastructure functionality		Spatial Impact		
		Local	**Regional**	**National**
	No loss of functionality	**LOW**	**LOW**	**LOW**
	Short term or minor disruption to service	**MEDIUM**	**MEDIUM**	**HIGH**
	Severe impact or disruption to service/ failure of infrastructure	**MEDIUM**	**HIGH**	**HIGH**

Low - Do not anticipate any loss of function of the infrastructure – i.e. no impact expected that will disrupt functionality.

Medium – An impact is expected but is only expected to be associated with a disruption of service for a short period on a local basis. OR, where we believe there will be an impact but there are certain uncertainties that require additional work to be done.

High – There is a risk of significant impact either at a national scale or that could cause severe disruption or failure to the functionality of the infrastructure.

The application of this classification in the impact assessment has enabled the infrastructure that is most vulnerable to be identified. The outcomes of the assessments across the three sectors are shown in Figures 2-4.

By considering the significance of these impacts with reference to UKCP09 in the 2030s, 2050s and 2080s, the outcomes suggest how vulnerability may change over time. In many cases, data is not available to identify specific thresholds for when these impacts will be observed. It has not been possible to undertake threshold analysis as part of this analysis due to the gaps in knowledge and data within the sectors. Further work is required in this area to investigate critical tipping points for infrastructure.

The assessment is therefore based on URS' judgement, reflecting the views of stakeholders consulted; it should be considered to be indicative rather than absolute. As increased technical information and knowledge is gained, additional benefit might be gained from reviewing how vulnerability changes over time.

Following identification of potential vulnerabilities of infrastructure to climate change, priority technical risks have been identified which have been subject to further evaluation. The technical risks have been identified from the vulnerabilities by considering:

- Issues raised during discussions with stakeholders;
- Risks identified in existing literature and sector specific reports; and,
- Professional understanding and experience of the URS team sector leads in the individual sectors.

Each technical risk has been considered in detail using a series of criteria. The extent of knowledge and information available for these criteria within and across the sectors has varied; which has limited the consistency of our assessment and discussions. The criteria considered are:

- What is the technical issue and associated operational implications?
- How quickly could the impact be resolved (i.e. speed of recovery)?
- What are the effects of future socioeconomic scenarios?
- How does the likely timeframe for the issue compare with the typical design life of the infrastructure? And therefore what are the possible target dates for intervention?
- How widely might the impact be felt?
- Will the impact result in service failure or disruption?

The outcomes of this detailed assessment is presented in Appendix C and summarised in this section. Finally we have considered whether there could be indirect impacts for other elements of infrastructure (in the three sectors) and for associated ICT. This is detailed in Section 6.

Energy

Introduction

Infrastructure in the energy sector is vulnerable to increases in precipitation, wind intensity and frequency of storms on energy generating infrastructure and its operation, as well as the potential impacts of increases in temperature and precipitation intensity on substations and key energy users. These are likely to become significant by the 2050s.

Energy infrastructure operators generally have a pragmatic response to vulnerability and risk. Whilst it is apparent that energy infrastructure is vulnerable to climate change, it is felt that the infrastructure has a significant degree of resilience to change and that technically, it is entirely feasible to deal with adaptation issues over short, medium and long-term periods. This is already occurring for adaptation to extreme weather such as flooding and infrastructure location Energy infrastructure maintains output in a variety of different climates such as those that will be experienced in the UK. This experience can be readily transferred and, as many of the UK operators have international operations, this is already occurring, for instance in our approach to design for carbon capture and storage infrastructure.

Generally all areas of energy infrastructure need to respond to climate impacts on the infrastructure by the 2080s. Pressing issues are identified as: transformer thresholds being exceeded; coastal infrastructure at risk and generation efficiencies being affected. In most instances energy transportation and distribution systems will require reinforcement, in some instances, retrofitted cooling approaches, but not a complete overhaul.

In addition, the climate change is expected to alter the pattern of energy demand. For instance, climate change mitigation measures such as electric vehicles and heat pumps may result in increased electricity demand. Projected increases in summer temperatures may also result in increased use of air conditioning. To enable the sector to meet these changing demands for energy use, access to new climate and weather predictions and demand information will be important.

The energy sector infrastructure has been divided into fuel processing, storage and supply, power generation and energy distribution systems. The specific vulnerabilities and associated impacts have been summarised against each of these infrastructure elements.

The outcome of the vulnerability assessment for energy infrastructure is shown in Figure 2.

Figure 2:

Energy vulnerability matrix (precipitation and temperature)

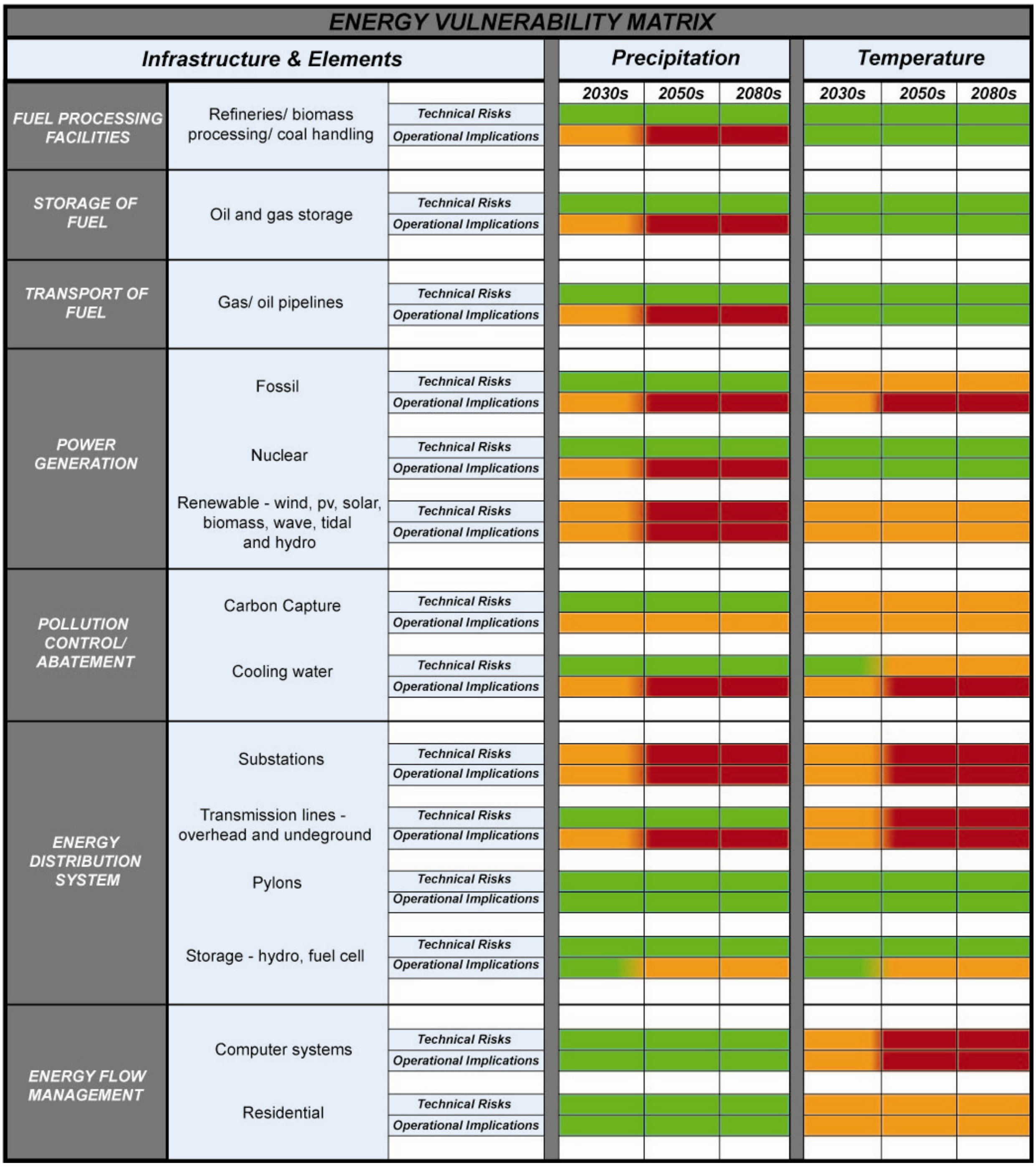
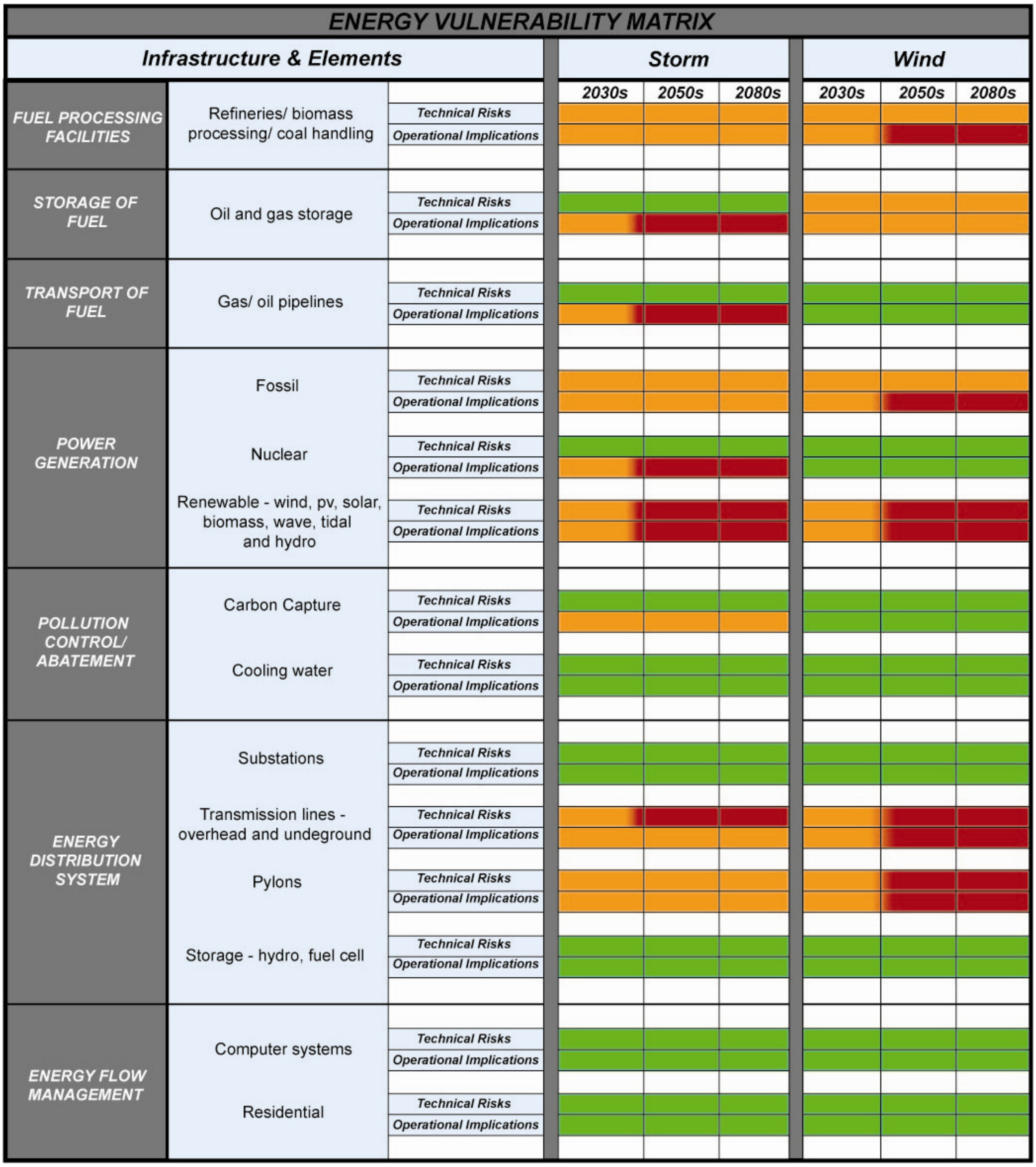


Figure 2 (cont)

Energy vulnerability matrix (storm and wind)



Fuel processing facilities/ storage of fuel/ transport of fuel

Vulnerability of infrastructure to climate change

Changing precipitation patterns (including sea level rise)

These aspects of the energy infrastructure, which include gas oil and oil storage and associated refining and port side activity, coast oil and gas landings and onward transport to generators, rely predominantly on imports. They are vulnerable to increased precipitation and flood as these could affect delivery of goods; coastal and pluvial flooding can disable infrastructure. In addition, the overland infrastructure associated with these elements (e.g. oil and gas pipelines) may be vulnerable to flooding and potential subsidence.

Increased temperatures

Whilst considered to be less significant than the other climate variables, increased temperature may cause increased evaporative losses and pressure increases which might require stronger storage and pipework specifications. More research and assessment is required in this area to confirm the significance of impact.

Increased storminess and wind

These aspects of the energy infrastructure are vulnerable to increased sea storms affecting delivery of goods. Storm winds could affect containment of material on the portside. Coastal and pluvial floods, a consequence of storms, can disable infrastructure.

Key technical risks

The key technical risk for the fuel supply infrastructure that has been identified is potential for flooding from increased storminess, sea level rise and storm surges.

Flooding of fuel supply infrastructure due to increased storminess, sea level rise and storm surges

Extreme events and, to a lesser extent, gradual sea level rise may cause severe disruptions to fuel supply infrastructure due to flooding of internal docking facilities as a result of floods from storm and sea surges.

This will affect operation of the infrastructure in many ways such as:

- Potential delays in fuel deliveries due to damage to supply infrastructure;
- Re-routing of fuel deliveries to other ports with changes in overland routes; and
- In extreme situations, suspension of services for long periods of time.

The frequency and duration of extreme storm events determine the significance of this issue. The risk of fuel supply disruption increases as sea storm intensity and duration increases. The significance of risk also varies depending on the nature of the import fuel:

- For coal supply this is a lower risk as some alternative supplies exist in the UK.
- For gas deliveries and biomass imports risk increases as these are vulnerable if the duration of events that disrupt landings increases.

Over the short-term (up to 2050s) it is likely that increased storm events may delay deliveries or require re-routing to other ports. Over the longer-term (2050s+) there is a risk to portside facilities being overwhelmed by sea level rise and storm surge. Assessment considering either low or high emissions scenarios compared to the medium emissions scenario that formed the focus for this study suggests that the risks will still be experienced but be delayed or accelerated.

It is expected that by the 2030s significant areas of sea defences will need to be realigned or enhanced. In the long term, combined increases in sea level and storm surges could result in sea levels beyond that which infrastructure can be readily defended. Ports in the east of England are considered to be most vulnerable. Possible resource constraints may leave some coastal areas to sea level rise encroachment, e.g. the gas landing location at Easington is already considered highly vulnerable to flooding and has few defence structures.

The impact of this risk is likely to be felt regionally at any one point in time but potentially flooding of infrastructure for import of energy (e.g. port facilities) could have a national impact with the potential to cause a major disruption. The lack of fuel supply would affect all sectors and the impact is likely to be felt nationally, but only expected to cause a minor disruption as supply should be resumed after the storm event.

Power generation (fossil, nuclear and renewable), pollution control and abatement

Vulnerability of infrastructure to climate change

Changes in precipitation (including sea level rise)

Changes in precipitation patterns, particularly increased intensity, are expected to result in more frequent flood events. Already fossil fuel plants such as Thorpe Marsh have been threatened by pluvial flood in recent years while coastal plants such as Longannet and Cockenzie are located on the coast and are vulnerable to sea level rise and storm surge.

Current and planned nuclear generation capacity is also located mainly at low level and near to the coast. Nuclear plants therefore are vulnerable to coastal erosion, storm surge and flood and pluvial flood.

Continued access to a sufficient water supply may become an issue due to changes in rainfall patterns affecting the availability of water. This is of prime concern for inland generation plants as coastal facilities utilise seawater, cooling requirements should still be able to be met with this resource.

Changes in rainfall intensity have the potential to affect hydro generation particularly where decreased summer rain affects levels in watercourses, as these plants require constant water flows. This will be particularly important for local micro-hydro schemes which tend to have only small water take off areas and limited storage capacity.

New pollution control equipment such as carbon capture and storage will primarily be located adjacent to fossil fuel infrastructure and will therefore be vulnerable to flood, sea level rise and storm surge. Overland pipelines will suffer potential vulnerability to subsidence and flood events that occur as a result of increases in rainfall intensity.

Increased temperatures

Generation efficiencies reduce as ambient air temperatures increase. Increased temperatures will affect air density and therefore lower mass flow during combustion. This presents a difficult technical issue to resolve; in most operating environments, external air temperatures are a fact of life affecting efficiency.

Additionally, the provision of adequate cooling will be affected by increased temperatures. As temperatures increase, stations will be presented with the challenge of reducing cooling water temperature before discharge, or providing increased dry cooling. This may present technical opportunities for recovery of energy from the wet cooling system for district heating or recycling.

Continued access to a sufficient water supply may become an issue due to changes in rainfall patterns (exacerbated by increased temperatures) affecting the availability of water. This is of prime concern for inland generation plants as coastal facilities utilise seawater, cooling requirements should still be able to be met with this resource.

Increased summer temperatures may also cause an increase in use of air conditioning equipment with a subsequent increase in electricity demand.

Increased storminess and wind

Increased variability in weather may also result in decreased generation capability right across the renewable energy sector. Wind turbines are vulnerable to high wind damage; (e.g. undermining the foundations and causing subsidence).

Generation of wind-sourced energy is also vulnerable if average wind speeds drop, however, there is significant uncertainty with future wind speeds. The potential for this to be a significant technical risk will require assessment as the climate predictions for wind become more certain.

Generation of electricity and heat from solar sources is vulnerable to increased cloud cover associated with increased rainfall. Increased sea storm intensity may place tidal and wave generation vulnerable to damage.

Long periods of intense, extreme weather activity may place fossil fuel generation vulnerable to fuel shortage, due to impacts for deliveries.

Key technical risks

The key technical risks for power generation infrastructure that have been identified are:

- Flooding of fossil fuel and nuclear power plants due to changes in precipitation and sea level rise
- Loss of efficiency of fossil fuel power plants due to increased temperatures
- Loss of efficiency of, and storm damage to, renewable energy sources due to increased storminess.

Flooding of fossil fuel and nuclear power plants due to increased precipitation and sea level rise

Nuclear and fossil fuel power station sites are already at risk from flooding which applies to both coastal and inland infrastructure.

Significant flooding of a generation site can be catastrophic. Immediate close down procedures and de-electrification would be required and recovery would be lengthy. In addition, for nuclear plant, key safety measures will still require power, therefore, power must be maintained through on site back-up facilities should the site be at risk of flooding.

The anticipated growth in new build and re-powering of sites in the energy sector over the next decades provides significant opportunities to address these issues in the design (and potentially site selection) phase. Given the 25 year plus timeframe for energy infrastructure, all new developments and re-powering activities need to undertake a full assessment of climatic impact on the specific site. In the redevelopment of each potential fossil fuel or nuclear plant, coastal erosion and management of pluvial flood waters will need to be taken into account. This should not only consider gradual change but also the likelihood of extreme events such as storm surge. This will require assessment of each site to climatic impacts and a long-term evaluation of likely extremes.

The impact of this risk is likely to be felt locally to regionally, unless a key region such as Yorkshire and Humber is affected which generates 17% of the UK's electricity generation capacity (see Humberside case study in Section 6).

In addition, as is generally recognised by industry and the UK government the capacity of the UK energy supply infrastructure is likely to be under pressure in the next 30 years due its age and increasing demand for energy; disruption of generation due to climate change events will further increase this. The potential significance of any loss of generation capacity would likely be dependent, at least in part, on the number of power stations affected, their generation capacity and additional spread load elsewhere in the UK.

Loss of efficiency of fossil fuel power plants due to increased temperatures

Temperature increases will decrease efficiency – particularly affecting combined cycle gas turbine plants. There could be reductions in thermal generation efficiency of fossil fuel power plants from the 2030s as a result of rising air temperatures. This would become more significant later in this century when coupled with extreme hot summer days. This presents a difficult technical issue to resolve; in most operating environments, external air temperatures are a fact of life affecting efficiency. According to a company specific risk assessment by a UK generator, an average temperature increase of 5^0C in summer would result in an estimated 0.34% decrease in efficiency (with a marginally lower efficiency decreased in the milder winters) of its combined cycle gas turbine fleet.

Increased operating temperatures also present a risk to stations requiring increased cooling options. With predicted fluctuations in rainfall patterns (i.e. less summer rainfall combined with hotter temperatures) affecting water supply, there will be an increasing risk, over time, of water resource problems, or a requirement to invest in dry cooling methods. Once affected generation may be disrupted until availability of water changes or dry cooling is retrofitted; this latter option is costly.

The capacity of the UK energy supply infrastructure is likely to be under pressure in the next 30 years; disruption of generation due to climate change events will further increase this. Incremental inefficiency in the system due to increasing temperatures will only cause disruption if the UK has not built enough capacity to cope with such and to cope with peaks in demand. The potential significance of any loss of generation capacity would likely be dependent, at least in part, on the number of power stations affected, their generation capacity and additional spread load elsewhere in the UK.

Loss of efficiency of, and storm damage to, renewable energy sources due to increased storminess

Climate change impacts present a number of significant technical risks across several renewable energy technology areas.

Changing wind (i.e. direction, velocity, turbidity, duration) will influence turbines and extreme events may cause damage, particularly to turbines. Design standards for wind turbines will need to be assessed to ensure they can cope with increased wind speeds, while existing wind turbines may require retrofitting to strengthen their foundations and increased protection against flooding/subsidence and wind strength.

Storm surge may require enhanced specifications for wave and tidal energy infrastructure. If existing designs cannot cope with increased wind speed then there will potentially be reduced availability of wind source energy.

Further enhancements will need to be made to photovoltaic and solar power generation to secure energy even on overcast or rainy days. If photovoltaic and solar efficiencies are reduced significantly because of increased cloud cover, then solar sourced energy availability will be reduced.

Information gaps in thresholds as well as the challenges of modelling future wind predictions has limited the assessment of this risk.

As climate change may impact on the availability of renewable energy affecting the grid, increased emphasis will need to be placed on balancing the grid, requiring optimisation technology, good modelling and monitoring data as well as good ICT connections across the country.

As renewable mix increases, it will be important to be able to model predicted supply changes as a result of the impacts of climate change.

The impact from this risk is likely to be felt locally to nationally. While it is likely to only cause a minor disruption on a national scale, it could in the future mean substantial disruption at a local level for any communities that develop decentralised energy systems supplied by renewable energy sources.

Energy distribution systems

Vulnerability of infrastructure to climate change

Changing precipitation patterns (including sea level rise)

Energy distribution systems are particularly vulnerable from extreme weather events (e.g. intense rainfall) that will damage key infrastructure such as the flooding of Neepsend substation near Sheffield in June 2007.

Increased temperatures

Increased temperature, combined with increased usage during summer months will lead to requirements for improvements to technical specifications for cabling, substations and transformers to enable effective cooling and provision of greater loads. In addition, increased temperature may cause some subsidence to underground cable channels, possibly exacerbated by decreased summer rainfall.

Increased storminess and wind

Overhead lines in the electricity transmission and distribution network are vulnerable to damage from windborne debris in periods of high winds. This can result in short circuits or in extreme cases can bring down the lines; either can cause significant disruption to services. The absence of reliable wind projections in UKCP09 does not allow evaluation of this issue but it is a potential technical risk which requires reviewing when improved forecasts become available. Options for adaptation could be associated with better management of trees in the vicinity of lines to reduce potential for windborne debris or engineering controls to increase spacing between conductors.

Key technical risks

The key technical risk for the energy distribution infrastructure that has been identified is reduced capacity of distribution network due to increased temperatures and precipitation.

Reduced capacity of distribution network due to increased temperatures and precipitation/storminess

Energy distribution systems are particularly at risk from:

- Increased temperatures that will place increasing pressure on capacity thresholds as customers increase their demand particularly in the summer; and
- Extreme weather events that could damage key infrastructure through flooding (e.g. Neepsend substation near Sheffield in June 2007) and failure of pylons and overhead cables.

Sub-stations located on the urban fringe due to the heat island effect are at greatest risk from temperature increases and are likely to bring some elements of the substation infrastructure to capacity thresholds. Increased loads for cooling/heating/transport associated with population forecasts will also draw distribution systems to threshold delivery capacity.

Major sub-stations are also vulnerable to flood; guidance and protection standards have recently been increased to address this advising on protection to increased potential flood depth and for increased flood frequency. Emergency procedures have also been improved, along with improved communications with local authorities and emergency response teams. It is technically possible to protect sub-stations from flooding and to re-energise key infrastructure rapidly after flood events.

The ability of major infrastructure (e.g. the distribution network) to cope with incremental increases in temperature is more difficult to rectify quickly, once thresholds of capacity and risk have been exceeded.

Capacity thresholds of distribution networks will be 100% overloaded in the 2080s and 65% overloaded in the 2020s at peak locations (e.g. southern England.) Action is required now with substantial re-siting and re-engineering required. The technical implications are well understood but the scale of the work will present challenges. Spatial and economic modelling for the development of city wide energy infrastructure is required to enable future socio-economic trends to be reflected as well. It is anticipated that reaching, and exceeding capacity of the electricity distribution network, will be felt alongside increased demands, for example from electric vehicles, heat pumps and increased use of air conditioning.

The impact is likely to be felt nationally and is likely to cause a loss of functionality and potential major disruption if these risks are not planned for.

Transport

Introduction

The transport sector comprises four sub-sectors, roads, rail, ports and air, with very different types and ages of infrastructure. The transport sector is vulnerable to the predicted increase in frequency and intensity of storms (wind, rain, snow). All transport operators consulted referred to recent incidents such as the floods in summer 2007, gales in January 2007 and snow in February 2009 when technical deficiencies caused significant disruption to services. Examples of technical deficiencies encountered included: inadequately sized drainage; and, poor planting design and maintenance of trees resulting in trees falling on lines.

Transport operators were less concerned by predicted gradual changes in, for example, temperature or levels of winter rainfall, and pointed to overseas experience where many solutions are available, for example temperature resilient road surfacing. It is apparent that where national guidance has already been introduced, for example in Planning Policy Statement 25 "Development and Flood Risk"[31], operators are more advanced in planning to adapt to climate change.

Roads

Vulnerability of infrastructure to climate change

The outcome of the vulnerability assessment for roads is shown in Figure 3a.

Changing precipitation patterns (including sea level rise)

Bridges across the road network are vulnerable to scouring from high river flows, as demonstrated by the recent flooding in Cumbria in November. Scouring of bridge foundations can lead to instability of the structure and in extreme cases, to failure and collapse (see Box 6). Higher and stronger river flows are predicted for winter months due to increased levels of rainfall, and so the vulnerability of bridges may increase. Severance of communities due to the failure of bridges on even local roads can lead to major disruption.

The road network is also vulnerable to surface water runoff from intense storms, as seen on the M5 in summer 2007 floods. The intensity of the rainfall can lead to such high rates of runoff that the road drainage system is overwhelmed and ponding results. As rainfall is predicted to increase in both frequency and intensity, so may the vulnerability of roads.

Road embankments are vulnerable to washaways or landslips from either surface water runoff or from overflowing streams or rivers, as the high flows can scour and destabilise the earthworks. With the predicted increase in precipitation, their vulnerability may increase. Such failures will lead to major disruption.

[31] Communities and Local Government, Planning Policy Statement 25: Development and Flood Risk, December 2005, http://communities.gov.uk/publications/planning and building/pps25floodrisk

Discussions with transport operators indicate that development times for new vehicles are about 10 years. With new technology, such as the 4x4 vehicles being used by the AA to rescue people trapped by floods or snow, being developed, it is considered that vehicles themselves will be resilient to the effects of climate change.

Box 6
Floods in Cumbria, November 2009

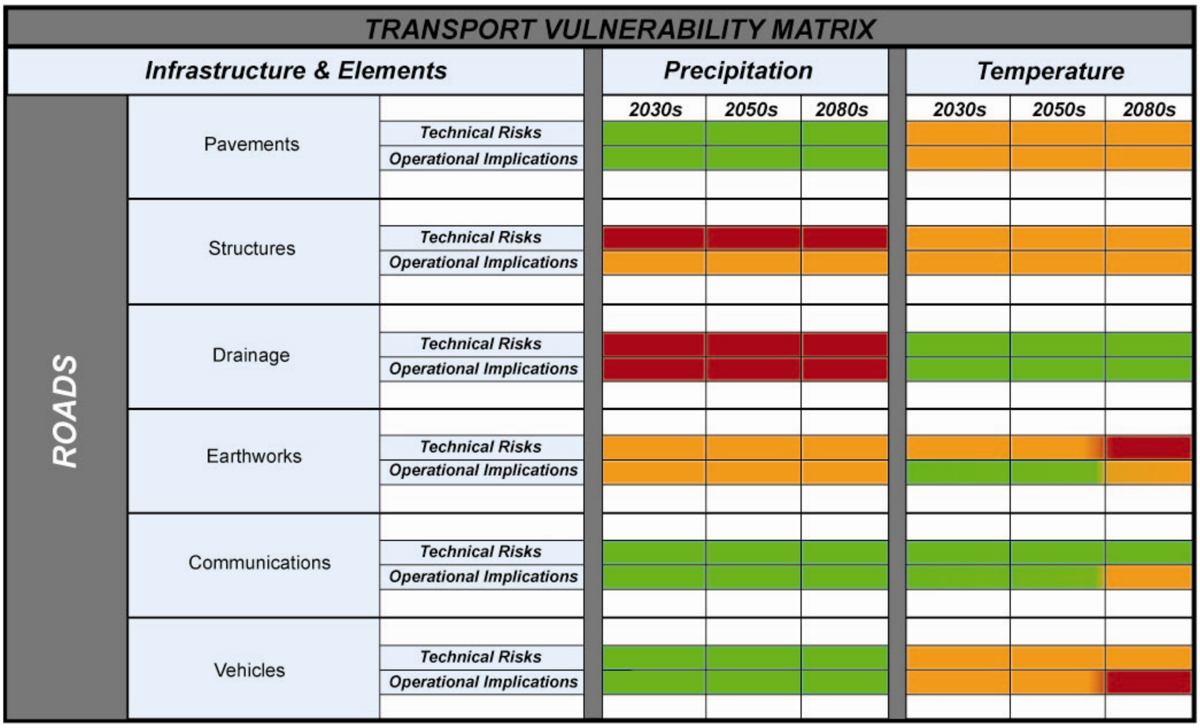
Heavy and prolonged rainfall between 17 and 19 November 2009 led to the collapse of several road bridges in Cumbria. Several rain gauges in the county measured over 100mm of rain within that period, with some recording two to three times that figure. The rainfall was due to a slow moving front which was the interface between warm air over England meeting colder air from the North Atlantic. The rainfall intensity was increased by the warm air being lifted as it encountered the Cumbrian fells. This is the sort of winter rainfall event that is predicted to occur more frequently with the effect of climate change.

The rain ran off the fells into rivers which burst their banks in several areas leading to widespread flooding. The strength of the river flow undermined the foundations of at least six masonry road bridges, which collapsed. Communities were severed, not only by transport, but also with services such as telecom, water, gas and electricity being carried over the bridges.

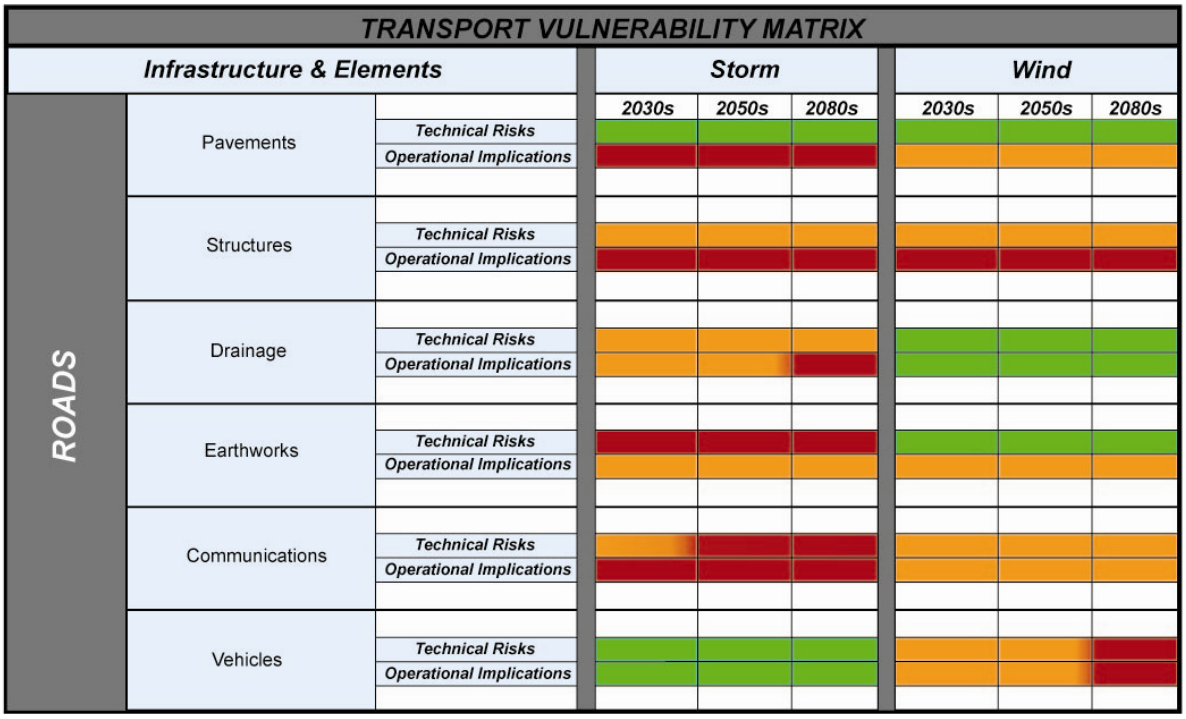
This event highlights the need for bridges over streams and roads to be inspected to ensure they are strong enough to withstand the flows predicted for the remaining life of those structures, taking account of the river flows resulting from the rainfall events likely to occur with climate change.

Figure 3a:

Road vulnerability matrix (precipitation and temperature)



Road vulnerability matrix (storm and wind)



Increased temperatures

Embankments made of clay and more than 30 years old are vulnerable to settlement, which can cause unevenness in the surface of the roads.[32] This is caused by swelling of the clay in wet winters and drying out in summer. This is a particular risk to embankments located around London, because many are built of clay and especially as this region may experience wetter winters and hotter and drier summers. Disruption from such events is typically limited to speed restrictions.

Road surfaces (pavements) are vulnerable to hot weather, as some types of asphalt can soften, causing roads to be closed. Concrete road surfaces can also fail due to the expansion joints closing, which in certain cases can cause the slabs of concrete to lift up, and the road to be closed. Although temperatures are predicted to increase, the design life of asphalt road surfaces is about 10 years, and new design standards and improving asphalt technology is likely to be able to allow adaptation. Concrete road surfaces are being phased out on major roads, and will be replaced by asphalt.

Road bridges longer than 60 metres (and older ones longer than 20 metres) are designed with expansion joints. With temperatures predicted to increase these joints may fail, as the expanding bridge decks could cause the joints to shrink beyond the design parameters. This could cause further damage to the bridge, usually resulting in road closure. It is however considered that the maximum temperature for which the bridges are designed to operate is greater than that predicted by climate change.

[32] Embankments less than 30 years old are typically designed with more gentle slopes or reinforced with geotextile or gabbons which increase resistance to failures

One of the most common causes of vehicle breakdown is overheating. Without adaptation this may become more frequent with the hotter predicted temperatures. Improved vehicle design will be required to allow for such warmer temperatures and given the continual design improvements of vehicles changes could be expected to match climate change impacts.

Increased storminess and wind

High sided road vehicles are vulnerable to high winds, especially when crossing the older estuarial bridges, such as the Humber. With the predicted increase in stormy weather, they may become more vulnerable.

One result of the predicted increase in stormy weather is the expected increase in storms with intense rainfall. The bridges, drainage systems and earthworks are therefore vulnerable to such weather in the same way that they are vulnerable to increased precipitation, as described above.

During stormy conditions there is heavy reliance on the need to use mobile telephones, due to the increased number of emergency personnel on duty. The Highways Agency reported that their maintenance operators experienced difficulty during the snowfall in January 2003. With the predicted increase in stormy conditions, highway operators – and other emergency personnel – may experience greater problems.

Key technical risks

The key technical risks for the road infrastructure that have been identified are:

- Flooding from increased precipitation and/or storminess; and
- Scour of bridges due to increased precipitation and/or storminess.

Flooding from increased precipitation and/or storminess

The majority of the road network was designed and built with drainage systems to cope with rainfall intensities and flood levels experienced in the 20th century. The predicted increase in winter rainfall, and in the frequency and severity of storms may lead to the risk that roads will flood more frequently, as the drainage system is overwhelmed. This is already being experienced and the risk is likely to increase throughout this century, leading to more frequent instances of roads being flooded or washed away.

If no action is taken to adapt, this risk may lead to significant disruption to services throughout the UK, increasing deployment of emergency personnel and unplanned and uneconomic remedial measures. Where roads carry statutory undertakers services, the operation of, and access to, these services may also be affected. Typically, once flood waters have receded, services can resume; however, disruptions to other associated services e.g. ICT may remain affected for longer.

The Highways Agency is aware of these risks, and is planning strategies to manage them. This will involve assessing the most vulnerable sites and prioritising the work needed to make them resilient. Typical actions may include developing sustainable drainage or, where this is not possible, improving the drainage capacity by introducing large drainage pipes and improving the drains which intercept runoff from adjacent land. This could be done over the next 20 to 30 years and would last for at least 60 years once completed. The Highways Agency has already reviewed the design codes that it uses for new infrastructure and considers that these are appropriate for the respective design life periods. This risk could occur in many locations in England, however, the impact is confined to specific regions rather than nationwide.

Scour of road bridges due to increased precipitation and/or storminess

Those bridges on the road network which are not founded on piles are most vulnerable to scour due to their foundations being undermined by the energy of the flooded river. Predicted increases in winter rainfall, and intense storms, may increase this risk. Bridges most at risk are those located on rivers receiving runoff from impermeable or steeply sloping terrain, such as in northern England, Devon and Cornwall. The events in Cumbria in November 2009 exemplified the existing problem, and showed how a failure can sever communities for months at a time. The problem will get worse without adaptation.

Bridge failures will lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities, often diverting resources from planned activities.

Adaptation should begin with an inspection and assessment of vulnerable bridges, leading to a prioritisation of remedial works where necessary. Remedial work may involve placing new scour prevention measures in the river to protect the structure, or in extreme cases (usually after a failure) building bridges with piled foundations, or higher crossings. As bridge design lives are 120 years, this work could take place over the next 30 to 40 years. The Highways Agency has already reviewed the design codes that it uses for new infrastructure and considers that these are appropriate for the respective design life periods.

Rail

Vulnerability of infrastructure to climate change

The outcomes of the vulnerability assessment for rail is shown in Figure 3b.

Changing precipitation patterns (including sea level rise)

The majority of the rail network was designed and built with drainage systems to cope with rainfall intensities and flood levels experienced in the 19th and 20th centuries. The predicted increase in winter rainfall, and in the frequency and severity of storms may lead to the risk that rail will flood more frequently, as the drainage system is overwhelmed. This is already being experienced and the risk may increase throughout the century. If no action is taken to adapt to the predicted changes, this risk may lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities. The risk from flooding is considered an issue for all infrastructure except overhead line equipment.

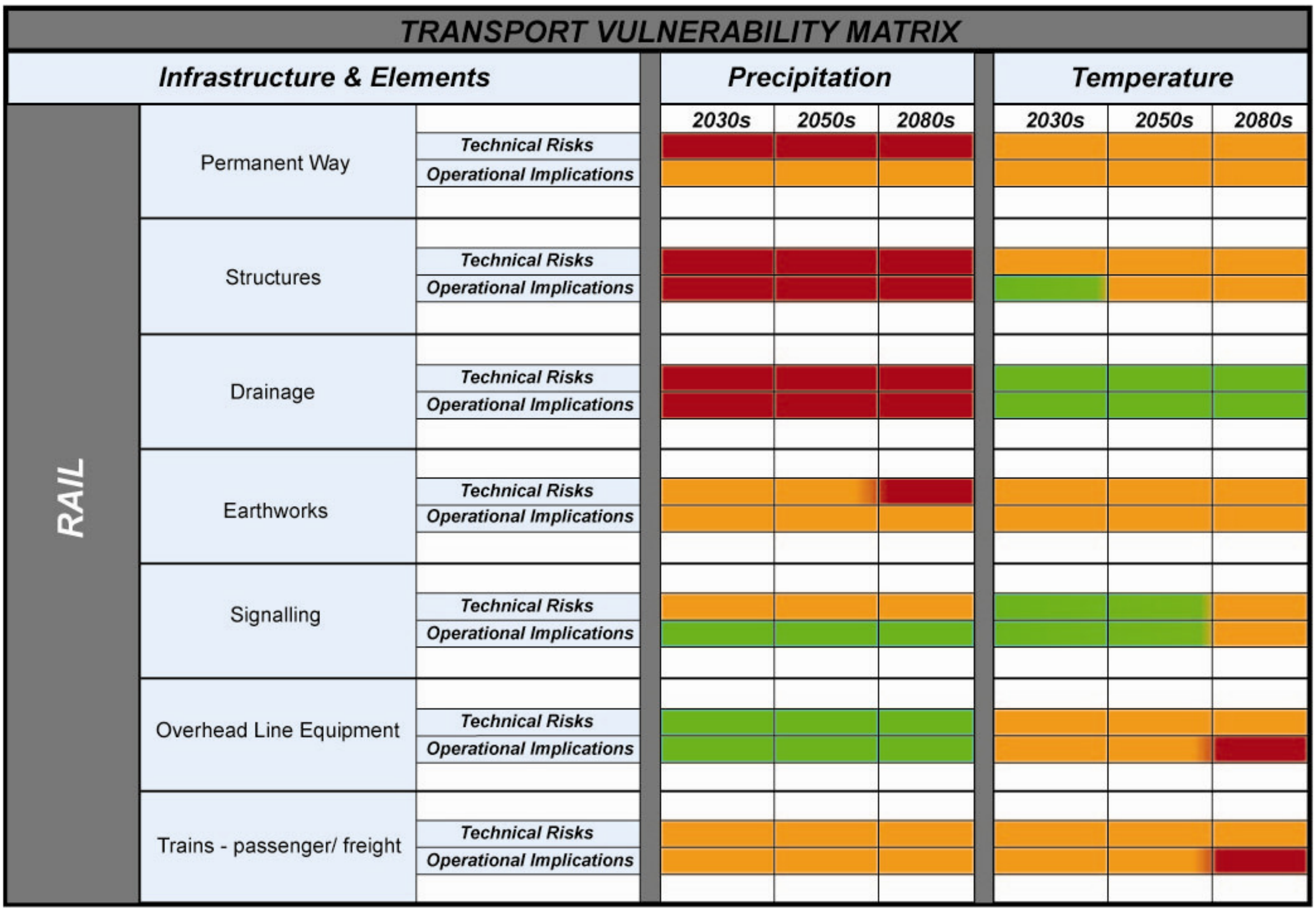
Coastal flooding presents a particular problem for some parts of the rail network, for example on the line south of Exeter and the Cumbrian lines. All these lines run adjacent to the coast and are close to sea level, they are therefore vulnerable to the predicted rises in sea level.

Increased temperatures

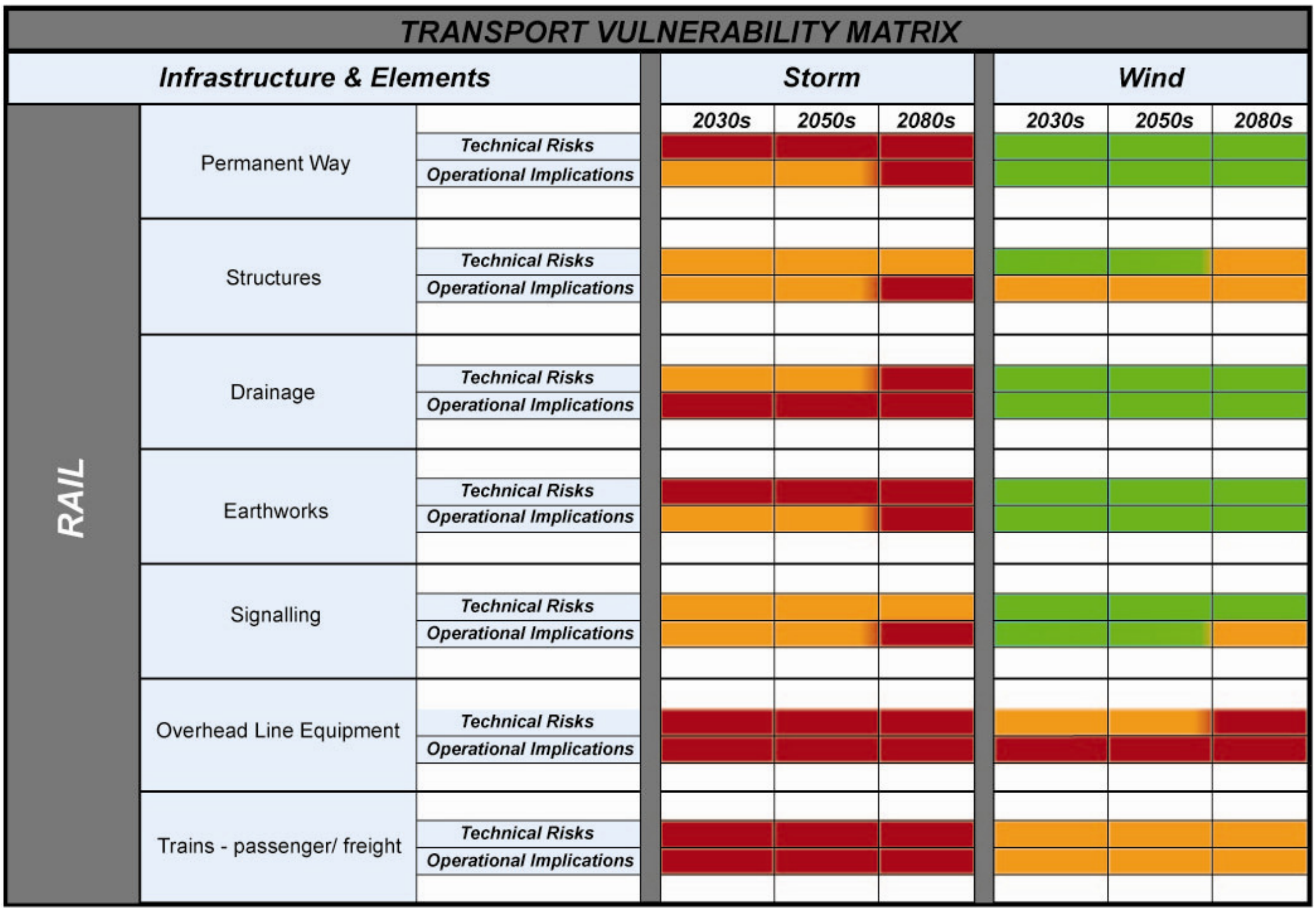
Underground trains, especially those operating in the "deeper" underground lines in London (e.g. Central and Bakerloo), are vulnerable to overheating in prolonged hot weather, as they currently have no inbuilt cooling systems, and rely on the cooling effect of the air in the tunnels. With temperatures predicted to increase, this vulnerability may increase, and without adaptation is likely to become a problem by the 2050s as users go elsewhere, or operators are forced for health reasons to reduce the frequency of service. In either case there would be a severe loss of service. Some impacts may also be felt in over-ground trains but this is considered to be of lower risk.

Figure 3b:

Rail vulnerability matrix (precipitation and temperature)



Rail vulnerability matrix (storm and wind)



Rails, sleepers and stone ballast (i.e. the permanent way) are vulnerable from high temperatures, as the rails may buckle. Although continuous welded rails are pre-stressed to a neutral temperature of 27°C (i.e. there is no stress in the rails at that temperature) to minimise the compressive stresses from high temperatures, buckling can still occur and may become more frequent with the predicted higher temperatures. The likely result would be line closures, or possibly derailment if the problem is not noticed before a train passes. It is considered that as rails are replaced every 10 – 15 years, technology will improve to adapt them to higher temperatures.

Embankments made of clay and more than 30 years old are also vulnerable to settlement, which can cause unevenness in the surface of the rail network. This is caused by swelling of the clay in wet winters and drying out in summer. There is a particular risk to embankments located around London, as they are mostly built of clay and especially as this region may experience wetter winters and hotter and drier summers.

Overhead Line Equipment (OLE) on some electrified lines, especially on the line from London to Norwich which was built without the usual tensioning system that allows for thermal expansion of the wires, is vulnerable to high temperatures, which can cause the line to break from increased stresses and result in significant disruption to services. The predicted increase in temperatures may increase this vulnerability. New overhead line equipment incorporating temperature resilient apparatus, which allows for expansion, should overcome this problem.

Increased storminess and wind

OLE on electrified lines, especially on the East Coast Main Line where they were built to a lower specification than on other lines, are vulnerable to high winds, which can bring down the lines and cause significant disruption to services. The predicted increase in storminess may increase this vulnerability.

Empty freight wagons can blow over in high winds, and rail services are cancelled if gusts of more than 80mph are forecast. This is partly to minimise passenger discomfort and also to reduce the risk of damage from falling trees and other debris. With the predicted increase in stormy weather, such occasions may become more frequent.

Key technical risks

The key technical risks for rail infrastructure that have been identified are:

- Flooding from increased precipitation and/or storminess;
- Scour of bridges due to increased precipitation and/or storminess;
- Moisture fluctuation in road embankments in south east England – due to wetter winters and drier summers; and
- Overheating of underground trains due to increased temperatures.

Flooding (from increased precipitation and/or storminess)

The majority of the rail network was designed and built with drainage systems to cope with rainfall intensities and flood levels experienced in the 19th and 20th centuries. The predicted increase in both winter rainfall, and in the frequency and severity of storms may lead to the risk that rail will flood more frequently, as the drainage system is overwhelmed. This is already being experienced and the risk may increase during the latter part of this century, leading to more frequent instances of elements of the permanent way being flooded or washed away, such as occurred in 2009 on the main line south of Aberdeen.

Rail services are cancelled if flood water rises more than 100mm above the tops of the rails. There have already been occurrences of rail re-routing due to flooding. Any rail closure or cancellation leads to disruption to service, and in major cases can last for more than a week. With the forecasted increase in the use of rail transport, such disruption could become a more significant problem.

If no action is taken to adapt to the predicted changes, this risk may lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities.

Network Rail is aware of these risks, and is planning strategies to manage them. This will involve assessing the most vulnerable sites and prioritising the work needed to make them resilient. Options should include developing sustainable drainage for all new developments and where opportunities for new drainage infrastructure arises or, where this is not possible, introducing large drainage pipes and improving the drains that intercept runoff from adjacent land. This could be done over the next 20 to 30 years and would last for at least 60 years once completed. The main barrier is perceived to be the process required to obtain funding now to carry out improvements which may only have a benefit in several years time. Lack of knowledge of some of the drainage network prevents a full analysis of the risk, and surveys will be needed to define what drainage exists and whether it is likely to carry the expected storm flows.

This is likely to primarily be a regional or local issue associated with the actual flood events. However, if a major national rail route is affected some disruption could be felt more widely.

Scour of bridges due to increased precipitation and/or storminess

Those bridges on the rail network, which are not founded on piles are most vulnerable to scour due to their foundations being undermined by the energy of the flooded river. Predicted increases in both winter rainfall, and to a lesser extent intense storms, may increase this risk.

Bridge failures will lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities, often diverting resources from planned activities.

Adaptation for existing infrastructure should begin with an inspection and assessment of vulnerable bridges, leading to a prioritisation of remedial works where necessary. Remedial work may involve placing new scour prevention measures in the river to protect the structure, or in extreme cases (usually after a failure) building bridges with piled foundations, or higher crossings. As bridge design lives are 120 years, this work could take place over the next 30 to 40 years. Design standards have been considered by Network Rail and are understood to be appropriate for the long-term.

Bridges most at risk are those located on rivers receiving runoff from impermeable or steeply sloping terrain, such as in northern England, Devon and Cornwall. This risk is therefore likely to primarily be a regional or local issue. However, if a major national rail route is affected some disruption could be felt more widely.

Moisture fluctuation in rail embankments in SE England – due to wetter winters and drier summers

Many of the railway lines emanating from London are built on embankments of London Clay. Most date from the 19th century and therefore were not built to modern standards. During wet weather they absorb moisture which softens the clay, leading to settlement of the rails. In hot dry summers, there is a tendency for the clay to shrink and crack, also leading to movement. Although the movement is slow, not leading to sudden failures, it does affect the alignment of the rail, often requiring extensive maintenance to ensure a reliable service. Settlement of the rails usually leads to speed restrictions being imposed, often for months at a time, while the problem is assessed and repaired. This can disrupt services and affect timetabling; with forecast increase in the use of rail transport the significance of this risk can only increase.

Embankments have design lives in excess of 60 years, so without adaptation, this is likely to become a significant problem by the 2050s and severe by the 2080s, taking ever more resources to manage the problem. Adaptation measures can be implemented by locally strengthening the embankments, as has been done already on some parts of the railway network. Design standards for new embankments need to reflect future conditions for their typical design and operational life.

As noted above, this risk is primarily a regional issue for the south east of England (and London). However, as many strategic rail route emanate from London; severe disruption on these could result in impacts that are felt more widely.

Overheating of underground trains due to increased temperatures

Underground railways, especially those in London which were built in the 19th and early 20th centuries without any method of cooling, are vulnerable to prolonged spells of hot weather which causes the trains to warm to uncomfortable temperatures. Such spells of hot weather are predicted to occur more frequently and at higher temperatures, leading to the risk of further high temperatures on trains. With the high emissions scenario this would be even more severe. The exact relationship between the outside air temperature, duration of a hot spell of weather, and its effect on the temperature in trains is not fully understood, and is currently being studied by Transport for London. Without new trains with inbuilt air conditioning it is considered that by the 2050s such episodes will be more frequent, leading to disruptions to an acceptable service. This is based on the medium emissions scenario and therefore delay or acceleration in this disruption could be expected with the low or high emissions scenarios. It is noted that some new trains with air conditioning are being introduced on the Metropolitan, Circle, Hammersmith & City and District lines. This issue is however more of a concern on the older and deeper lines such as the Central and Bakerloo.

The forecast increase in the use of the London Underground is likely to make the situation worse, as more trains may be running more frequently. Although the design life for underground structures is 120 years, in practice the layout of London Underground is unlikely to be significantly changed in the foreseeable future, so existing tunnels are likely to continue in service. Adaptation may be possible by introducing systems to cool the infrastructure at certain stations, but this too needs further research.

Ports

Vulnerability of infrastructure to climate change

The outcome of the vulnerability assessment for ports is shown in Figure 3c.

Changing precipitation patterns (including sea level rise)

Being located on the coast, ports are vulnerable to the predicted changes in sea level rise, which will render certain operations such as berthing, loading and unloading impossible at times of high tide, particularly when combined with storm surges which can cause locally raised sea levels, as docks will be under water.

Increased temperatures

Ports are not considered to be particularly vulnerable to increases in temperature. An advantage of being on the coast is that it is often cooler than the hinterland on hot summer days.

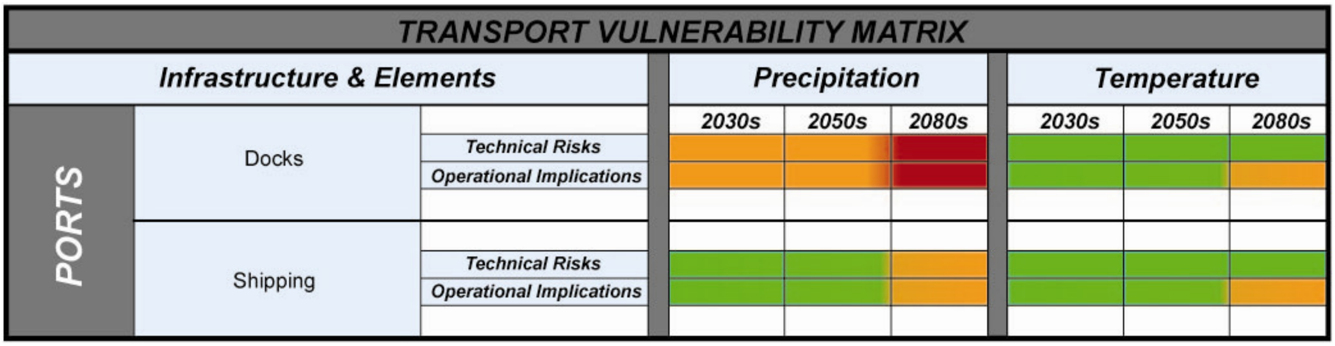
Increased storminess and wind

Operations in ports are curtailed during severe storms, especially if the wind is blowing from a direction other than the prevailing direction from which the port is usually protected by breakwaters or the design of its harbour. Shipping tends to be buffeted by these winds, making them unsafe for berthing or loading. The predicted increase in stormy weather will increase this vulnerability.

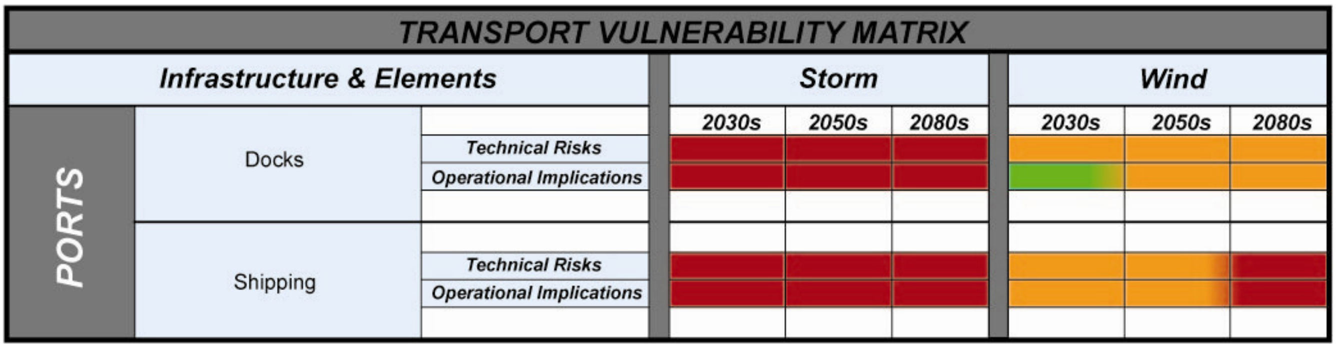
Berths are designed to ensure that shipping is usually aligned to the prevailing wind, minimising the effects of buffeting. Ports are therefore vulnerable to any change in prevailing wind direction, as that would increase the number of days when berths are exposed to a cross-wind.

Figure 3c:

Ports vulnerability matrix (precipitation and temperature)



Ports vulnerability matrix (storm and wind)



Key technical risks

The key technical risks for the port infrastructure that have been identified are:

- High tides/storm surges causing increased sea level at ports; and
- High winds at ports due to an increase in storminess

High tides / storm surges causing increased sea level at ports

Ports are at risk of disruption due to high tides or storm surges (and occasionally both together). As sea level rises are also felt; this risk will be increased. These weather events can curtail operations as it is anticipated that the water level may rise too high to allow berthing, embarking or loading, or the conditions may be too rough to allow these operations. Such conditions would usually close a port for up to a day, and the extent of disruption will depend on the port, so a closure at Dover for even a few hours (e.g. during an exceptional high tide) will be very disruptive. Normal service should be able to resume once the tide falls or the storm subsides, unless there has been flood damage to any harbour buildings.

Whilst there has been no systematic assessment within the sector of what increases in sea level will cause a problem, URS considers that predicted changes in sea level rise may start to take effect in the 2050s and become severe by the 2080s, especially considering high emission scenarios.

Planning for new infrastructure, which typically will have a design life of 100 years, to be built on higher ground will mitigate some of the effects, as is being done at Dover, and improved forecasting of imminent storm surges will also reduce the risks, as shipping can be safely moored or diverted to ports where effects are likely to be less.

Ports on England's east and south coast may be at highest risk, as sea level rise is predicted to be greatest there, but all ports are vulnerable to storm surges, therefore this is a UK wide vulnerability. Ports may also be affected if destination ports are being impacted, so that operations at Portsmouth, for example, would be affected if Le Havre had to be shut due to high tides.

High winds at ports due to increase in storminess

During stormy weather, shipping activity is severely reduced due to the risks from sailing in such conditions and risks from trying to berth. With the predicted increase in stormy weather, there is likely to be further reduction in activity, leading to delays and disruption. Improvement to breakwaters and harbour walls can help to adapt to this possible effect.

Docks in ports are usually aligned to the prevailing wind direction, as shipping is more stable when moored into the wind. A change in prevailing wind direction may result in shipping being exposed to winds side on, increasing the risk of disruption and even damage. However the risk of such events is unknown, due to the lack of certainty in future wind predictions and is a barrier to future action. This risk will need to be revisited once more accurate predictions on wind strength / direction become available. As with other technical risks for ports, this is a UK wide vulnerability due to potential for disruption occurring at either destination or arrival.

Airports

Vulnerability of infrastructure to climate change

The outcome of the vulnerability assessment for aviation is shown in Figure 3d.

Changing precipitation patterns (including sea level rise)

Runways, taxiways and aircraft parking areas are vulnerable to changes in precipitation, as drainage systems can be overwhelmed leading to flooding. This can disrupt operations, as it would not be safe for aircraft to take off or land in such conditions. The disruption usually only occurs for a matter of hours; although backlog of flights in our busiest airports (e.g. Gatwick or Heathrow) would result in the impact on operations lasting considerably longer.

Increased temperatures

Aircraft are less efficient in hot weather, as there is less "lift" available in the less dense air, so aircraft movements must be more widely spaced. With the predicted increase in temperatures this is expected to become more frequent, leading to delays. Although not assessed in detail as part of this project, it is likely that this will require operational changes rather than a technical resolution.

Runway surfaces are vulnerable to hot weather as the asphalt may soften. However improved asphalt technology, as used overseas in hot climates, will prevent this happening. Terminal buildings are vulnerable to hot weather as they may overheat, although improved cooling systems, as used overseas, will reduce this.

Increased storminess and wind

The wide open spaces at airports make them vulnerable to the effects of storms: whether wind, rain, snow or a combination. During storms, aircraft can be grounded and disruption will result. The predicted increase in stormy weather may increase this vulnerability.

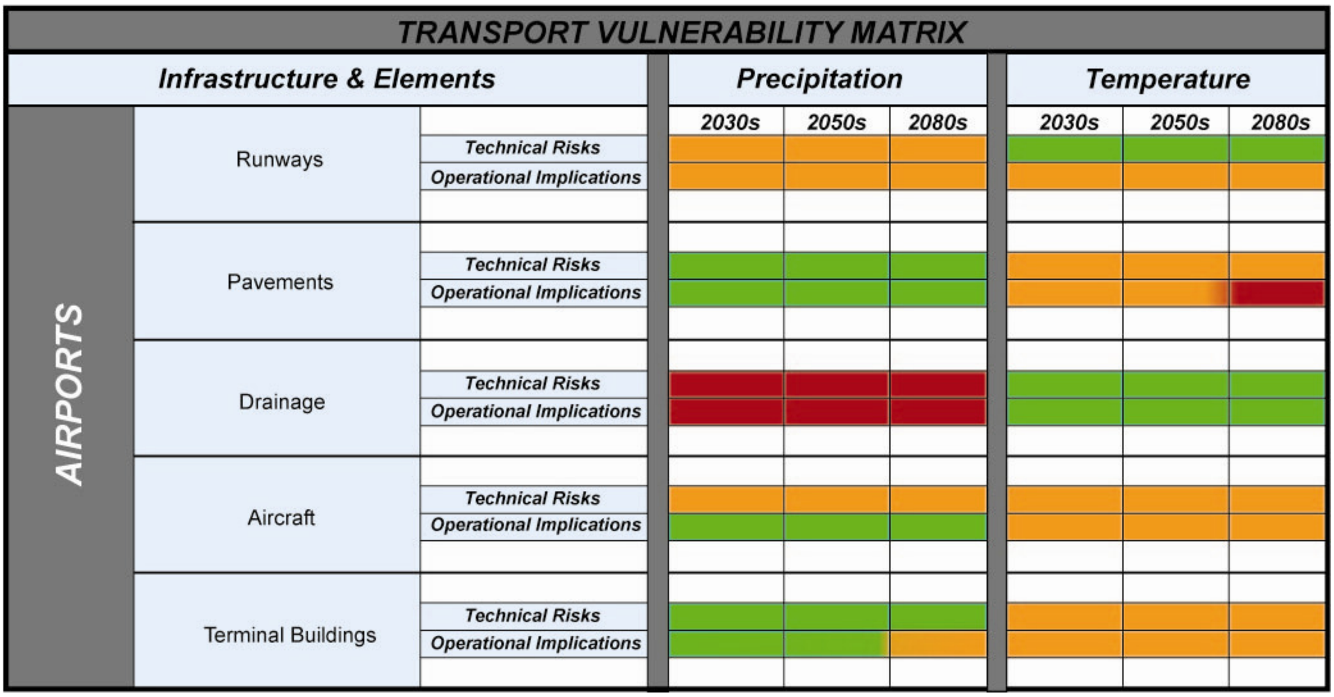
The runways at UK airports are aligned to the prevailing wind: either E-W, or SW-NE. Many only have a single runway or parallel runways, which means on days when there is a strong cross wind, there can be severe disruption. These airports could therefore be vulnerable to a change in prevailing wind direction, but there is no robust climate prediction for this parameter.[33]

Runways, taxiways and aircraft parking areas are vulnerable to storms producing intense rainfall, as drainage systems can be overwhelmed leading to flooding. This can disrupt operations, as it would not be safe for aircraft to take off or land in such conditions. The disruption usually only occurs for a matter of hours. Aircraft are vulnerable to stormy weather, as they may not be able to take off or land safely in such conditions. Some terminal buildings may also be vulnerable, if located in exposed positions in the airport.

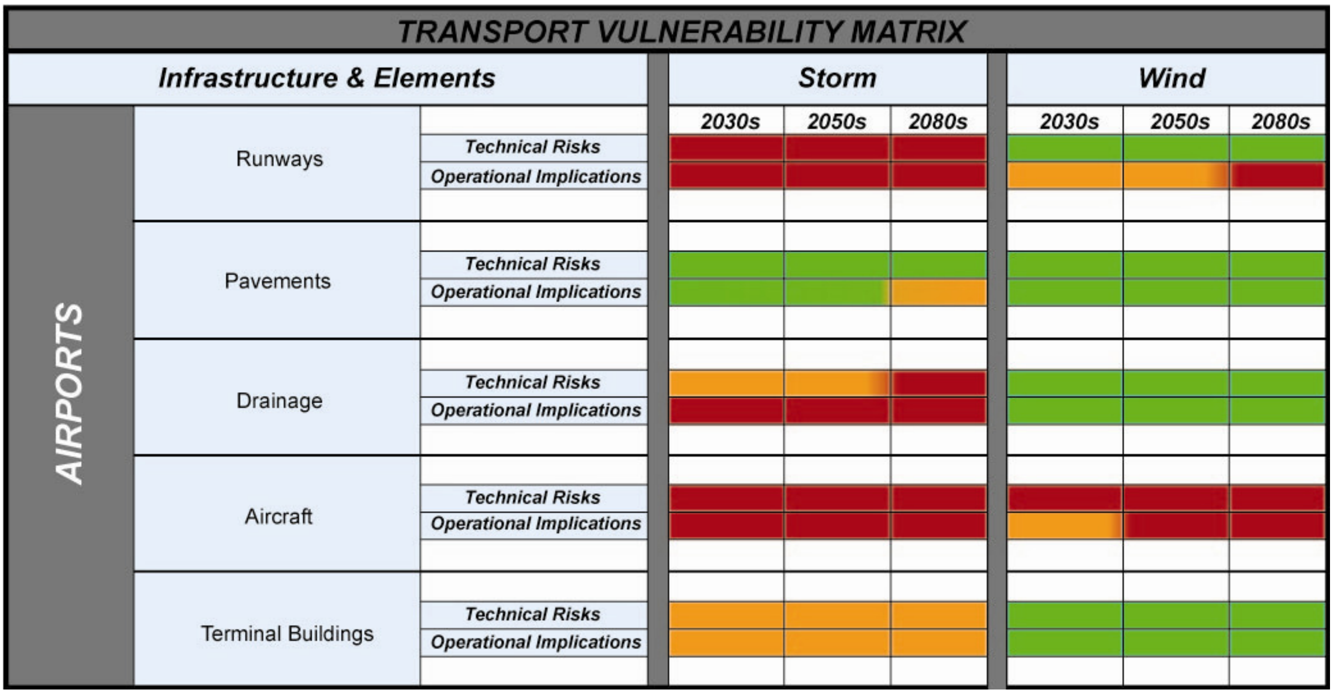
[33] Communication with UKCIP during this project has identified that there has been considerable modelling and work associated with projecting future wind patterns. However, the modelled outcomes are highly variable and neither wind strength nor direction can be predicted with any certainty. Whilst our strong prevailing wind direction is due to coriolis effects which will not be affected by climate change, even a slight change in prevailing wind direction or increases of weather events not in line with our current prevailing wind, could cause considerable disruption.

Figure 3d:

Airport vulnerability matrix (precipitation and temperature)



Airport vulnerability matrix (storm and wind)



Key technical risks

The key technical risk for the aviation infrastructure that has been identified is associated with high winds at airports due to increase in storminess.

High winds at airports due to increased storminess

Airports are potentially vulnerable to two different climate change impacts. The predicted increase and severity of storms may create a risk that airports have to close more frequently due to aircraft not being able to fly in such conditions, or due to flash flooding of runways. Modern aircraft tend to be more resilient to these conditions, and generally smaller, lighter aircraft are the worst affected. The incidence of closure due to snow will probably decrease, as possibly will the incidence of closure due to fog.

The incidence of flooding can be mitigated by improved drainage. For closures due to high winds, there is no mitigation for an open space like an airport. However the risk of such events is unknown; due to the lack of certainty in future wind predictions.

It is this same lack of knowledge of future wind characteristics that makes it impossible to assess the risk to airports of closure due to even a slight change in wind direction and is a barrier to further action. This risk will have to be revisited once more accurate predictions become available. It is potentially a significantly major risk, as there is the prospect of several of the major airports in south east England being affected. All of these have runways aligned to the prevailing west or south-west wind and construction of a cross runway is, in many cases, impracticable. Loss of capacity at these airports would create severe disruption especially as increased use of air is expected both for domestic and international travel.

For local storms affecting our smaller airports, closure may only create local disruption as it will be possible to divert to other airports; however storm events affecting our major airports (e.g. Gatwick or Heathrow) or covering a wider region of the country (e.g. south east England) the impacts could be far greater, causing significant disruption. It is also important to note that airport operations could be affected if either an arrival or destination location is affected.

Water

Introduction

Infrastructure in the water sector is vulnerable to:

- Extreme weather events anticipated to be more frequent and severe with climate change; and,
- Gradual changes in climate that can have a direct impact to water resources and a corresponding indirect impact to the water sector infrastructure.

Water utilities currently prepare Water Resources Management Plans with a 25 year forecast that consider aspects such as population change, climate change and investment projections. Many feel that the severity of the recent floods in Gloucestershire in 2007 and Cumbria in 2009 were the result of climate change which had a significant impact on water sector infrastructure in those regions. Action on climate adaptation in this sector is already occurring which includes consideration for long-term issues as well as short-term resilience planning. The water sector as a whole has already commissioned a number of infrastructure and climate change studies.. All operators contacted were aware of the key issues for their sector and identified near term flood protection from extreme weather as the main area of concern in the immediate future. Operators also recognised that longer term, the key risk for the sector will concern water availability which the will be impacted by the gruel nature of projected climate change.

The water sector has been divided into water supply, treatment and distribution and wastewater collection, treatment and disposal. For the purposes of this report, surface water drainage is considered as part of the wastewater system.

The outcome of the vulnerability assessment for water is shown in Figure 4 below.

Figure 4:

Water vulnerability matrix (precipitation and temperature)

WATER VULNERABILITY MATRIX								
Infrastructure & Elements			Precipitation			Temperature		
			2030s	2050s	2080s	2030s	2050s	2080s
Water Resources	Storage reservoirs, aqueducts, boreholes, source pumping stations,raw water supply pipelines & intake pumping stations.	Technical Risks						
		Operational Implications						
Water Treatment	Treatment works, service reservoirs & water towers, treated water pipelines & treated water pumping stations.	Technical Risks						
		Operational Implications						
Water Networks	Distribution networks including ancillaries, distribution pumping stations & distribution storage.	Technical Risks						
		Operational Implications						
Wastewater Networks	Sewer networks including trunk sewers, pumping stations, rising mains, CSO & other overflows.	Technical Risks						
		Operational Implications						
Wastewater Treatment	Pumping stations, treatment works, & outfalls.	Technical Risks						
		Operational Implications						
Sludge Disposal	Sludge treatment (including CHP & incineration) Sludge disposal or recycling.	Technical Risks						
		Operational Implications						

Water vulnerability matrix (storm and wind)

WATER VULNERABILITY MATRIX								
Infrastructure & Elements			Storm			Wind		
			2030s	2050s	2080s	2030s	2050s	2080s
Water Resources	Storage reservoirs, aqueducts, boreholes, source pumping stations,raw water supply pipelines & intake pumping stations.	Technical Risks						
		Operational Implications						
Water Treatment	Treatment works, service reservoirs & water towers, treated water pipelines & treated water pumping stations.	Technical Risks						
		Operational Implications						
Water Networks	Distribution networks including ancillaries, distribution pumping stations & distribution storage.	Technical Risks						
		Operational Implications						
Wastewater Networks	Sewer networks including trunk sewers, pumping stations, rising mains, CSO & other overflows.	Technical Risks						
		Operational Implications						
Wastewater Treatment	Pumping stations, treatment works, & outfalls.	Technical Risks						
		Operational Implications						
Sludge Disposal	Sludge treatment (including CHP & incineration) Sludge disposal or recycling.	Technical Risks						
		Operational Implications						

Water supply, treatment and distribution

Vulnerability of infrastructure to climate change

Changing precipitation patterns (including sea level rise)

Changing precipitation patterns will have both gradual and sudden, more extreme impacts on water sector infrastructure. Water supply collected from winter rain events will either gradually diminish or increase in unison with the amount of rainfall projected for any watershed into the future. Winter rainfall is expected to lead to an increase in the number and intensity of flood events, while the gradual shift in precipitation patterns may change a river's vulnerability to flooding. Decreased summer rainfall combined with hotter temperatures will also affect water resources with gradually changes either increasing or decreasing stress on supply and extended period of no rain causing an increase in the length and severity of droughts.

Changing precipitation patters have a number of direct impacts to water sector infrastructure (see Table 8).

The impacts of sea level rise on infrastructure in the water sector may include salt water intrusion on groundwater abstraction wells, coastal flooding and erosion from storm surges causing damage to coastal assets.

Increased temperatures

One of the biggest impacts of increased temperature is in conjunction with a decrease in summer precipitation, affecting water resources through the increased the risk of longer and more severe periods of drought. In addition, increasing temperatures can decrease in water quality in reservoirs.. Increasing temperatures reduce the amount of dissolved oxygen in water, increasing micro-biological activity causing colour and odour issues as well as impacting the chlorine demand in the distribution network. Increasing temperatures may also cause changes in peak demand; periods of high temperature are likely to become associated with increasing demand but decreasing supply.

Increased storminess and wind

Infrastructure vulnerability to wind was not considered significant.

Table 8: Impacts from changing precipitation patterns to water sector infrastructure

Increase in precipitation	Decrease in precipitation
Various reservoir impacts • Slippage or scour of soil dams • Sedimentation reduces reservoir capacity. Various distribution network impacts • Asset flooding (fluvial) • Asset deterioration from changing use patterns • Increased infiltration from higher groundwater • Dry/wet cycles may cause soil movement and crack pipes. Various water treatment impacts • Supply & demand fluctuations • Changing raw water quality • Asset flooding. Changing consumption patterns from population shifts resulting from drought or flooding events. Ability to capture flood water for beneficial use may be affected as short, intense and sporadic rainfall is more difficult to capture than long periods of continuous rain.	Reduced availability of water resource supply. Various reservoir impacts • Improper design for new water levels • Changes to water quality (silt, colour & odour). Various distribution network impacts • Sedimentation from reduced flows • Changes in chlorine demand from reduced flows • Asset deterioration from changing use patterns • Blockages from loss of supply or depressurisation • More frequent depressurisation/re-pressurisation may lead to pipe failure • Dry/wet cycles may cause soil movement and crack pipes. Various water treatment impacts • Supply & demand fluctuations • Capacity issues • Changing raw water quality.

Key technical risks

The key technical risks for the water supply, treatment, and distribution infrastructure are:

- Reduced security of supply due to changing precipitation patterns and droughts; and
- Increased fluvial flooding due to increased precipitation and increased coastal impacts from storm surges.

Reduced security of supply due to changing precipitation patters and droughts

This risk relates to the impact climate change will have on the quality and quantity of water available for consumption. Climate change may have a number of specific technical impacts on reservoirs, water networks and treatment facilities. Changing precipitation patterns may have adverse effects on some watersheds (e.g. receiving less rain in the future) and positive effects on others (e.g. receiving more rain). The majority of the impacts identified on the water supply infrastructure will likely be gradual in severity. More immediate impacts may result from flooding and damage to coastal assets from storm surge.

Climate change impacts related to the physical infrastructure itself may be resolved quickly, but impacts to the quantity of water available, or an issue like saltwater intrusion would not likely be resolved quickly.

It is possible that internal and external migration will alter the patterns of supply and demand. There will be a limited population that any single water resource will be able to support. Reduced water availability in the south may cause a migration north. The changing weather may also impact the timing of peak demand. Increasing temperatures intensify water demand, particularly for agriculture, human consumption, cooling water for electric-power and industrial plants, and natural ecosystems. Changing precipitation also modifies demands for irrigation, particularly in regions with soils of low water-storage capacity. Peak demand may increase at a time of year where the least amount of rain falls causing maximum stress on the resource or lead to restrictions on use to minimise demand.

Any new infrastructure will need to consider climate change impacts in their design so there may be less of an impact on future new infrastructure. Measures need to be introduced to ensure that climate change is factored into design.

Typically water storage reservoirs are designed to last hundreds of years, so existing reservoirs may need some form of adaptation before the end of their design life. Below ground assets have a typical design life of up to 100 years. The replacement of underground assets from the beginning of the century will need to consider climate change in the design, and before the end of its design life. Above ground assets typically have a shorter design life (40-50 years), so existing treatment works, pump stations and above ground storage may be beyond their design life and require replacement before adaptation actions are required.

The level and extent of the impact will be region specific, as each water company has its own Water Resources Management Plan. Based on UKCP09, the region most vulnerable is south-east England (including London) which is already water stressed to meet population demands (which is forecast to grow further). The biggest risk associated with this issue would be a failure of service as a result of a water shortage. Security of water supply is sensitive to climate change as the majority of water collected for consumption is a direct result of precipitation. A short severe drought, or a longer period of continuously low rainfall may both have the same impact in jeopardising the security of supply.

Increased fluvial flooding due to increased precipitation and increased coastal impacts from storm surges

All water infrastructure assets may be at risk from increased fluvial and coastal flooding due to increased precipitation and storm surges as well as their physical proximity to watercourses. This could result in a disruption of service but may also impact security of supply if a water treatment works or distribution network were flooded. The speed of recovery depends on the extent of impact. Bottled water may need to be provided as a potable water source for the public.

Any new infrastructure such as desalination plants will need to consider the impact of storm surges and flooding when selecting a location for construction.

Internal migration to drier climates or away from the coast would reduce risks associated with coastal flooding.

The level and extent of flooding will be region specific but the impact may be most predominant along the coast and south east England where both sea-level rise and intense rainfall increases are predicted to be greatest.

Wastewater collection, treatment and disposal

Vulnerability of infrastructure to climate change

Changing precipitation patterns (including sea level rise)

Changing precipitation patterns will have both gradual and sudden, more extreme impacts on wastewater infrastructure. Decreased summer rainfall combined with hotter temperatures will reduce the volume of water flowing in many rivers that are used to dilute treated wastewater effluent. The dilution capacity of these rivers will impact the level of treatment required prior to discharging effluent. An increase in winter rainfall will have converse affects, but a substantial increase in rainfall could cause flooding of wastewater infrastructure

Changing precipitation patterns have a number of direct impacts to wastewater collection, treatment and disposal infrastructure (see Table 9).

The impacts of sea level rise on wastewater infrastructure includes: coastal erosion, flooding and asset damage. Coastal CSOs could become tide blocked and back up sewers.

Salt water intrusion may infiltrate sewers, increasing sewage salinity, impacting hydrogen sulphide formation, which reduces primary sludge “settleability”, reduces dewaterability of settled sludge, impacts activated sludge process from microbial changes and impacts dissolved oxygen saturation in aerobic biological reactors.

Table 9: Impacts from changing precipitation patterns to wastewater sector infrastructure

Increased precipitation	Decreased precipitation
• Increase in sewer flooding from insufficient surface water drainage capacity (pluvial flooding) • Asset flooding (fluvial) • Increased number of discharges from combined sewer overflows (CSO) • Increase infiltration and inflow (I&I) from changing groundwater levels • Stronger (higher ammonia and organic load) dry weather flows and more dilute wet weather flows impact treatment plant performance. • Increased flows from surface water drainage may be outside of designed pump curve causing rapid deterioration of assets. • Frequent surcharging of sewers may cause significant early damage and lead to early failure and collapse. • Dry/wet cycles may cause soil movement and crack pipes • Insufficient capacity or over capacity at pump stations and treatment works. • Lower flows in receiving water may require higher standard of treated effluent prior to discharge, higher flows in winter may support greater dilution (positive impact)	• Increase infiltration and inflow (I&I) from changing groundwater levels • Stronger (higher ammonia and organic load) dry weather flows and more dilute wet weather flows impact treatment plant performance. • Decrease in flow through sewer network can lead to blockages, deposits, and hydrogen sulphide gas build-up, • Increased flows from surface water drainage may be outside of designed pump curve causing rapid deterioration of assets. • Frequent surcharging of sewers may cause significant early damage and lead to early failure and collapse. • Dry/wet cycles may cause soil movement and crack pipes • Insufficient capacity or over capacity at pump stations and treatment works. • Lower flows in receiving water may require higher standard of treated effluent prior to discharge, higher flows in winter may support greater dilution (positive impact)

Increased temperatures

An increase in temperature combined with a decrease in precipitation reducing water resources and increasing the risk of longer and more severe periods of drought may greatly reduce the flows in natural surface waters and thereby have an indirect impact on the level of treatment required to maintain a minimum level of environmental protection. Lower flows may result in more stringent discharge standards for water treatment facilities.

Biological treatment of wastewater typically improves at higher temperatures which would be a positive impact, although higher temperatures may also cause septic conditions in holding tanks and stagnant sewers. Hydrogen sulphide gas associated with septic conditions is corrosive, causes odour and is a health and safety concern. Septic wastewater also results in poor primary settlement at the treatment facility and increased load onto secondary processes.

Higher temperatures may also be associated with an increase in ultraviolet (UV) exposure that decreases micro propagation and survivability having a negative impact on biological treatment systems exposed to UV. In addition, higher temperatures decrease the oxygen transfer efficiency in aerobic reactors impacting treatment performance.

Increased storminess and wind

Infrastructure vulnerability to wind was not considered significant.

Key technical risks

The key technical risks for the wastewater collection, treatment, and disposal infrastructure are:

- Increased sewer (pluvial) flooding due to changes in precipitation; and
- Increased fluvial flooding due to changes in precipitation, sea level rise and storm surges; and
- Increased pollution incidents due to changing precipitation patterns and periods of drought

Increased sewer (pluvial) flooding due to changes in precipitation

Increases in the frequency and intensity of storms may put pressure on the capacity of sewers to deal with larger volumes of surface water resulting in more frequent sewer flood events. Existing sewer systems have a finite hydraulic capacity established during design.

Inadequate drainage can lead to property damage, increase erosion, cause excessive wear on pumping and transmission systems while combined sewer overflows can also negatively impact environmental water quality and the increased flow can overwhelm wastewater treatment systems.

Recovery from sewer flooding is relatively quick in terms of getting the drainage system operational again, but the damage to property and the environment can be much more difficult to resolve. In addition, sewer flooding presents a risk to human health and safety.

Population growth or movement will alter the patterns of demand for sewer services. Sewage treatment facilities will have to balance an increase in demand with their ability to protect the environment. Rivers that receive treated effluent may have a finite capacity to dilute, due to reduced river flows, which may require higher levels of treatment or alternative disposal routes.

New infrastructure will need to consider the impacts of climate change in its design, so there may be less of an impact on future new infrastructure.

Below ground assets (e.g. drainage network) have a typical design life of up to 100 years. The replacement of underground assets from the beginning of the century will likely consider climate change in the design, where infrastructure installed 20-30 years ago may require adaptation in the future. Above ground assets typically have a design life of 40-50 years, so existing treatment works, pump stations and above ground storage may be beyond their design life and replaced before adaptation actions are required.

The level and extent of impact will be region specific, as each region has its own drainage systems. Based on the UKCP09 projections, the most significant impact will occur in south-east England which is predicted to receive more intense and more frequent storms. Sewer flooding is sensitive to climate change as the design capacity of sewers is fixed. An increase in precipitation has an immediate and direct effect on sewers used for surface water drainage.

Increased fluvial flooding due to changes in precipitation, sea level rise and storm surges

In addition wastewater infrastructure assets may be at risk from increased fluvial and coastal flooding due to increased precipitation, sea level rise and storm surges as well as their physical proximity to watercourses. Wastewater treatment plants are often built in the flood zone because it is hydraulically favourable (low point) and also close to the ultimate discharge of treated effluent. One positive impact of a fluvial flood is that the additional water will dilute the negative impact of sewage washed out of the treatment plant. Flooding of a sewage treatment plant could significantly damage the treatment process. Biological systems take time to acclimatise to changing conditions so recovering from a flood event may take a significant amount of time to recover, during this time sewage would continue to flow to the facility and potentially be discharged with only preliminary treatment.

The typical design life of a sewerage treatment plant is approximately 40-50 years, so existing treatment works, pump stations and above ground storage may be beyond their design life and replaced before adaptation actions are required.

Fluvial flooding is fairly sensitive to climate change as the location of wastewater infrastructure in the flood zone is fixed. An increase in precipitation has an immediate and direct effect on river levels and potential flood scenarios.

Increased pollution incidents due to changing precipitation patterns and periods of drought

This risk is indirectly related to climate change but has significant implications for wastewater treatment. As a result of drier summers and more variable rainfall patterns during spring and autumn, reduced water levels in a watercourse receiving treated wastewater effluent will have less ability to dilute the discharge. To maintain a similar level of environmental protection, tighter discharge consent limits may be imposed on utilities requiring a higher standard of treatment in order to improve effluent quality.

This risk also ties in with an increase in sewer flooding which would mean an increase in the frequency of CSO discharge to the environment.

It will be the responsibility of treatment plant operators to keep treated effluent within consent limits with existing and/or new treatment technology. Water and wastewater treatment is an energy intensive process and typically higher quality effluent requires more energy. There is a contradiction within the sector between providing higher quality effluent as well as lowering the carbon footprint.

New infrastructure will need to consider the future dilution capacity of the planned receiving water to ensure that appropriate treatment capacity exists.

The typical design life of a sewer treatment plant is approximately 40-50 years, so existing treatment works may be beyond their design life and replaced before adaptation actions are required.

The risk of environmental pollution from wastewater infrastructure is fairly sensitive to climate change. As previously described, increased rain may increase sewer flooding and CSO discharge, increased rain may cause more frequent or sever fluvial flooding which could wash out sewage from a treatment plant. Periods of reduced rain and increased temperatures causing drought may limit the flow in rivers increasing their sensitivity to the impact of treated wastewater effluent.

Section 6
Interdependencies

Interdependencies

Introduction

There are many interconnections between the infrastructure components both within and between sectors and with the ICT sector. Where these interconnections are associated with the supply or receipt of a service (e.g. water) on which the receiving sector is reliant and an impact on this supply could be critical, we have termed these interdependencies. Where these interdependencies are vulnerable to climate change these are expected to increase our overall vulnerability to climate change and the significance of the associated risks. A summary of the identified interdependencies is presented in Table 10.

Two key aspects of these interdependencies are cascade failures and regional convergences.

- **Cascade failures –** this term has been used to refer to a series of linked impacts or failures, and are often the result of the interdependencies breaking down. They also occur when the failure of one item leads directly to failure of another, even though the second item may not be reliant on the first for a supply. For example, during the floods of summer 2007, keys elements of the flood protection system for properties adjacent to the river Severn could not be delivered in time to prevent flooding, as they were delayed on M5 where traffic flow had been severely affected by the floods.

- **Regional convergences –** throughout the country, there are certain regional concentrations of infrastructure which, if impacted by a severe weather event, could have consequences on functionality at a national scale in one or more of the three sectors. Two such regions (i.e. Humberside and Kent) have been identified through experience of the project team but it has not been possible within the scope or timescale of this project to systematically identify all such areas.

Further work is required to identify these and enable potential consequences and associated adaptation options to be fully evaluated.

This section has been structured to enable a discussion of the key interdependencies that have been identified for each sector and based on the sector vulnerability and risks discussed in section 5 the potential consequences of climate change on these.

Table 10 – Example infrastructure interdependencies between sectors (and ICT)

Sector	Service or Supply being provided			
	Energy	**Transport**	**Water**	**ICT**
Energy	• Gas storage and distribution relies on electricity supply • Widespread use of gas to generate electricity via combined cycle gas turbines (CCGTs)	• Operator access to power stations during severe weather • Access to local distribution facilities • Raw material supply • Road/rail/ports disruption leading to disruption of supply of certain fuels (e.g. diesel & petrol)	• Water critical for cooling at power plants • Non-coastal power generators may compete for same water resources	• Supply is required for all aspects of ICT • Little evidence of climate change risk assessment • ICT becoming increasingly important for real-time monitoring of localised energy generation supplying to grid (smart meters)
Transport	• Transport sector becoming increasingly reliant on electricity (e.g. for signage, stations, lighting etc) • Increased demands on energy from rail network (electrified lines) • Flooding of oil refineries and depots disrupting supply • Electric cars reliant on functional network of recharging stations	• Road failure impact on rail • Road network capacity issue on port closure • Airports dependent on good functioning of road and rail • Airport failure leading to diversion onto roads and rail • Rail failure leading to diversion onto roads	• Fire water supply to airports and ports • Pluvial flood protection • Drainage design and maintenance can impact on road flooding as well as quantity and quality of surface run-off received at the treatment plant. • Ownership of surface water drains may become an issue • Provisioning and cleaning of vehicles	• Critical for all transport:(e.g. signage on motorways, signalling on rail, or air traffic control). • Fixed links less vulnerable than mobile ones. • Little evidence of climate change risk assessment • Disruption of mobile networks may impact on efficiency of emergency services in event of accidents
Water	• Water infrastructure requires energy for operation	• Wastewater sludge often requires transport for off-site disposal. • Road access to treatment works, pumping stations • Overland transport of potable water during flooding or failure of service.	• The water sector is a highly integrated system. Water and wastewater infrastructure is dependent on multiple other elements within the system.	• Increasing demand on remote operation of assets • Little evidence of climate change risk assessment

Energy

The energy sector's dependence on the transport, water and ICT sectors is outlined below with specific reference to examples of where impacts have already been identified, regional convergences and cascade failures.

As well as dependencies on other sectors, there are interdependencies between different sector components within the energy sector. For instance, gas storage and distribution requires electricity supply for compression, pumps, isolation values and monitoring systems. This supply is typically provided by the national grid; therefore failure in electricity could also impact other energy supplies. Regional convergences in energy supplies, such as observed in the Humber region, are therefore of particular concern (see Box 7).

Key Transport Services to the Energy Sector

Road transport of employees to and from power stations is a key strategic requirement since most power stations are located in remote areas often not well served by public transport links. This creates a direct dependence of the generation element of the energy sector on the road transport network potentially leading to operational disruptions for power stations in the event of a failure of the road network due to extreme weather events. As increased extreme weather events are observed, a greater potential for such disruptions could be reasonably expected.

Such impacts will likely be regional in nature and therefore impact only part of the UK's energy generation capacity. If the impact should occur where there is a significant convergence of energy generation capacity, such as the Humber area, this would clearly increase the risk. The Humber is identified as a particularly important convergence area for the energy sector.

Opportunities for maintaining staffing levels for the operation of power stations are likely to depend on the implementation of adaptation options for maintaining the operation of our road network. However, an additional opportunity would also exist around identifying whether certain operational functions could also be managed from a remote location through the use of ICT. This does, however, assume that ICT functions are maintained; however, building in redundancy to ICT networks (e.g. duplicate systems) can help increase resilience. This is an issue which could be evaluated during the development of design codes for the next generation of power plants.

Equally, the energy sector cannot function without the supply of essential raw materials (e.g. bulk fuel) via the various transport networks. Supply chains for the energy sector tend to be short, tightly managed and largely operated on a 'just-in-time' basis, which makes them highly vulnerable to disruptions with knock-on implications for the population as a whole. Opportunities to increase storage capacity of raw materials in energy infrastructure due to be built in the short to medium term could reduce the impact.

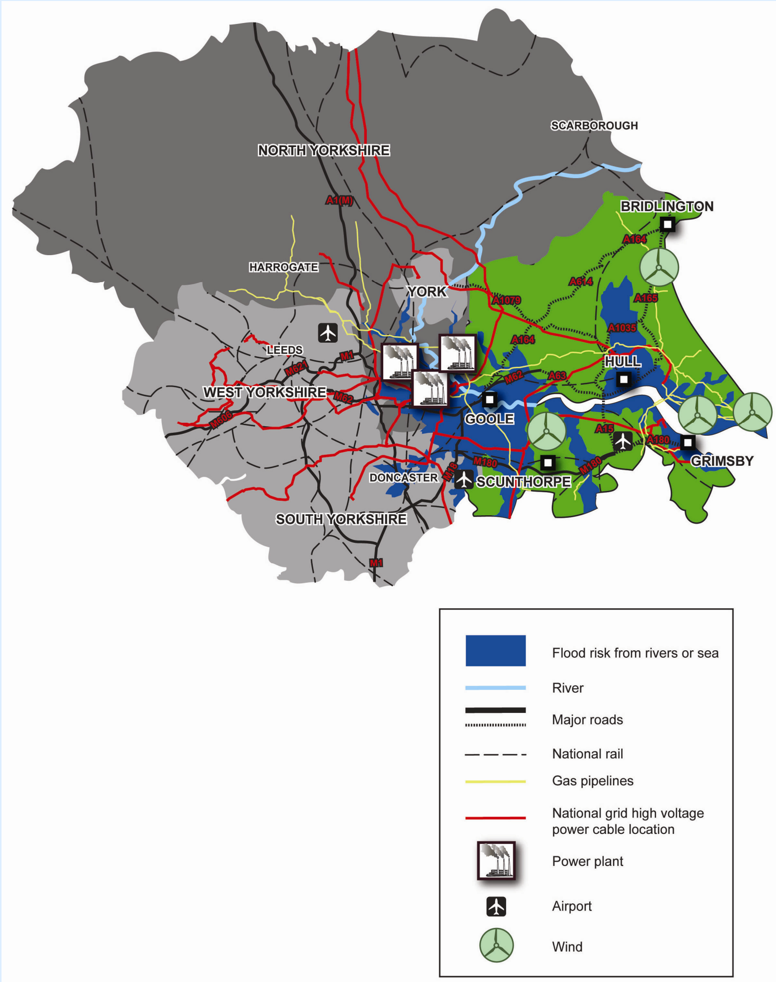
Box 7
Humberside case study

Humberside is supported by a vast network of energy, water and transport infrastructure, either side of the estuary. This densely populated region, could be severely affected by projected changes in rainfall, sea level and temperature. Due to heavy pluvial impacts and its coastal location, it has already demonstrated a vulnerability to flooding, resulting in significant costs across the region. Intense rainfall led to severe floods in June 2000 which caused over £150 million of damage. Flooding in 2007 caused widespread disruption right across the region, and in Hull the floods led to damage to 7208 residential properties and over 1300 businesses[1]. Water levels close to the main coal fired electricity generators in the region were all high, particularly for Ferrybridge coal fired power station. A number of factors contribute to making the region particularly vulnerable to the impacts of extreme weather events:

- Flood plains - by Goole and Hull are vulnerable to freshwater and tidal flooding.
- Coastal location – vulnerable to sea level rise, tidal flooding and coastal erosion.
- Low elevation: 90% of the area around Hull lies below high tide level.

The incidence of extreme weather events could, in future, impact key infrastructure with more severe consequences occurring where different elements of infrastructure converge, such as:

- Road and transport infrastructure: M62 and M180 with smaller A-roads link the major centres. A network of rail connections exists between Leeds, York, Hull and the East Coast. Flooding of these could result in thousands of stranded travellers and significant transport delays.
- Gas pipelines: The gas landing station near Hull is supported by a large network of pipelines with significant onward supply to adjacent regions. Coastal flooding and erosion could disrupt supplies.
- Power stations: a combined a capacity of 14GW including three major coal fired power stations: Ferrybridge, Eggborough and Drax. Humberside also has 160MW renewable power and 1200 MW CHP capacity. Together these comprise 17% of the UK's electricity generation capacity. Loss of generation capacity or damage electrical transmission systems from flooding would result in a significant loss of power affecting the region. As over 10% of the power is exported, significant impacts would be felt across the UK.



Water supply for the three main power stations is taken from river water. Water supply in the Goole area is sourced primarily from groundwater reserves. Reduced summer rainfall, increased agricultural needs and a growing population could mean a greater pressure for this resource. This could be further aggravated by the potential incursion of seawater due to a rising sea level.

In the long term, it is likely that there will be a shift from an energy mix to a more diverse, decentralized energy network relying on a range of renewable technologies such as wind, tidal and biomass. Planning permission exists for a biomass plant near Drax shortly to be followed by two others. Sea storms have the potential to disrupt the landing of biomass imports. A scenario of biomass and gas both of which are imported could present high risks in terms of security of supply.

[1]Prof. Coultard et al. The June 2007 Floods in Hull, August 2007. http://www.coulthard.org.uk/downloads/floodsinhull1.pdf

Key Water Services to the Energy Sector

As already discussed water supply is crucial to the operational continuity of power plants. Specifically, nuclear and fossil fuel power plants require large amounts of water for reactor vessel and condenser cooling. The short to medium term plan for renewal of fossil fuel power plants and development of new nuclear power plants is likely to increase the demand on cooling water from this part of the energy sector in the next 30-50 years. This increased demand for cooling water needs to be considered alongside the anticipated decline in available water resources, which in turn will be driven by increasing demand for drinking water due to the impacts of climate change as discussed in Section 5.

Increasingly limitations on abstraction may be enforced by the regulator at times when water flows are low and drinking water supplies need to be maintained or when local river ecosystems are threatened. It is recognised that water abstracted for cooling purposes is returned to the same source under environmental consent conditions. In coastal locations, cooling water will often be abstracted from rivers impacted by tidal waters or the sea. Tidal water used for cooling such as at the Trent and Humberside power stations is brackish and less useful to the water sector for other uses. The use of tidal waters or sea water for cooling therefore reduces the risks associated with this interdependence.

Changing temperature in the cooling water source, which is anticipated as summer temperatures rise, may also become important. During the heat wave of 2003, many of France's nuclear power stations were unable to operate at their design capacity due to a lack of cooling capacity in the available water as the temperature differential was insufficient.[16] This resulted in some of the plants being shut down entirely.

Key ICT Services to the Energy Sector

ICT provides a critical operational service for much of the UK energy infrastructure; both at individual plants and also across networks where it supports supply and demand forecasting and re-routing of gas and electricity supplies through the transmission and distribution networks. Further developments in the energy sector in the next decades, including increased uptake of Government support for localised micro generation renewable energy schemes, are anticipated to further increase the reliance on ICT. Localised microgeneration renewable energy schemes feed electricity back into the grid, leading to an increased requirement for real-time monitoring to allow peaks and troughs in demand to be accurately forecast. As identified above, understanding the vulnerability of ICT to climate change is therefore critical for the energy sector to ensure that both sectors can develop effective adaptation measures for these key supplies.

At the time of this project, there has been little discussion between the energy and ICT sectors regarding resilience and the implications of long term climate change on the resilience of key ICT services. Further work is required.

Transport

The transport sector's dependence on the energy, water and ICT sectors is outlined below with specific reference to examples where impacts have already been identified, regional convergences and cascade failures.

There are clear interconnections between the four key sub-sectors considered as forming part of the transport sector. For instance, rail and road infrastructure are heavily interconnected, often serving the same group of users for the same transport routes. Whilst there may not be obvious interdependencies during the time when the networks are both operating effectively; failure on one could result in cascade failures. A significant failure of the road network is likely to lead to temporary shifts from road to rail, which, if of sufficient magnitude, would in turn have the potential to result in capacity failure on parallel rail routes. The same would apply visa versa. Road networks have already been shown to have a capacity issue during operational failure of port facilities (e.g. Operation Stack, which involves closing part of the M20 to create space for an emergency lorry park when operations at Dover are affected). These examples therefore demonstrate potential cascade issues. Box 8 identifies some of the regional convergences in the Dover area.

Key Energy Services to the Transport Sector

The transport sector as a whole relies on energy both for vehicles and the associated infrastructure such as signage, stations and lighting. Disruptions to fuel supply chains (e.g. flooding of an oil refinery) will have an impact on road and air travel as well as interruptions to electricity supply (e.g. due to failure of generation capacity caused by flooding). However the likely significance of such climate change impacts will vary depending on the specific transport infrastructure. For instance, reliance on electricity supply from the energy sector is not perceived as a significant risk to highway infrastructure. However railways are far more reliant on electricity supply, and likely to become more so as more lines are electrified. A major power failure could cause a failure in service, for example to the electrified lines out of London Waterloo or to the underground.

Key Water Services to the Transport Sector

Whilst water is used within the transport sector associated with provisioning and cleaning of vehicles, the key water related service on which the transport sector relies is drainage. Fluvial and pluvial flooding can close major strategic road networks with significant national impact. In urban areas, similar flooding issues occur as local roads are frequently drained into public storm sewers .

Effective removal, treatment and disposal of surface water run-off could therefore be considered to be an interdependency and one which requires long term planning.

This interdependency raises an important issue of ownership and connection; the drainage system within a specific transport infrastructure such as an airport, might be developed, maintained and owned by the airport operator; however, the system into which it is connected will be owned and regulated by the sewage undertaker, if a sewer, or managed and regulated by the Environment Agency, if a water course. Ensuring effective capacity throughout such a system is important and therefore engagement with all possible interrelated parties will be important to ensure this.

Box 8
Dover case study

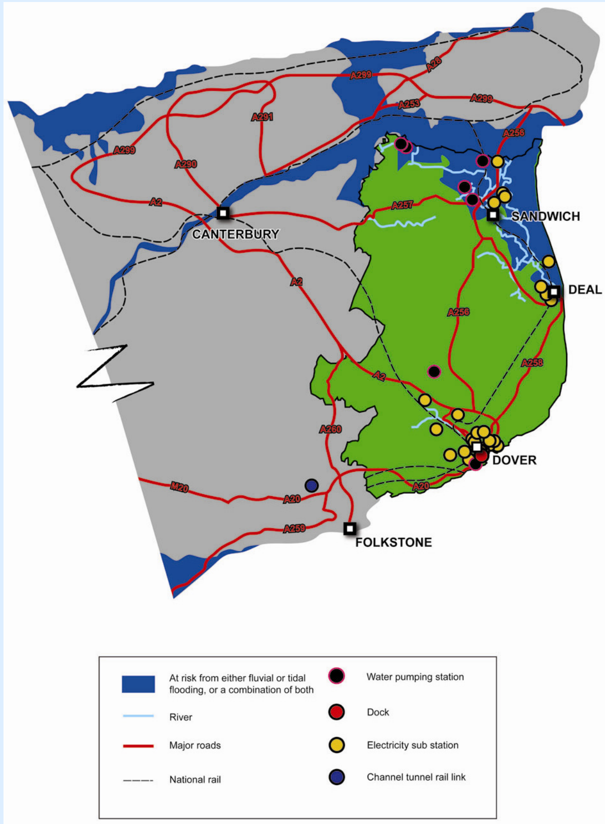
Often referred to as the gateway to Europe, Dover is home to one of the busiest ports[2], with over 13 million ferry passengers and in excess of 2 million road haulage vehicles passing through annually.[3] Dover's limited capacity to support the significant volume of traffic for the port and the nearby Eurotunnel, has caused severe congestion. Ferry strikes have been responsible for congestion in the past; extreme weather events could result in the same impact in the future.

Several factors increase Dover's vulnerability to the impacts of climate change, these include:

- **Valley location:** heavy rainfall has a tendency to collect in one area rather than dissipating, increasing the likelihood of flooding[4].
- **Coastal location:** a rise in sea level and more storm surges could have a large impact, enhancing vulnerability to tidal flooding.
- **Flooding from rivers:** Even though the River Dour has been heavily modified and flood defences have been built, intense periods of rainfall during Autumn 2003 led to fluvial flooding caused by urban run off.

An extreme weather event could impact key infrastructure with severe consequences occurring where different elements of infrastructure converge e.g.

- **Electricity sub stations: A large cluster of electricity sub stations in and around the city**
- **Water pumping stations: A number of pumping stations are located north of Dover**
- **Road and transport infrastructure: Key transport routes to and from the port e.g. A2 and A20, supported by a network of smaller roads. Railway links approach Dover from three directions.**



UKCP09 projects a 20% increase in precipitation on the wettest day in winter by 2080s in this region.[5] Presuming this rainfall occurs primarily in more intense events as is projected, there will be large volumes of rainfall requiring management. Improvement of the drainage systems will be required. As shown on the diagram below, flood risk is greatest north of Dover where a number of water pumping stations, electricity substations and key transport routes are located. Tidal and fluvial flooding could have repercussions in terms of water and energy supply in the area affecting access to Dover.

Transport access approaching from the north, such as the rail line through Canterbury, and running parallel along the east coast into Dover, is extremely vulnerable to fluvial and tidal flooding. A disruption to this link would add pressure on the other two rail links. Flooding around Canterbury could also affect the A2, one of the main access roads into Dover. A high risk of flooding can also be observed south west of Dover. As sea level rises and the intensity of storm surges increases, this is likely to cause flooding over a wider area, thus potentially impacting on the A20 and the channel tunnel rail link in the longer term.

1 Dover Town Council, A Dover Study. Available at: http://www.dovertown.co.uk/article/a_dover_study.aspx

2 Port of Dover website: http://www.doverport.co.uk/?page=AnnualTrafficStatistics

3 Dover District Council, Strategic Flood Risk Assessment, September 2007. Available from: http://www.doverdc.co.uk/pdf/2007finalreporta.pdf

4 UK Climate Projections, Pre-prepared maps and graphs. Available from:
http://ukclimateprojections.defra.gov.uk/images/stories/Preprepared_maps/UK/UK_WinWet_Med_2080_50.png
50% probability estimate assuming a medium emissions scenario.

There are also instances where the road infrastructure is used to support other services such as a bridge being used for water or sewage pipelines as well as ICT. An example of a cascade failure associated with this type of instance is identified in Box 9.

Box 9
Scenarios demonstrating cascade failures

The events in Cumbria in November 2009 highlight the impact of bridge collapse on transport communications. However, what if this bridge had been used as a connecting structure for the water mains supply? The bridge failure could have resulted in damage or complete failure to the water pipeline resulting in a total loss of clean water to the local community.

Another scenario is where a critical transport link can be affected by a failure in the water sector. Such an instance almost occurred near Sheffield recently.

A section of the M1 near Sheffield had to be closed in June 2007 for 36 hours as a precaution against the possible failure of the nearby Ulley reservoir. Large quantities of rainfall led to high volumes of water flowing over the spillway, which led to scouring and cracking on the slope of the reservoir's dam. Because the engineers advised that this could lead to dam failure, they recommended the motorway be shut as it lies in the inundation path of the reservoir. Had the dam failed this would have been an example of cascade failure.

Key ICT Services to the Transport Sector

ICT provides a critical operational service for much of the UK transport infrastructure, from road information on the motorway network through to air traffic control. This reliance on ICT is also likely to increase into the next decades. Understanding the vulnerability of ICT to climate change is therefore critical for the transport and ICT sector to ensure effective adaptation measures for these key supplies.

Those maintaining the road network also tend to rely heavily on mobile phones. At times of major disruption, such as the snow event in January 2003 on the M11, the loss of a signal, due for example to communication masts being put out of action, can cause much greater operational difficulties. The forecast increase in stormy weather will make such systems more vulnerable.

At the time of this project, there has been little discussion between the transport and ICT sectors regarding resilience and the implications of long term climate change on the resilience of key ICT services. This requires further work.

Water

The water sector's dependence on the energy, transport and ICT sectors is outlined below with specific reference to examples where impacts have already been identified, regional convergences and cascade failures.

The water sector itself is a highly integrated system. Water and wastewater infrastructure is dependent on multiple other elements within the system. The intra-sector dependencies have been discussed in Section 5 in the technical risks for the water sector.

Key Energy Services to the Water Sector

The water sector is almost entirely dependent on energy supply for the operation of its plant and equipment. Water treatment plants, in particular, require a significant amount of energy to operate. Whilst most key equipment are equipped with back-up generators which reduce this dependency, this may not always be the case, or the capacity of the generators could be insufficient for sustained operation. Without emergency power the water sector would be affected significantly during a power outage; such an outage could be associated with the impact of climate change on the energy sector. Potable water distribution systems require power to service the public and sewerage systems require power to protect the environment.

Developing on-site generation of electricity from renewable sources could prove a viable source of emergency power during energy service disruptions and could reduce dependence on the grid. However, careful selection of the renewable supply is required. For example, solar or wind powered mechanisms may not provide the on-demand capability or consistency likely to be required. Although renewable energy from biogas created from the digestion of wastewater sludge is a well established and a growing technology; due to technical and financial issues associated with economy of scale, biogas may only be feasible for larger facilities or on a regional level.

Key Transport Services to the Water Sector

Provision of staff and materials to parts of the water infrastructure is currently key for their operation. Therefore climate events which impact the ongoing operation of the transport infrastructure, particularly the road network, will also have an impact on the water sector.

Road transport of employees to and from treatment plants is important; however, the widespread nature of the treatment plants creates less of a strategic issue than for example for electricity generation plants. Adaptation opportunities for maintaining staffing levels are likely to depend on the adaptation options implemented for maintaining the operation of the road network. However, an additional opportunity would also exist around identifying whether certain operational functions could also be managed from a remote location through the use of ICT. This does however, assume that ICT functions are maintained; however, building in redundancy can help increase resilience

Equally, the water sector cannot function without the transport of wastes off-site via the various transport networks. An important element of this is off-site sludge disposal by road from sewage treatment works which requires the transport network to function. Sewage sludge is produced continuously during wastewater treatment. Most treatment sites do not have the space to process or dispose of sludge and therefore it must be transported off site for disposal options such as land application. The ability of sites to store sludge is finite, often in the order of days, so where local transport networks are affected, such as through flooding, storage facilities at the treatment works may quickly back up which could disrupt operation of these plants. Adaptation options for temporary or permanent off-site disposal of sludge include increased storage capacity and on-site digestion or incineration facilities.

Finally, in the event of an interruption to water supplies (e.g. pipe failures) the distribution of bottled water (or bowsers) requires transport. Adaptation opportunities for this are two fold around reducing the potential for interruptions to the supply as well as measures that enable maintenance of the required transport services.

Key ICT Services to the Water Sector

ICT in the water sector primarily consists of personal communication with staff (land lines, mobile phones, two-way radio, etc), internet and intranet services as well as telemetry including some control of remote assets. Many pumping stations and treatment works will have internal SCADA systems. Climate change impact on any of these modes of communication and data transfer will impact the operation of water and wastewater infrastructure and have the potential for disruption or failure of water supply or wastewater treatment provisions.

At the time of this project, there has been little discussion between the water and ICT sectors regarding resilience and the implications of long term climate change on the resilience of key ICT services. Further work is required.

Summary

This short section on key interdependencies, cascade failures and regional convergences provides an overview of these key issues for long term resilience of the UK's infrastructure. It is clear that further work is required to ensure that interdependencies are better understood and that they are considered systematically when assessing climate change risks and issues. Any such assessment needs to reflect potential for regional convergences and cascade failures.

Section 7

Adapting our new infrastructure

Adapting our new infrastructure

Introduction

Over the period covered by this study, 2030 through to 2100, new infrastructure will be introduced to the networks in the three sectors. There will be many reasons for this new infrastructure including:

- Replacement of aging assets, (e.g. renewal of our electricity generation network);
- Provision of new assets associated with decarbonising our economy, (e.g. on-shore and off-shore wind farms);
- Provision of additional capacity to reflect socio-economic growth (e.g. motorway widening, new or increasing the size of treatment plants and drainage systems);
- Replacement of assets or construction of new assets as part of adapting to climate change (e.g. new flood defences); and,
- Increasing efficiencies to support economic growth (e.g. high speed rail network; port expansions to cater for mooring of super tankers).

It is not the purpose of this section or study to identify specific drivers for this new infrastructure, nor the specific items of infrastructure that will be needed. However, understanding possible additional vulnerabilities to climate change and associated technical risks which require effective adaptation options to ensure that such new infrastructure has adaptive capacity is important; this forms the focus of this section. Potential new infrastructure that is discussed in this section has been identified through both stakeholder consultation as well as review of key sector and Government publications such as the Low Carbon Transition Plan.[34]

[34] The Low Carbon Transition Plan: National Strategy for Climate and Energy; HM Government, July 2009 (http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx)

Energy

The energy sector in the UK, potentially more so than water or transport, is in the process of significant investment on new infrastructure, estimated at £230 billion over the next 30 years[35]. This investment, whilst partially associated with supporting the UK in meeting its climate change and renewables targets in the short term (through to 2015-2020), is also critical for securing future energy supplies for the UK. Given the likely design life of new infrastructure in the energy sector (typically upwards of 20 years for major plant and well over 50 years for nuclear plant), it is critical that adaptive capacity is incorporated.

New infrastructure expected for the energy sector includes: increased on-shore and off-shore wind farms, wave and tidal power, a new generation of nuclear power plants, carbon capture and storage facilities, changes to transmission and distribution networks to reflect new siting of generation plants, increased decentralised electricity and heat generation, district heating schemes, additional fuel storage capacity, a network for electric vehicle recharging points; hydrogen power, increased bio gas plants and greater microgeneration.

What will the technical risks associated with climate change be for this new infrastructure? Does this result in new technical risks over and above that already existing?

On-shore and off-shore wind power is already a key part of our developing renewable electricity generation capacity and infrastructure already exists. Technical risks and solutions for these are discussed in section 5 and 8. However, for tidal little infrastructure exists to date. Key for this infrastructure will be a need for considerable resilience to anticipated off-shore extreme storms and resulting high waves and wind strengths. It is also possible that sub-sea infrastructure (e.g. connections) associated with these technologies will be less vulnerable to storm damage than their overland equivalents. The future growth of these technologies will need to integrate long term climate resilience into their design.

A new generation of nuclear power plants is planned. Proposed locations for these have been identified, some of which are close to existing generation facilities - others in new locations. However, probably one of the most important issues for their long term climate resilience is their coastal locations. Consideration of both gradual sea level rises and increased storm events and associated tidal surges should be incorporated into their design. The planning for appropriate sea defences should probably be specific for each location reflecting current predictions for sea level rises; this would reduce the likelihood of over-engineering. However, some important decisions regarding which predictions for sea level rise should be used are required. Given the apparent differing views on this parameter, there may be benefits in sea defence design being itself flexible for further adaptation.

Fossil fuels will continue to play a significant role in the energy mix of the UK for the foreseeable future; however, in order for the Government to meet its targets on climate change, solutions need to be found for reducing emissions from fossil fuel power stations substantially. Carbon Capture

[35] Ernst & Young launches new study commissioned by Centrica plc – *Securing the UK's energy future – meeting the financing challenge, 2007*

and Storage (CCS) presents one such solution in that it has the potential to reduce CO^2 emitted to the atmosphere from fossil fuel power stations by up to 90 percent. CCS sites will primarily be located adjacent to fossil fuel infrastructure and will therefore be vulnerable to flood, sea level rise and storm surge. New overland pipelines will suffer potential vulnerability to subsidence and flood. Additionally, ambient air temperatures will increase cooling demands and if sea temperatures increase there may be further knock on effects on pressure (and therefore temperature) requirements in pipelines transmitting carbon sub-sea. Finally, affects on river flows from changing precipitation patterns may affect availability of sufficient cooling water for inland fossil fuel plants. Availability of sufficient cooling water in the relevant watershed will therefore require assessment or new plants with alternatives such as dry cooling technologies being identified and considered where necessary.

It is also recognised that changes in the sourcing of energy e.g. electricity from renewables rather than our current power station network requires investment in new grid infrastructure. Again, this presents opportunity for long term resilience to be integrated into initial design and investment. But what adaptation measures might be appropriate?

Clearly part of the adaptation solution would require increasing the resilience of the network itself. This might be associated with its resilience to extreme weather events but also to efficiency of operation in the increasing predicted temperatures. It is also possible that part of the adaptation response is changing societal expectations; should we expect there to be electricity black-outs or periods where gas is unavailable?

One option would be for dual fuelling for domestic heat so that households can use low carbon electricity when it is available and gas (mains grid or supplemented from local anaerobic biogas) when it is not. There will also be a requirement to maintain grid stability as the penetration of nuclear and wind increases. All the micro-generation technologies, control systems, and many efficiency measures rely on a stable grid connection. With increasingly anticipated failures in essential national energy infrastructure as a result of climatic changes (see section 5), and a gradual shift to renewable energy sources that are inherently dependent on climatic conditions (i.e. sun, wind, waves, and tides) for their electrical output, this stability in gird connection may be difficult to guarantee in the future.

Transport

Much of the anticipated investment in the short to medium term for the UK transport infrastructure will be on upgrading or replacing infrastructure. The need to adapt infrastructure to climate change is likely to overlap with work carried out to ensure the transport sector is resilient to existing risks such as flooding. Therefore this will largely be replacing roads, rails, bridges etc in the same locations. Clearly design parameters need to be considered in light of design life of the relevant infrastructure; which is already being used by key parties such as the Highways Agency and Network Rail. The use of new technologies such as sustainable drainage systems will reduce both existing and future risks of flooding.

However, there are already some specific major transport projects and others can be expected such as widespread electrification of our rail system and introduction of electric cars. Each of these is likely to require some new infrastructure, some of which may also be in new locations.

The increased electrification of the railway, for example on the lines out of London Paddington station, is planned later this century. This new infrastructure will further increase the dependency of the rail sector on electricity. The sub-sector would then be totally reliant on electric power. A critical point for long term adaptation will be for the overhead electrical lines to be designed and built for the predicted storm events and wind speeds.

It is likely that road vehicles, particularly cars and light vans, will become less reliant on fossil fuels and be powered by electric motors. This will require a new energy supply system: either battery charging / replacement points, or some form of direct supply from the road, perhaps using inductive or magnetic means. Wherever batteries are charged there will need to be a reliable electricity supply; protection from flooding will therefore be important.

New roads and bridges will need to be built using specifications for bridges that are designed for the highest predicted river flows, and highest temperature variations. They will also need to have drainage systems that are both sustainable (do not cause any increase in flood risk elsewhere) and sufficient to cater for the most intense storms.

New technologies will be developed for road surfacing, particularly those that use recycled materials such as crushed glass or shredded tyres, and their performance will be tested against the standards in use for existing materials, making due allowance for climate change effects.

The growth in the airline industry is likely to require further infrastructure on the ground: possibly new airports, new runways and longer runways. The orientation of runways, drainage systems, protection from floods, and materials used to surface the runways will all have to be designed and built to cater for long term impacts of climate change.

Ports will need to be expanded to cater to further increases in the volume of goods, and possibly the number of containers. The predicted increase in population will require a corresponding increase in the volume of goods imported and this has to come via the ports and airports. Larger berths may be needed to cater for larger cruise liners and ferries. These will have to be designed and built to cater for the long term impacts of climate change which affect ports such as sea level rise and storm surges.

Water

New infrastructure is expected for the water sector as part of the sector's response to decrease greenhouse gas emissions as well as adapting to climate change. Examples of new infrastructure include: underground reservoirs, increased membrane treatment, desalination and anaerobic digestion (biogas).

With increasing temperatures and changes to precipitation patterns, water companies may potentially face a situation where there are insufficient water resources to fill the existing or new capacity of underground reservoirs. New infrastructure may be required to maximise water storage as well as potentially supplement existing water sources with alternatives like groundwater, capturing and storing floodwater, desalination or buying water from other regions.

The potential effect of climate change on this new infrastructure includes salt water intrusion from rising sea levels on underground assets located near the coast. Also a potential increase in groundwater from a longer winter rainy season may infiltrate new underground storage and other assets. The groundwater abstraction may not be available or be contaminated from salt water intrusion. Infrastructure required to capture and store floodwater may be at risk from extreme flood events. Desalination plants may run the risk of damage from coastal erosion or storm surges and infrastructure for delivering water from other regions has the same risks as previously described for existing infrastructure.

Desalination plants are a possible solution to supplementing reducing water resources as temperatures rise and precipitation patterns change. These, however, are relatively energy intensive plants to run. Similar to membrane waste water treatment plants, there may be a need to supplement grid-sourced electricity with locally generated renewable energy in order to maintain continuous operation. This may be particularly important in light of the increasingly pressure on energy supply. Due to their inherent need to be located close to the coast, they are also particularly vulnerable to potential sea level rise, coastal erosion and flooding from storm surges. There will therefore be a need for the provision of flood protection, or alternatively for planning to account for the unsuitability of particularly high risk areas for the construction of such plants.

Solutions for these impacts include careful consideration of groundwater levels and potential salt water intrusion boundaries when constructing new infrastructure. Infrastructure for capturing and storing flood water may need to be particularly robust. Desalination plants should be located well outside any potentially hazardous areas and new infrastructure for water from other regions will need to be designed with consideration for further climate change.

Modern waste water treatment plants applying membrane technologies are particularly energy intensive. To achieve a secure energy supply for continuous operation, there may be a need to supplement energy sourced from the grid with localised renewable energy generation such as wind turbines. This would enable these plants to reduce dependence on the national grid which may increasingly become subject to failure as a result of climate change impacts as outlined in section 5. Membranes are high-tech pieces of equipment that are particularly sensitive to changing water/wastewater quality. Various forms of pre-treatment will therefore be required to deal with expected future fluctuations in incoming water quality as a result of increasing temperatures and changing precipitation patterns.

A need for renewable energy to power more extensive treatment may come from anaerobic digestion and biogas production as this method is also an effective way to reduce wastewater sludge required for disposal. Anaerobic digesters are sensitive to temperature and work better with a stable warm temperature therefore digesters located in areas that will see a decrease in temperature or experience extreme variations in temperature may be negatively impacted. Also digesters located in flood zones along side wastewater treatment plants run the same risks of fluvial flooding.

Solutions for these impacts include using a portion of the biogas to heat digesters, flood proofing digesters and/or moving digesters out of the flood zone.

Commonalities

Whilst the detailed technical solutions vary considerably, new infrastructure in all sectors will require several common issues to be dealt with. These common issues include:

- Identification of the likely impact of long-term climate change impacts on the new infrastructure and examining the possible acceptable minimum level of resilience.
- New or revised advice/constraints on design and/or construction.
- Statute and/or regulation to ensure any interconnectivities and/or interdependencies are properly addressed for the design life of the infrastructure.
- If necessary, financial controls and undertakings to ensure any operating costs are covered; again for the duration of the life of the infrastructure.

Section 8

Adaptation options

Adaptation options

Introduction

This section discusses adaptation options for the key technical risks identified and evaluated in section 5.

The options identification and appraisal process applied has been qualitative, evaluating benefits and costs through posing a series of questions and challenges across the team. The questions/challenges developed include:

- What are the potential measures that could reduce the significance of the issue or mitigate or remove it?
- Are the potential measures different for different stakeholders involved or different parts of the system?
- What are the benefits of these measures, beyond that of addressing the climate change issue?
- What are the economic and socio-environmental impacts of these measures?
- What are the existing barriers for these measures being introduced? How can these be overcome? Are there indirect benefits or impacts that are associated with addressing these barriers? Are the barriers different for different stakeholders involved?

Through this process a number of adaptation options have been identified for each of the technical risks identified in Section 5. These have been categorised into technical, operational, cultural, financial, regulatory, and repair, retrofit and replacement options. A qualitative evaluation process assessed the net benefit of each option considering the anticipated benefits versus the main barriers or challenges. This applied a number of assessment criteria which framed the overall decision on whether the net impact of an adaptation option was considered to be high, medium or low. The assessment criteria used included the following:

- Does the option have a national, regional or local impact?
- Does the option have a reversible or irreversible impact?
- Does the option lead to a gradual or a step change?
- Does the option have a short or long term impact?

Options with a national, irreversible, gradual and long term impact were considered to potentially have a higher net impact than those with a local, reversible, gradual and short term impact. Furthermore, the expert knowledge gained from previous project stages also played a key role in evaluating the net impact of each option.

Energy

For each option identified for adaptation for energy infrastructure, the outcomes of the qualitative evaluation process are summarised in Appendix D. The highest impact options for each risk areas are summarised below. In practice it is likely that a number of the options would need to be introduced to provide a robust collective response.

Risk Areas: Flooding of fuel supply infrastructure due to increased storminess, sea level risks and storm surges

Key infrastructure whether located on the coast or within flood plains is vulnerable to increased flood events expected with increased sea level, extreme weather and storm surges. This can cause severe disruption to fuel supply, particularly those that are imported.

Whilst a number of adaptation options can be identified when considering the expected benefits against the likely barriers, key options include:

- New or upgrade of (coastal) flood defence systems near affected facilities. This could include re-engineering to increase the height of quaysides.
- Development of controlled flood management zones, e.g. Alkborough on the River Humber, near affected receptors (see Box 10).
- Increase fuel storage capacity on land to mitigate for supply disruption. This could be relatively easily implemented for coal and biomass but less so for oil and gas storage which requires greater investment.
- Re-routing of supplies in the short term either temporarily or permanently. This could be an easy and cost effective investment option as it would involve the use of existing facilities. However, if it results in increased overland distribution there will be considerably higher fuel costs associated with secondary distribution. Such costs would need to be factored into a detailed cost appraisal process.
- Development of new inland ports that are less vulnerable to coastal flooding. This is clearly an expensive and radical option and likely to only be fully developed if conditions deteriorate substantially. It would require abandoning £billions of existing assets in vulnerable locations. Re-development of former major inland ports (e.g. Goole, which has recently become a thriving inland port) could provide broader economic benefits.

Box 10
The Humber Flood Risk Management Strategy 2008

There is a high risk of flooding around the Humber Estuary and the construction and adaptation of flood defences and coastal protection is ongoing. The Environment Agency has devised a Shoreline Management Plan for the Humber Estuary region[36]. This document sets out the Environment Agency's strategy for managing the flood defences of the Humber Estuary over the next 50 years. There are about 235 kilometres of flood defences in the area covered by the plan. These consist mostly of simple earth embankments between 2 and 5 metres in height. A rising sea level means that many of these embankments either currently require setting back or will require it in the future. A number of priority areas have been identified by the plan including the Alkborough Flat on the east bank downstream of Burton Stather. Significant erosion has occurred on the front of this defence line and realignment would provide benefit.

There are a number of significant barriers to overcome to deliver such a comprehensive approach. These include adequate and timely release of land and progressive, substantive stakeholder engagement. The Humber management plan commenced activity in 1997; major events took place in 2004 and the report released in 2008. Some properties, residential, commercial and industrial, will not be protected; society as a whole needs to determine what is the acceptable approach to deal with those individuals affected. The cost of defending the Humber Estuary will outstrip available central funding quickly and the Environment Agency is exploring several potential funding approaches and providers.

Combinations of the above hard and soft engineering responses would have significant net benefits. Although there are few technical barriers to these options, a number of other barriers, can be identified, such as:

- Operational barriers - holding greater stocks of fuel on land to mitigate for supply disruption would require an operational change either by the energy infrastructure or individual businesses.
- Policy barriers – a scheme such as the case study discussed above, may well require changes in land-use categorisation and potentially re-location of businesses and residential housing.
- Financial barriers - current financial models do not routinely allow long term or uncertain benefits to be considered in return on investment calculations. Capital expenditure would be required for many of the options identified, although the scale of this does vary.
- Cultural barriers – there is likely to be a negative public (and business) reaction to potentially having to abandon expensive infrastructure which will require management.

[36] Environment Agency, Planning for The Rising Tides – The Humber Estuary Shoreline Management Plan, September 2000

Risk Area: Flooding of fossil fuel and nuclear power plants

Flooding of power generation sites presents a significant risk. Nuclear and fossil fuel power station sites are already at risk from flooding, which applies to both coastal and inland infrastructure. The flooding of generation sites can be catastrophic with immediate close down procedures and de-electrification required. In addition, for nuclear sites, some critical safety measures require constant power.

There are a number of options with a high net benefit, which apply to both new and existing infrastructure, and are associated with increased protection to plants:

- New or upgrade of (coastal) flood defence systems near affected facilities.
- Development of controlled flood management zones

An alternative would also be to increase energy storage facilities that could be used to smooth supply issues. Technology requires more development in areas such as fuel cells and it is currently unclear how significant any contribution from this could be in the study timescale.

For new infrastructure, given the 25 year plus design and operational lifetimes, design specifications need to consider the projections for gradual and extreme climate over this period. It is possible that some defences can be designed and constructed with additional adaptive capacity (e.g. ready options for further increasing the height of defences); this option might stagger investment and might also avoid/minimise unnecessary investment.

Downtime for generation plant following flood events, could be significant, due to the length of repairs. Where the flood event affects a number of units on one or a number of sites this could have a noticeable impact on available electricity. Securing substantial decreases in energy consumption and increased efficiency can contribute to a more long term resilient national infrastructure. Pressure on the national grid can also be reduced by developing new distributed energy generation, including biomass and biogas; this could decrease the significance of downtime for specific generation plants.

Barriers to decreasing the impacts of flooding of fossil fuel and nuclear power plants are identified as follows:

- Operational barriers - ensuring that the necessary long-term climate impacts are considered
- Cultural barriers - changing widespread high energy consumption behaviours
- Financial barriers - current financial models do not routinely allow long term or uncertain benefits to be considered in return on investment calculations.

Risk Area: Loss of efficiency of fossil fuel power plants due to increased temperature

Anticipated increases in temperature will decrease the efficiency of fossil fuel plants, resulting in reductions in the thermal generating efficiency of power plants and potential energy shortages. Thermal power plants operate throughout the world under different climatic conditions, but in most operating environments, external air temperatures are a fact of life affecting efficiency.

There is the possibility of designing in additional cooling capacity; however there are issues associated with this such as:

- With predicted fluctuations in rainfall patterns (i.e. less summer rainfall combined with hotter temperatures), affecting water supply, there will be an increasing risk, over time, of water resource problems, or a requirement to invest in dry cooling methods. Increased operational temperatures are factors faced in many countries but through careful siting options analysis, it may be possible to avoid combinations of low water availability and high temperatures for new plants.

- Increased cooling facilities, particularly dry cooling, would comprise an expensive retrofit. There needs to be an effective mechanism to ensure that design standards properly consider predicted climate change over their planned operational life.

A more radical option, but one that could be considered for new build, is to focus investment for thermal generation in locations of the country where temperatures are likely to be cooler although the costs of providing additional transmission capacity and the transmission losses of transferring the power need to be factored in before making such a decision.

In addition, proactive measures to reduce demand of electricity can help to mitigate the supply issues as decreases in efficiency are observed associated with increasing temperature.

Barriers to decreasing the loss of efficiency of fossil fuel power plants due to increases in temperature are identified as follows:

- Operational/financial barriers -. generation plants work on a 25 – 40 year viability plan; climate change scenarios need to be built into financial models.

- Cultural barriers - changing widespread high energy consumption behaviours

- Financial barriers - current financial models do not routinely allow long term or uncertain benefits to be considered in return on investment calculations. As much of the investment in new build in energy is from the private sector this is particularly important.

Risk Area: Loss of efficiency of, and storm damage to, renewable energy sources

Key infrastructure in the renewable energy sector is subject to climate change impacts including flooding, increased cloud cover, fluctuations in rainfall and damage from severe storms. All of these have significant capacity to affect generation; with the possible consequence of electricity shortages. Whilst renewable sources are not a major contribution to the UK electricity mix at present, this issue will become more significant with increased use of renewable energy technologies.

The optimal proposals to manage the adverse impacts of climate change on renewable energy sources include the following:

- Increasing the use of new renewable energy technologies, which are evolving with improved efficiencies. .
- Regularly reviewing the optimal mix of renewable energy sources contributing to the national grid. Certain technologies could prove to be more resistant to the adverse impacts of climate change than others.
- Balancing the grid with better information technology between inputs from renewable energy sources and other energy sources as climatic conditions vary. Smart grid technology developed to help control customer demand and make the best use of available energy sources clearly has a role. Investment will be required for installation of smart grid technology.
- Spatial city wide energy and economic modelling required to establish viable operational portfolio
- Widespread understanding and action by the population to manage their energy demands more efficiently. .

Barriers to decreasing the loss of efficiency of, and storm damage to, renewable energy sources are identified as follows:

- Operational/technical barriers - the biggest barrier to a balanced energy portfolio with a strong renewable component, remains the need for a huge efficiency gain or a huge drop in energy use. There are significant technological, economic and operational constraints across the technologies.
- Cultural barriers - changing widespread high energy consumption behaviours and; social/cultural risks associated with greater employment of renewable technologies – e.g. adverse impacts on the landscape of windfarms.
- Financial barriers - huge investments in new infrastructure that may have short lifetimes due to technology improvements. This would need to be factored into financial models which could decrease attractiveness of the investment.

Risk Area: Reduced capacity of energy distribution network due to flooding and increased temperatures

Higher temperatures will impact on electricity substations and transformers and associated underground cables and overhead lines, which are often located in urban areas and subject to higher ambient temperatures (urban heat island effect) even before considering the predicted rise due to climate change. In addition, extreme weather events can cause damage to the network through flooding of specific sites (e.g. sub-stations) or damage to pylons and overhead cables.

Options for addressing the risk of flooding through increased defences have been covered above. Potential for re-location of specific high-risk sites may be an additional option for this part of the infrastructure, but would still be very costly. Furthermore, whilst pylons and overhead lines are subject to storm damage, until there is more specific experience of wind modelling, investments in strengthening this infrastructure is unlikely to take place.

Options include:

- Designing in or retrofitting increased cooling of electricity substations and transformers. Increased emphasis on cooling technologies, increased shading etc for equipment (existing and new) as well as siting new equipment in cooler locations (e.g. near river banks where appropriate flood protection exists and or areas on the edge of urban areas outside the urban heat island),.

- Decentralised energy systems with back-up access to the national grid. Although already recognised as an important part of future energy supply in some regions (e.g. London and Sheffield) there are a number of barriers

- Contingency plans should be established to enable re-routing on networks in the event of disruption.

- Encourage widespread understanding and action by the population to manage their energy demands more efficiently.

Barriers to improving the resilience of the energy distribution network to flooding and increased temperatures are identified as follows:

- Financial barriers - mechanisms need to be in place to ensure that return on investment assessments consider the long-term benefits of such expenditure.

- Policy barriers - planning permissions will be required if infrastructure needs to be re-sited. There may also be a need for policy provisions to enable changes in siting such infrastructure to be implemented when the main drivers are longer term benefits.

- Regulatory barriers - need for advance planning by OFGEM to develop the financial plans needed to deliver a robust distribution system that is resistant to the adverse impacts of climate change

- Operational barriers - requirement for energy and urban designers to work closely on the integration of energy islands into the urban framework

- Cultural barriers - changing widespread high energy consumption behaviours; lack of public acceptance of decentralised energy systems

Transport

For each option identified for adaptation for transport infrastructure, the outcomes of the qualitative evaluation process are summarised in Appendix D. In this evaluation some of the technical risks for the road and rail infrastructure have been combined as many of the adaptation options are similar. The highest impact options for each risk areas are summarised below. In practice it is likely that a number of the options would need to be introduced to provide a robust collective response.

Risk Area: Flooding of roads or rail

Roads and rail will be vulnerable to the increased frequency and severity of flooding associated with climate change. Measures have been assessed that have the greatest net impact and much of this work would build on any flood resilience work already carried out. Measures could involve a combination of:

- More frequent and improved inspection of the affected locations;
- Assessment of the infrastructure's ability to withstand the more extreme floods predicted as a result of climate change;
- Prioritisation of remedial works for those locations that are assessed as posing the highest risk of failure or disruption to service;
- Following the review into the suitability of current road infrastructure assets, repair, replace, retrofit as necessary; and
- Taking account of the findings of the above to incorporate appropriate considerations into the design of new infrastructure in light of making this more resilient to the anticipated long-term risk of floods.

Appropriate contingency planning aimed at ensuring that resources are optimally organised for the areas most affected by floods will play a key role. It has been identified as having a high net benefit due to the relatively low capital costs involved in upfront planning in comparison to emergency remediation action. This will require liaison across sectors to ensure interdependencies are covered.

The mitigation options outlined have the potential to bring about significant economic and social benefits associated with a more reliable road and rail networks and reduced need to respond to emergencies. This would also lead to lower costs over the long-term due to effective forward planning rather than reactive responses. Work done recently in Malaysia on its road network is an example from a country with a more extreme climate, where planning and prioritisation of effort reduced costs of the overall work (see Box 11).

Box 11
Overseas experience – landslide prevention on a road in Malaysia

Monsoon rains in Malaysia cause landslides on roads, so the Public Works Department in Malaysia commissioned a study to assess the risk of slopes failing. This enabled engineers to determine the areas posing the greatest risk, considering both the likelihood of a failure and the potential impact it could have on people and supply routes. The assessment led to planned measures to stabilise the highest risk slopes. It was found that pre-planned works costed about a fifth of those carried out to remedy failures.

The work shows the benefits of assessing the risks of slope failure in a region where rainfall intensities are much greater than the UK. Several infrastructure owners such as the Highways Agency and Network Rail already carry out slope surveys and assessments.

Source: ICE proceedings, August 2001, pp 129 – 134

Barriers to decreasing the impacts of flooding of roads or rail are identified as follows:

- Natural barriers - currently significant knowledge gap with respect to the actual long-term effects of climate change and associated trigger points for certain climate change parameters
- Financial barriers - mitigation actions may be perceived to be expensive in comparison to other, more immediate and better understood pressures on the limited financial resources for the sector; the implementation of identified priority mitigation options will require an appropriate investment process to recognise future benefits.

Risk Area: Scour of road or rail bridges

Many rail and road bridges crossing rivers and streams survive from Victorian times. A large number date from the first half of the 20th century. Although often designed and built to a high standard they were not designed to cope with the scouring associated with river flooding at a frequency and severity that could happen with climate change.

Roads and rail bridges will be vulnerable to scour from the increased river flows resulting from predicted increases in precipitation intensity and summer storms. Measures have been assessed that have the greatest net impact and much of this work would build on any flood resilience work already carried out. Measures could involve a combination of:

- More frequent and improved inspection of the affected bridges;
- Assessment of the bridge’s ability to withstand the more extreme flows predicted as a result of climate change;
- Prioritisation of remedial works for those bridges that are assessed as posing the highest risk of failure or disruption to service; and
- Taking account of the findings of the above to incorporate appropriate considerations into the design of new bridges in light of making this more resilient to the anticipated long-term risk of high river flows.

The mitigation options outlined above have the potential to bring about significant economic and social benefits associated with more reliable road and rail networks and reduced need to respond to emergencies. This would also lead to lower costs over the long-term due to effective forward planning rather than reactive responses.

Barriers to decreasing the impacts of scour of road or rail bridges are identified as follows:

- Natural barriers – currently significant knowledge gap with respect to the actual long-term effects of climate change and associated trigger points for certain climate change parameters

- Financial barriers - mitigation actions may be perceived to be expensive in comparison to other, more immediate and better understood pressures on the limited financial resources for the sector; the implementation of identified priority mitigation options will require an appropriate investment process to recognise future benefits

Risk Area: Moisture fluctuation in road and rail embankments

Much of the ground in Greater London is made up of London Clay. Clay is particularly vulnerable to movement when its moisture content changes. With drier summers and wetter winters as a result of climate change it is expected that roads and rail lines that are sited on clay embankments will be vulnerable to movement and therefore closure.

The adaptation options assessed as having a high net benefit include a combination of:

- Monitoring the movement in existing embankments;

- Better inspection and assessment regimes for vulnerable clay embankments aimed at assessing their current condition and their ability to withstand more extreme temperature and weather conditions as the climate changes;

- Prioritising remedial works for those locations that are assessed as posing the highest risk of failure or disruption to service, particularly considering the possible impact of the high emissions scenario.

- Strengthening the embankments identified as vulnerable to movement as necessary.

Appropriate contingency planning aimed at ensuring that resources are optimally organised for the embankments most affected will also play a key role. This has been identified as having a high net benefit due to the relatively low capital costs involved in upfront planning in comparison to emergency remediation action.

Barriers to decreasing the impacts of moisture fluctuation in road and rail embankments are identified as follows:

- Technical barriers - a significant barrier for establishing an efficient programme for remedial work is the lack of knowledge of the asset, stemming from a lack of assessments currently carried out on road and rail embankments, and those assessments that are made very rarely consider the forecasts predicted by climate change

- Natural barriers – lack of understanding of the actual long-term effects of climate change

- Financial barriers - mitigation actions may be perceived to be expensive in comparison to other, more immediate and better understood pressures on the limited financial resources for the sector; the implementation of identified priority mitigation options will require an appropriate investment process to recognise future benefits

Risk Area: Overheating of underground trains

London Underground was largely designed and constructed over 75 years ago. Operational advances have significantly increased the frequency of train movements through the tunnels but this greater consumption of energy results in higher temperatures, particularly on the narrower single-track deeper-ground lines. Further predicted increases would add to the problem, as would increases in the ambient temperature due to climate change. Transport for London's Cooling the Tube[37] project is currently studying this risk.

The solution to this risk identified as having the greatest net benefit will be to initially carry out a detailed study of the problem. It may be possible to introduce and utilise systems and technologies as they emerge to cool underground infrastructure at certain stations. Retrofit of equipment with current technology to increase cooling of underground trains has been shown, however, to further increase energy demand.

Similarly to other adaptation options discussed, it would be prudent to implement an emergency planning regime to be better prepared to cope with the adverse health reactions from passengers in the event of underground trains overheating, as this on the whole will be far more cost efficient than emergency remediation action.

Barriers to decreasing the impacts of overheating of underground trains are identified as follows:

- Operational barriers - requires liaison across sectors, particularly the energy sector on which the trains rely; also requires thresholds to be set, to determine when such plans should take effect.

Risk Area: High winds, storms, and changing wind direction at airports

Predicted climate changes impacts which are likely to impact on airport infrastructure are the greater frequency and severity of high wind and storms, as well as changes in the wind direction. Weighing the expected benefits against the likely barriers and constraints to implementation, adaptation options with the greatest net impact for the addressing the vulnerability of airports to these risks are considered to be the following:

- Improved forecasting of imminent storms may also reduce the risks to airports, as planes can be safely grounded, or diverted to airports where effects are likely to be less severe.
- Better contingency planning for the passenger and freight implications of airport closures, as well as for greater limitations on operational times due to weather conditions. This will require liaison across sectors to ensure dependencies are covered.
- The new Infrastructure Planning Commission should help ensure the incorporation of climate change adaptation in new airports.

[37] Transport for London, Cooling the Tube, June 2008, http://www.tfl.gov.uk/corporate/media/newscentre/archive/8694.aspx

A much greater potential net benefit would be gained from incorporating considerations of potentially changing wind direction and strength into design of new airports or airport expansions, such as the possible new runways at Heathrow and Stansted. Also, improved contingency planning increasing the preparedness of airport operators to extreme weather events are considered to have a high net benefit. This could include diversion of flights to alternative airports if crosswinds or extreme weather conditions at the intended airport make landing impossible.

There are a number of landuse, political, environmental, social constraints associated with the implementation of the identified adaptation options for decreasing the impacts of high winds, storms, and changing wind direction at airports. These are identified as follows:

- Natural barriers - uncertainties associated with how wind direction and strengths may change with a changing future climate are likely to make investment decisions for the implementation of identified adaptation more difficult to justify
- Cultural barriers - people's non-flexible attitude with respect to acceptance of delays and forced itinerary changes increases pressure on critical transport hubs
- Financial barriers - the large financial costs associated with retrospectively making amendments to airport layouts and re-orientation of airport runways are likely to prove inhibitive

Risk Area: High tides, high winds and changing wind direction at ports

Predicted climate change impacts which are likely to impact on port infrastructure are the greater frequency and severity of storm surges, changes in the tidal range and wind direction. Weighing the expected benefits against the likely barriers and constraints to implementation, adaptation options with the greatest net impact for the addressing the vulnerability of ports to these risks are considered to be the following:

- Improved forecasting of imminent storms may also reduce the risks to ports, as ships can be safely moored, or diverted to ports where effects are likely to be less severe.
- Better contingency planning for the freight implications of dock closures (e.g. 'Operation Stack' which uses the M20 as a lorry park during ferry closures), as well as for greater limitations on operational times due to adverse tidal conditions. This will require liaison across sectors to ensure interdependencies are covered.
- Retrofitting more resistant flood defences as required, including possible re-alignment of docks to minimise disruption caused by changing winds.
- The siting and location of new ports, docks and expansions needs to consider greater tidal ranges.
- The new Infrastructure Planning Commission should help ensure the incorporation of climate change adaptation in new ports.

If implemented, the measures outlined are likely to lead to significant economic and social benefits associated with a more reliable transport network. Costs are also likely to be reduced over the long-term due to effective forward planning rather than reactive responses

Barriers to decreasing the impacts of high tides, high winds and changing wind direction at ports are identified as follows:

- Natural barriers - uncertainties associated with how wind direction and strengths may change with a changing future climate are likely to make investment decisions for the implementation of identified adaptation more difficult to justify.
- Cultural barriers - people's non-flexible attitude with respect to acceptance of delays and forced itinerary changes increases pressure on critical transport hubs.
- Financial barriers - the large financial costs associated with retrospectively making amendments to port layouts are likely to prove problematic.

Water

For each option identified for adaptation for water infrastructure, the outcomes of the qualitative evaluation process are summarised in Appendix D. The highest impact options for each risk areas are summarised below. In practice it is likely that a number of the options would need to be introduced to provide a collective robust response.

Risk Area: Reduced security of supply due to changing precipitation patterns and higher temperatures

This risk relates to the impact climate will have on the quality and quantity of water.

Weighing the expected benefits against the likely barriers and constraints to implementation of the adaptation measures identified, water recycling potentially has the highest net benefit for adaptation of water infrastructure to security of supply. Treating wastewater effluent to a high standard for potable water use is currently a viable technology and would create virtually a 'closed-loop' system greatly reducing the need for fresh water sources. Although this would create a secure water source, the issue of increased energy consumption associated with this level of wastewater treatment may not make this a sustainable solution. It could also be impacted by activities in the energy sector. Box 12 provides a case study on water recycling.

Box 12
Case Study : New Goreangab Water Reclamation Plant, Windhoek, Namibia

The capital of Namibia, Windhoek, is located in a semi-desert region in the most arid country in Southern Africa. The 250,000 people who live in the city are responsible for approximately 90% of the total water consumed in Namibia's central region. One of the main sources of drinking water is rainwater collected in reservoirs. Inconsistent rainfall and increasing pollution of reservoirs mean security of water supply is a growing challenge. New technical interventions were introduced in 2002 to increase the capacity of the Goreangab water treatment plant (now known as the Goreangab water reclamation plant). The plant now incorporates technologies such as ozonation and membrane ultra-filtration to allow for the recycling of waste water (reclamation) so that it may be reused as drinking water. Raw sewage is pumped into the facility and undergoes a number of purification processes, before it is blended in a 35:65 ratio with water extracted from boreholes and reservoirs and distributed as drinking water. Previously the the "Old" Goreangab Plant could supply 7,500 m3 of drinking water per day, the plant now has the capacity to supply 21,000 m3 of water per day, which is about 35% of the city's total demand[38].

Increasing capacity and structural stability of storage may also have a high net benefit for adaptation to security of supply. Dredging reservoirs, reinforcing dams, creating new reservoirs and underground storage are all examples of potentially effective adaptation measures.

Operational and cultural adaptation measures could be implemented immediately as they are fairly low cost options and represent an important component to a sustainable solution for security of supply. Any technical improvements implemented by the utilities will be dependent on regulatory and financial policy frameworks and interventions.

There are few technical barriers to increasing the security of supply, as all of the identified technology currently exists. However, a number of other barriers are identified as follows:

- Natural barriers - no alternative water sources available.
- Operational barriers - lack of willingness for utilities to work together.
- Cultural barriers - lack of appreciation for potential impacts and recognition this is a 'societal issue' and not a 'utilities issue', also unwillingness to accept the concept of water recycling for potable use.
- Regulatory barriers - all infrastructure spending must be approved by regulators.
- Financial barriers - high cost to implement and people typically do not want to pay more for water and sewer services - this is also a cultural issue.

[38] Petrus L. Du Pisani, Surviving in an arid land: Direct reclamation of potable water at Windhoek's Goreangab Reclamation Plant. December 2006 Available from: http://ag.arizona.edu/oals/ALN/aln56/dupisani.html Accessed: 10th December 2009

Risk Area: Increased sewer (pluvial) flooding due to increased precipitation and storm surges

Increases in the frequency and intensity of storms may put pressure on the capacity of sewers to deal with large volumes of surface water resulting in more frequent sewer flood events. Sewer flooding can be reduced in one of two ways:

a. Prevent storm water from entering the sewer at the source; and

b. Increase the capacity of the sewer and treatment system to accommodate additional flow.

Adaptation options can be identified that comprise operational, technical, cultural, financial and regulatory interventions.

Of the adaptation measures identified, the control of surface water run-off using Sustainable Drainage Systems (SUDS) would have the highest net benefit for adaptation of water infrastructure against sewer flooding as they make drainage more effective and robust to changes in climate. SUDS have already been successfully implemented at a number of sites in the UK, demonstrating that a SUDS solution is available for every site (see Box 13 overleaf).

Separating existing combined sewers and increasing pipe diameter would also have a significant benefit but the costs may not be feasible. In practice it is likely that a combination of many of these impacts will be required.

Previously the use of SUDS has been inhibited by operational and financial barriers. Currently there is a lack of clear jurisdiction for the adoption and maintenance of SUDS, while developers have an automatic right to connect to the water sewer. Both of these issues disincentivise the use of SUDS. Concerns have also been raised about the cost of using SUDS.

The Draft Flood and Water Management Bill 2009[39] would remove these operational and financial burdens:

- A new SUDS Approving Body would have responsibility for the approval, adoption and maintenance of SUDS.
- The costs of SUDS are not expected to exceed the costs of conventional drainage.
- National standards for SUDS covering design, construction, operation and maintenance will help developers and local authorities determine a suitable sustainable drainage system, taking account of site conditions.

[39] House of Commons Environment, Food and Rural Affairs Committee, The Draft Flood and Water Management Bill, September 2009, http://www.parliament.uk/parliamentary_committees/environment__food_and_rural_affairs/efra_draft_flood_and_water_bill.cfm

Box 13
Case Study : Dunfermline Eastern Expansion

The Dunfermline Eastern Expansion (DEX) is a large area in Scotland which will be developed over the next 20 years as a mixture of industrial, commercial, residential and recreational areas. This site is the largest site in the UK to use SUDS. Initially plans to introduce SUDS were motivated by the risk associated with the poor quality and high volumes of run off affecting areas downstream of the development.

The area comprises watersheds which are divided into a number of sub-catchments connecting into a SUDS network incorporating the following elements[40]:

- Soakaways: These are used for some residential roads to divert storm and rain water away from the over-burdened sewer systems.
- Filter drains and swales: Much of the road system is drained using filter drains into large swales which provide attenuation and filtration of the run-off.
- Detention basins, ponds and wetlands: These serve adjoining housing areas and large areas of open land to allow for attenuation and treatment of surface water before it is discharge to nearby watercourses at Linburn, Keithing Burn and Pinkerton Burn. The ponds and basins are very large scale and have been designed to hold the runoff that can be expected from up to 90% of storms occurring in a single year.
- Permeable paving: This has been used in a Tesco car park and allows water to be absorbed into the paving structure for temporary storage before it is dispersed into the connecting basins and wetland.

The introduction of SUDS has brought many advantages including: the improved flood control and management of storm water; reduced pollution to rivers and aquifers due to run off and better recharging of groundwater and aquifers.

Operational adaptation measures could be implemented immediately as they are fairly low cost options and represent an important component of a sustainable solution for security of supply. In practice it is likely that a combination of different measures will be required to tackle the problem of sewer flooding. For example, the separation of existing combined sewers and an increase in pipe diameter would also have a significant impact. However, implementation of this is inhibited by operational and financial barriers and the separation of existing combined sewers would take decades and be extremely expensive.

Since the majority of sewer networks are under roadways, separating the combined sewers could have localised temporary impact on the transportation network in areas of construction. Any technical improvements implemented by the utilities would be dependent on regulatory and financial frameworks and policies and real-time monitoring and 'smart' telemetry will be reliant on communications systems.

Although there are few technical barriers to the prevention of sewer flooding, a number of other barriers, in addition to the financial and operational barriers outlined above, can be identified, such as:

- Operational barriers - lack of ownership for SUDS (although the Floods and Water Management Bill will help to resolve this)

[40] CIRIA. Available at: http://www.ciria.org.uk/suds/

- Cultural barriers - lack of appreciation for potential impacts and recognition this is a 'societal issue' and not a 'utilities issue'
- Regulatory barriers - all infrastructure spending must be approved by regulators
- Financial barriers - cost of separating existing combined sewers

Risk Area: Increased Fluvial Flooding due to increases in frequency and intensity of storms

Water and wastewater infrastructure is at risk from increased fluvial and coastal flooding due to increased precipitation and storm surges as well as their physical proximity to water sources. All of the identified measures for protection against sewer flooding will also be relevant when discussing overall flood risk to infrastructure, but the additional adaptation measures identified here relate specifically to protection from fluvial flooding as in rivers overflowing banks. There are primarily two ways to protect infrastructure from fluvial flooding:

- increased engineered flood protection or
- move the infrastructure out of the flood zone.

The highest net benefit for these options is likely to increase engineering flood protection for existing infrastructure, such as treatment works, while locating new infrastructure away from the flood zone. To illustrate this Box 14 identifies a relevant case study.

Typically water and wastewater infrastructure is located in the most hydraulically favourable place to minimise pumping. Moving or constructing new infrastructure out of the flood zone may cause a need for increased energy consumption for pumping which would result in an increase in carbon footprint for the utilities and therefore would be interrelated and potentially impacted by activities in the energy sector.

Barriers to these measures are primarily financial and regulatory.

- Regulatory barriers - all infrastructure spending must be approved by regulators
- Financial barriers - high cost to implement and people typically do not want to pay more for water and sewer services- this is also a wider societal issue.

Box 14
Case Study : King Country Sewage Plant, Seattle, USA

There is a high risk of flooding around the heavily developed area that sits below the Howard Hanson Dam in the Green River Valley, South of Seattle. The dam was subjected to record levels of water in the winter of 2008 which has resulted in depressions forming in the earth supporting the damn. As a result more water is seeping into the damn limiting the amount of water that it can hold back. Heavy rainfall could cause severe floods. In particular this could impact the South Wastewater treatment plant which serves more than 1.5 million people within the King County's region41.

Various measures are being implemented to increase resilience to flooding, including the construction of a floodwall comprising of giant rubber and fabric tubes that can be filled with water and work like sand bags. The Floodwall barriers are being used at a plant entrance and other vulnerable areas. The plant also currently has dual power feeds and onsite power generation capabilities to keep equipment running, in addition to secure emergency generators and diesel fuel that can provide up to 18 megawatts of back-up power if required.

Risk Area: Increased Pollution Incidents due to changing precipitation patterns and higher temperatures

This risk is indirectly related to climate change but has significant implications for wastewater treatment. As a result of drier summers and more variable rainfall patterns during spring, and autumn reduced water levels of a watercourse receiving treated wastewater effluent will typically have less ability to dilute the discharge.

As described in section 5,, there are a number of ways pollution incidents could potentially increase due to climate change. The primary causes of a pollution incident would include insufficient wastewater treatment for the receiving water quality, uncontrolled discharge from combined sewer overflows (CSOs) during a storm event, cracked or damaged network sewer pipes from ground movement or erosion and wash out of a treatment works during a flood.

Of the adaptation measures identified, SUDS, CSO abatement and improving the level of treatment and effluent quality at wastewater treatment plants either with existing or new infrastructure potentially have the highest net benefit for adaptation of water infrastructure to climate change in regards protection against pollution incidents. Separating existing combined sewers would also have a significant benefit but the costs may not be feasible.

Operational adaptation measures could be implemented immediately as they are fairly low cost options and represent an important component to a sustainable solution for prevention of pollution incidents. Implementation of the various identified technical adaptation measures are all currently technically feasible, although separating combined sewers throughout the network or switching to decentralised treatment would take decades to implement. Any technical improvements implemented by the utilities will be dependent on regulatory and financial adaptation frameworks and policies.

[41] King Country website. Available at:http://www.kingcounty.gov/environment/wtd/About/System/South.aspx

Box 15
Case Study : Reducing pollution from Combined Sewer Overflows – Muddy Creek, Ohio

The Muddy Creek drainage area is located in Ohio and comprises 19,195 aces of land adjacent to the Ohio River. The area is served by a waste water treatment and sewer system which includes a Combined Sewer Overflow (CSO). The CSO is responsible for discharging untreated, raw sewage into local waterways when there is too much wastewater for the sewer system and treatment plants to handle. As the area is vulnerable to flooding, it is particularly important that the sewer system has the capacity to handle large volumes of water so as to reduce pollution by untreated sewage to the environment. During wet weather, the primary source of bacteria in Muddy Creek is CSOs (94% annually); with storm water runoff the second largest source (6% annually). Measures have been implemented to reduce pollutant loads from CSOs to receiving waters, these include:

- Increasing the number of sewer lines and transport tunnels as well as the capacity the pumping stations and CSO treatment facilities. The sewage system is now able to handle a peak volume of 35 gallons of water per day.
- Incorporating improved wastewater treatment technologies such as off-line sedimentation tanks, fine screening and chemical disinfection.
- Reducing the amount of storm water entering the sanitary sewers.

These improvements have resulted in an 83 percent reduction in CSO volume per year (653 million gallons).

Source: The Metropolitan Sewer District of Greater Cincinnati (MSDGC), Reducing Raw Sewage Overflows, Muddy Creek Watershed. http://www.msdgc.org/downloads/overflows/fact_sheets/fact_sheet_muddy_creek.pdf

Technical adaptation measures such as improved effluent treatment may require an increase in energy consumption and cause an increase in carbon footprint for the utilities and therefore would be interrelated and potentially impacted by activities in the energy sector. Also, since the majority of sewer networks are under roadways, separating the combined sewers could have localised temporary impact on the transportation network in areas of construction.

There are few technical barriers to decreasing the risk of pollution incidents, as all of the identified technologies currently exists. Other barriers have been identified as follows:

- Natural barriers - irreversible changes to the receiving water bodies preventing effluent discharge
- Operational barriers - lack of ownership for SUDS
- Cultural barriers - lack of appreciation for potential impacts and recognition this is a ‘societal issue’ and not a ‘utilities issue’
- Regulatory barriers - all infrastructure spending must be approved by regulators and environmental regulations discourage private decentralised treatment when centralised treatment is readily available
- Financial barriers - high cost to implement and people typically do not want to pay more for water and sewer services- this is also a wider societal issue

Cross-Sectoral Adaptation Options

The individual option appraisal work has identified a number of barriers for each of the defined technical risks. These are summarised in Table 11 below. A review of these identifies a series of recurring common adaptation options were identified when carrying out the assessment of options for each sector. These have been given particular attention in section 9 on potential solutions as their cross-sectoral nature makes them particularly attractive solutions for further investigation in that their impact is likely to be more far reaching than adaptation options with a likely impact on one specific sector only. Key cross-sectoral adaptation options identified include:

- Improve understanding by the general public with respect to the impacts of climate change adaptation leading to a broader recognition of limitations placed on the energy, transport and water sectors with respect to their ability to adapt to these impacts.
- Improve maintenance, inspection and assessment regimes for all aspects of the vulnerable infrastructure.
- Implement appropriate contingency planning regimes aimed at ensuring that resources are optimally organised for the infrastructure elements most affected by specific climatic changes. These comprise a greater net benefit due to the relatively low capital costs involved in upfront planning in comparison to emergency remediation action.
- Improved forecasting of climatic extremes in order to increase the time available for emergency response.
- Ensure all new infrastructure considers the long-term impacts of climate change in the planning stage.

Table 11: Key barriers to change identified for the reviewed technical risks

Risk Area	Barriers Identified
Energy	
Flooding of fuel supply infrastructure due to increased storminess, sea level risks and storm surges	• **Operational** e.g. holding greater stocks of fuel on land would require change either by the energy infrastructure or individual businesses. • **Policy** e,g. a broad flood management scheme may well require changes such as land-use categorisation, re-location of businesses and housing. • **Financial** e.g. current financial models do not routinely allow long term or uncertain benefits to be considered in return on investment calculations. • **Cultura**l e.g. reaction to having to abandon expensive infrastructure.
Flooding of fossil fuel and nuclear power plants	• **Operational** e.g. ensuring that long-term climate impacts are considered. • **Cultural** e.g. changing energy consumption behaviours. • **Financial** e.g. current models do not allow long term or uncertain benefits to be considered in return on investment calculations.
Loss of efficiency of fossil fuel plants due to increased temperature	• **Operational/financial** e.g. generation plants work on a 25 – 40 year viability plan; climate change scenarios need to be built into financial models. • **Cultural** e.g. changing energy consumption behaviours. • **Financial** e.g. current models do not allow long term or uncertain benefits to be considered in return on investment calculations.

Risk Area	Barriers Identified
Loss of efficiency of, and storm damage to, renewable energy sources	• **Operational/technical** e.g. the need for a huge efficiency gain or a huge drop in energy use. • **Cultural** e.g. changing widespread high energy consumption behaviours and; social/cultural risks associated with greater employment of renewable technologies. • **Financial** e.g. investments in new infrastructure may have short lifetimes due to technology improvements.
Reduced capacity of energy distribution network due to flooding and increased temperature	• **Financial** e.g. mechanisms need to be in place to ensure that return on investment assessments consider the long-term benefits of such expenditure. • **Policy** e.g. planning permissions will be required if infrastructure needs to be re-sited. • **Regulatory** e.g. need for advance planning by OFGEM to develop financial plans. • **Operational** e.g. requirement for energy and urban designers to work to integrate energy islands into the urban framework. • **Cultural** e.g. changing energy consumption behaviours and lack of public acceptance of decentralised energy systems.
Transport	
Flooding roads or rail	• **Natural** e.g. knowledge gap for long-term effects of climate change and associated trigger points. • **Financia**l e.g. mitigation actions may be perceived to be expensive in comparison to other more immediate pressures
Scour of road or rail bridges	• **Natural** e.g. knowledge gap with respect to the actual long-term effects of climate change and associated trigger points for certain climate change parameters • **Financial** e.g. mitigation actions may be perceived to be expensive in comparison to other more immediate pressures
Moisture fluctuation in road and rail embankments	• **Technical** e.g. lack of knowledge of assets as assessments that are made very rarely consider climate change • **Natural** e.g. lack of understanding of the long-term effects of climate change • **Financial** e.g. mitigation actions may be perceived to be expensive in comparison to other more immediate d pressures on the limited financial resources for the sector
Overheating of underground trains	• **Operational** e.g. liaison across sectors, particularly the energy sector on which the trains rely
High winds, storms and changing wind direction at airports	• **Natural** e.g. uncertainties associated with how wind direction and strengths may change with a changing future climate • **Cultural** e.g. people's attitude to delays and forced itinerary changes • **Financial** e.g. costs associated with retrospectively making amendments to airport layouts
High tides, high winds and changing wind direction at ports	• **Natural** e.g. uncertainties on wind direction and strengths are likely to make investment decisions more difficult to justify. • **Cultura**l e.g. people's attitude to delays and forced itinerary changes • **Financial e.g.** costs associated with retrospectively making amendments to port layouts

Risk Area	Barriers Identified
Water	
Reduced security of supply due to changing precipitation patterns and higher temperatures	• **Natural** e.g. no alternative water sources available. • **Operational** e.g. lack of willingness for utilities to work together. • **Cultural** e.g. lack of appreciation for potential impacts and recognition this is a 'societal issue' and not a 'utilities issue', also unwillingness to accept the concept of water recycling for potable use. • **Regulatory** e.g. spending must be approved by regulators. • **Financial** e.g. high cost to implement and people typically do not want to pay more for water and sewer services
Increased sewer (pluvial) flooding due to increased precipitation and storm surges	• **Operational** e.g. lack of ownership for SUDS • **Cultural** e.g. lack of appreciation for potential impacts and recognition this is a 'societal issue' and not a 'utilities issue' • **Regulatory** e.g. infrastructure spending must be approved by regulators • **Financial** e.g. cost of separating existing combined sewers
Increased fluvial flooding due to increases in frequency and intensity of storms	• **Regulatory** e.g. infrastructure spending must be approved by regulators • **Financial** e.g. high cost to implement and people typically do not want to pay more for water and sewer services
Increased pollution incidents due to changing precipitation patters and higher temperatures	• **Natural** e.g. irreversible changes to the receiving water bodies • **Operational** e.g. lack of ownership for SUDS • **Cultural** e.g. lack of appreciation for potential impacts and recognition this is a 'societal issue' and not a 'utilities issue' • **Regulatory** e.g. environmental regulations discourage private decentralised treatment when centralised treatment is readily available • **Financial** e.g. high cost to implement and people typically do not want to pay more for water and sewer services

Section 9

Discussion: overcoming barriers and challenges

Discussion: overcoming barriers and challenges

Introduction

A systematic review of the adaptation options developed to address sector specific technical risks (Section 8) has identified a number of common barriers and constraints that will require national, cross sector action. These barriers and constraints also reflect the messages gathered during the stakeholder consultation sessions. Key issues to be resolved include:

Investment	How to ensure that investment in adaptation is incorporated into new infrastructure investment and/or refurbishment of existing infrastructure?
Policy, Standards and Design	How to ensure that policy, standards and design for new and existing infrastructure ensures that the long-term impacts of climate change are considered?
Business Operations	How to incorporate the issue of resilience of climate change into operational business decisions so that monitoring and planning for the impacts become part of core business operations?
Interdependencies	How to identify key interdependencies and vulnerabilities within and between the three infrastructure sectors so that appropriate and robust cross sector solutions can be developed?
Knowledge and Awareness	How to ensure that the climate change projections, science and impacts are better understood by those in the planning, investment and asset management for infrastructure so that appropriate measures are incorporated into the decision making process?
Societal Expectations	How to manage the expectations and demands of society to enable greater appreciation of the strains that climate change may put on infrastructure and key services (e.g. water and energy supply)?

Development of solutions for these issues is needed to provide the policy, regulatory, investment and operational framework that will enable improvements to the long term resilience of the national infrastructure. However, it is important when considering solutions for such issues to recognise and reflect the complexity of the three sectors. Whilst there are some commonalities, there is not one single business, operational or investment model. Detailed analysis of the themes is therefore required to develop solutions that will be effective across and within energy, transport and water sectors.

Each of the six themes is explored in more detail in this section and options for making progress relating to these are presented at the end of this report.

Maximising availability of investment

Options available to increase the availability of investment in adapting new and existing infrastructure includes:

- Establishing a system for financial bonds or insurance to cover maintenance for major or highly vulnerable national infrastructure or networks.
- Establishing a system for investment in new and existing infrastructure to consider long term resilience to change change; matching design or operational life with predicted climate change impacts.

There is a clear need for investment in adaptation measures to be available at the right time for both new infrastructure and/or technologies and for improvements to existing infrastructure. Designing and constructing more resilient new infrastructure is likely to have associated financial implications therefore, determining what is the "right time" for the investment to adapt existing infrastructure is critical.

This is likely to vary widely so a key challenge is making the case for investment 'now', when the impact may not be seen until decades later (i.e. investing in extra capacity/flexibility to allow for adaptation to occur rather than expensive retrofit or in the worst case, abandoning of the infrastructure).

Traditional investment appraisal processes for projects seek to identify robust and relatively short term returns on investment. For example regulators assessing the effectiveness of public spending need to demonstrate value for money to the customer, i.e. balancing effective service delivery and minimising price increases.

A wide range of investment models (e.g. regulated, government funded, private funded) exist in these three sectors. For example in the regulated elements of the water (water supply and waste water treatment) and energy (electricity and gas transmission and distribution) sectors, whilst decisions for investment are made via investment plans, the regulator is required to review investment planning to ensure customer value for money. Whereas in unregulated privately owned elements of the sectors (e.g. the ports sector, electricity generation), investment decisions are made by solely by private investors. Investment in new and existing infrastructure must be required to consider long term resilience to climate change; matching design or operational life with predicted climate change impacts.

Another aspect to be considered is how to fund monies for long-term maintenance to ensure that infrastructure designed to be resilient retains this function throughout its design or operational life. In the road sub-sector there are currently certain provisions around maintenance fees for local roads as managed though the Section 106 agreement process. Whilst an interesting model, this process assumes that the nature of maintenance activities is clearly defined and known at the time of the asset construction; something that is not the case in terms of long term climate change adaptation. Another model could include establishing a system for financial bonds or insurance to cover maintenance for certain major critical infrastructure or networks. For such a system to be successful it requires careful consideration of how it could work, what is the correct amount of provisioning, who would own or control the monies etc.

In practice, the approach for these sectors might need to vary slightly for to reflect the sector complexities; however, the waste decommissioning fund required for nuclear power plants could provide some thoughts on a model (see Box 15). If the maintenance funds are not used, provision would also need to be made around who the money returned to.

Box 15
Nuclear decommissioning Funds

Companies that operate a nuclear power plant are required to have a number of types of decommissioning funds:

- An external sinking fund that builds up money for decommissioning gradually over the plant's operating lifetime. Revenues earmarked for decommissioning are collected from customers through rates and invested in a trust fund that is professionally managed.
- A prepayment account in which the company deposits money before the plant begins operation. The account may be a trust, escrow account, government fund, certificate of deposit or government securities. It is kept separate from a company's other assets and is outside its control.
- A surety bond, letter of credit or insurance, which guarantees that decommissioning costs will be paid if the company defaults on its obligation.

Potential solutions need to reflect the different business and investment models within and across the three key infrastructure sectors. It is recognised that the design life for much of the infrastructure in the three sectors is medium to long-term and that consideration needs to be given now for infrastructure that will still be operational well beyond 2050. If appropriate measures for incorporating adaptation considerations into infrastructure investment are not taken in the short term, significant risks of climate change on infrastructure may occur in the future resulting in disruption and failure with considerable economic impact.

Any approach needs to recognise that investing in preventative action rather than reactionary basis is a challenge; as return on investment cannot be guaranteed.

The timescales for 'payback' of investments in new or replacement infrastructure must allow for the potential impacts of future climate change to be considered and accounted for. This needs to be reflected in the decision making processes of both regulators and private investors for infrastructure.

Developing policy, standards and design

Options available to develop policy, standards and design to encourage adaptation for long-term climate change include:

- Development of over-arching national, and sector/region specific standards for the design of new and retrofit of existing infrastructure with respect to climate change adaptation;
- Integrate measures into the planning system to ensure the appropriate considerations of climate change resilience occurs in the planning stage – this has been started in documents such as the Draft National Policy Statement for the energy and ports sectors.

A general lack of consistency in approaches to long-term climate change adaptation is identified both across and within the three key infrastructure sectors. This can be attributed to a lack of over-arching national, sector and regional specific standards for the design of new, and retrofit of existing, infrastructure with respect to climate change adaptation.

Policy, standards and design need to take account of new infrastructure, retrofit of existing infrastructure (e.g. existing bridge) for increased resilience to climate change impacts and retrofit for improvement to the infrastructure itself (e.g. end of life of plant, increasing capacity etc). It is though recognised that there will not be a single solution that applies to all three, rather there will need to be a suite of solutions but usefully found in one single document/strategy.

There is also a lack of information on how to consider the interdependencies with other sectors when assessing infrastructure investment. As interdependencies between sectors are critical for functionality, a systematic process for evaluating and assessing interdependencies and potential supply and demand issues to the impacts of climate change will be vital.

The current planning system provides a number of mechanisms that could form the basis to ensure that appropriate considerations of climate change resilience occurs in the planning stage such as:

- The draft National Policy Statements for the energy and ports sector issued in November 2009[40],[41].
- The existing Planning Policy Statement (PPS) on Climate Change[42] (supplement of PPS1) that sets out how planning by regional planning bodies (preparation of Regional Spatial Strategies) and planning authorities (preparation of Local Development Documents) should take into account the unavoidable consequences of climate change.

However, specific guidance on systematic review of planning applications at a regional and local level for climate adaptation is needed to provide additional coverage of this issue, especially interdependencies. Any such guidance at a planning application level would need to clearly define for both project developers and planners what “appropriate” climate adaptation provisions might be.

Integrating solutions into the planning process, however, will not capture all infrastructure construction. This is particularly important for sectors where the focus of investment is expected to be on upgrades and maintenance (e.g. much of the water and transport sector) rather than new build. Ensuring that the appropriate requirements and specifications are reflected in standards will be important.

The engineering profession and infrastructure owners have a key responsibility and role to ensure that these standards are appropriate for the long term projected climate change so that existing infrastructure is able to adapt.

However, without greater understanding of trigger points for certain climate change parameters there may be a significant knowledge gap associated with developing such standards.

40 Department for Energy and Climate Change, Draft National Policy Statement for energy infrastructure, November 2009, https://www.energynpsconsultation.decc.gov.uk/

41 Department for Transport, Draft National Policy Statement for Ports, November 2009, http://www.dft.gov.uk/consultations/open/portsnps/

42 Communities and Local Government, Planning Policy Statement: Planning and Climate Change - Supplement to Planning Policy Statement 1, December 2007, http://www.communities.gov.uk/publications/planningandbuilding/ppsclimatechange

Changing operational practices

Options available to change operational practices to better integrate adaptation to the long-term impacts of climate change in businesses include:

- Develop mechanisms to help businesses operate both long and medium term business planning;
- Encouraging businesses to recognise the cross departmental nature of climate change: adaptation is not something that can be the sole responsibility of the environmental or climate change teams.

Existing business structures and systems tend to focus on timescales of 6-12 years. In consequence, there is little existing practice or focus on planning for longer timeframes. As.a result there are few mechanisms for considering long-term impacts of climate change. There needs to be a clear incentive for long-term operational planning to be integrated into existing business processes. Tackling this issue requires action and commitment at all levels of organisations, as well as across a number of internal disciplines. This is not something that an organisation's climate change or environmental team can address alone.

Consequently, climate change adaptation needs to build on existing resilience work and should be integrated into many business processes including project appraisal processes; design standards and requirements; system monitoring and maintenance planning; risk management; supply chain management; procurement of services; and, emergency and contingency planning.

The Adaptation Reporting Power under the Climate Change Act 2008[43] gives the Government authority to ask public sector organisations and statutory undertakers to assess the risks that climate change poses to them, the actions they are going to take in response to these and report on the findings of this assessment. This will enable the organisations covered by this regulation to examine their risks adequately, including those to their buildings, staff, services and operations, supply lines, customers and stakeholders or regulatory functions. However, not all organisations that manage and operate infrastructure in these sectors are covered by these regulations. Alternative mechanisms of driving change are also required.

It may also be possible for climate change adaptation issues to be incorporated into existing permitting mechanisms for certain sectors and organisations, for example environmental permits issued by the Environment Agency.

Inter- and intra- sector solution planning

Options available to encourage inter- and intra- sector planning include:

- Achieving wide recognition of the reliance that each sector has on the others operationally;
- Developing forums and mechanisms for inter- and intra- sector engagement; and

[43] Department for Environment, Food and Rural Affairs, Adapting to Climate Change: Ensuring Progress in Key Sectors - 2009 Strategy for exercising the Adaptation Reporting Power and list of priority reporting authorities, November 2009,

- Increasing understanding of each of the individual sectors, the interdependences and key vulnerabilities including with the ICT sector.

There is not enough recognition of interdependency; that all three of the sectors are wholly reliant on each other operationally, and that ICT is integral to all sectors and should be considered a shared resource. This means that connections and opportunities for the sectors to work together in a mutually beneficial way to adapt to climate change are often missed.

Interconnections need to be considered both horizontally (between and within sectors) and vertically (i.e. between national, regional and local levels), recognising that the levels of knowledge regarding climate change and adaptation vary significantly between sectors and levels.

There is a need to develop an improved level of understanding of each of the individual sectors and a route map of dependencies between them. More cohesion is needed between the sectors in maximising resilience to climate change and identifying where action in one sector results in an impact in another.

There also needs to be identification of the links to ICT in each of the sectors (current and potential); and how this can be used to link the sectors more effectively. Coupled with this is the requirement for these sectors to understand the medium to long term resilience of ICT and how this infrastructure may change in the medium to long-term.

The cross sector discussions should also seek to identify which interdependencies are critical and which are non-essential or unsustainable.

There are some developments which will assist in sharing of information on a consistent basis, for example the new flood forecasting centre (FFC), a collaboration between the EA and the Met Office, which opened in April 2009. This will improve river and coastal flooding forecast service as well as advising when extreme rainfall may result in flooding from surface water. It will help provide earlier warnings of floods to local authorities and the emergency services, to give them more time to prepare for floods and reduce the risk of loss of life and damage to property.

As cross sector understanding continues to develop there is a need for technical issues associated with long term adaptation to be reviewed. It is possible that greater cross sector understanding and knowledge will identify possible additional issues that need to be considered.

Improving knowledge and awareness

Options available to improve knowledge and awareness include:

- Engagement between climate change professions and engineers to agreement a clear process for considering climate change predictions into engineering and design codes.
- A requirement for public and private infrastructure owners to assess the vulnerability of their assets to climate change and assess the risks of failure / loss of service; and
- Ensuring that practices and standards used in other parts of the world, already experiencing predicted climate conditions are considered in developing solutions for the UK.

Key to increasing the long term resilience of infrastructure is understanding what is needed. There needs to be greater understanding of UKCP09, and of the tipping points and interrelations between sectors. Engineering and design codes typically define performance standards or tolerances; and engineers are then practiced at developing designs and specifications that met these clear standards.

The probabilistic approach used in UKCP09 has been developed by the climate change professionals to allow engineers to compare sensitivity of infrastructure to key thresholds enabling a risk based decision to be made. This approach is different from that which designers and operators are used to.

Those in infrastructure planning, design and development approval roles at national, regional and local levels need to be particularly aware of the key issues and scientific basis of climate change. They also need to have a greater understanding and appreciation of the technologies required to increase resilience to climate change impacts, in order that the UK continues to push the boundaries of our understanding.

In developing solutions, it is also important to refer to and use experiences of others. Many aspects of the projected future climate for the UK, are already experienced elsewhere in the developed world. Therefore designers and operators are already managing to design, operate and maintain infrastructure that can function in these climate conditions; e.g. road paving that is resilient to higher temperatures. These experiences should be used.

In addition there is a need for public and private infrastructure owners to assess the vulnerability of their assets to climate change and assess the risks of failure / loss of service so they can prioritise investment decisions to the highest risk sites. This should build upon any work being done to assess the existing resilience of infrastructure to current natural hazards.

As understanding climate change projections increases throughout the sectors, there needs to be a continued process of challenge and review of the key technical issues for long term resilience. This needs to include developing better understanding of infrastructure thresholds and trigger points, particular with reference to reducing the impact of interdependencies.

Societal expectations

Options available to change societal expectations include:

- Identifying particular “pinch points” for early action that can be the focus for initial targeted action; and
- Focused campaigns led by industry bodies providing knowledge and information to the public and identifying simple actions that can collectively support change.

Customer expectations in the UK are high. Customers do not expect interruptions to supply, restrictions on use or loss of quality, yet they demand low costs. It is recognised that this is not necessarily the case in other countries that are faced with resource shortages.

There is a need to increase the public’s understanding of how climate change impacts may affect infrastructure and the supply of essential services as well as how societal behavioural change can assist in reducing the impact of climate change in the long-term. As part of this work, challenging society's expectation that resources may not always be readily available will be important.

Such action will require action and involvement from many. Industry needs to review supply and demand forecasting mechanisms and assess how these may need to change in the future. This review should include identifying "pinch points" currently and as predicted in the future to identify particular aspects for targeting changing practices.

Industry bodies can work with industry to develop communication campaigns that identify the challenges, the work being done within the sector, as well as the actions that the public can take to support wider change. Identifying possible incentives for consumer change can also be affective.

Section 10
Conclusions

Conclusions

The technical identification and evaluation of risks and associated adaptation options, along with the stakeholder engagement that has underpinned this study have resulted in a number of clear, high level conclusions.

Sectoral and cross-sectoral considerations

- Existing infrastructure in the UK has been engineered and built for our past or current climate All sectors have considerable vulnerability to climate change in the long term although certain elements of infrastructure or functionality can be identified as being more so.

- There is a lack of understanding whether the infrastructure is vulnerable to specific climate thresholds or climate trigger points. Companies find it difficult to act until they know these and the likely conditions at the end of an assets life.

- The energy, transport and water sectors have complex and varying business and financial models that have been developed for their own sector's interests.

- Costs associated with adapting to climate change are complex, reflecting this complexity and the wide range of infrastructure components, their ages, interdependencies, design life and possible adaptation options.

- There is a lack of long-term foresight in all sectors for the period between 2030- 2100, although there is some evidence of consideration in this timescale (e.g. in the water industry). Current business and economic planning models tend to focus on the next 10-15 years, yet the design life of infrastructure ranges from 10 to over 120 years and much of the UK's existing infrastructure is considerably older than these design lives (e.g. parts of the rail network).

- The three sectors are interdependent but individually sectors are not proactive in recognising and tackling this. Identifying and understanding the specific links and using these to tackle interdependency will be of mutual benefit.

- Solutions need to encompass both new and existing infrastructure. Within the transport and water sectors, the majority of investment is for upgrades, whilst in the energy sector we are moving into a period when significant investment is on new build.

- Whilst the options to tackle technical risks are varied; the barriers are common. Focus at a national level on interventions which remove or reduce these barriers and constraints will have widespread benefits.

- Societal expectations are high. Customers do not expect interruptions to supply, restrictions on use or loss of quality yet demand low costs. It is recognised that this is not necessarily the case in other countries that are faced with resource shortage that may be replicated in this country due to long-term climate change.

Improved understanding

- Knowledge of trigger points for failure or disruption associated with gradual climate change is lacking. Without this knowledge it is difficult to identify when investment will be required and to predict the increased level of protection therefore additional investment that might be needed in the future

- There is a lack of consistent knowledge across the sectors of the scientific understanding of climate change and the range of adaptation options available

- Although UKCP09 is widely known, some companies are still finding it difficult to take on board its range of probabilities and uncertainties and to apply the projections to their own specific operations.

- Within some organisations there is a reluctance to plan for the long term (50-80 years) due to the perceived uncertainty associated with the impacts of climate change.

- Public understanding and appreciation of the challenges that climate change poses on infrastructure and operation of essential services, and the level of adaptation required is minimal.

Implementation of appropriate solutions

- To ensure new infrastructure, often with a life-time of 50-100 years (or more), is resilient to long-term climate change, we need to ensure that when commissioning new infrastructure the long-term impacts are always considered in its design and build.

- The inherent uncertainty in predicting our future climate does not promote action. Inaction is however, not an economic option. Failure has considerable impact on functionality of the UK infrastructure and retrofit measures can be highly expensive. Integrating climate change into business risk assessment frameworks is an option.

- Investment, both in terms of the amount allocated and its availability is a major barrier. Investment for long term resilience does not meet the current requirements for short term customer value for money or shareholder or investor return on investment.

- Increased regulation focussing on the long term adaptation to climate change will be required in all sectors, particularly those which are competitive markets.

- Consideration of climate change adaptation is lagging behind climate change mitigation in many sectors. Increased incentives are required for climate change adaptation.

Section 11
Recommendations

Recommendations

URS has developed a series of recommendations to the cross-departmental Infrastructure and Adaptation project. These recommendations will feed into the project's two-year programme of work; the project is due to be completed by March 2011 and will report into the Domestic Adaptation Programme Board.

Consequently, these recommendations should be seen as independent, not endorsed by Government, and which will be considered as part of the Infrastructure and Adaptation project's wider programme of work.

The recommendations are focused on overcoming the key barriers identified and, if implemented, will help increase the long-term resilience of infrastructure in the energy, transport and water sectors to the impacts of climate change

Financial

- More research into mapping and comparing the business and investment models used to finance each element of infrastructure in the three sectors is required to understand the various models that need to be considered for intervention and how to embed adaptation within these models.
- Mechanisms (e.g. financial bonds) need to be developed to ensure that the responsibilities for costs associated with future maintenance or upgrades to adapt to climate change are clearly defined and that funds are available over the lifetime of the asset to support appropriate adaptation measures.
- Without some form of indemnity, private sector operators will be unable to justify to shareholders the cost of adaptation where the benefits are unknown. The Infrastructure and Adaptation project's work should commission further work to examine how such costs could be underwritten and the issue of risk (including responsibility for risk) better understood.

Policy and Regulatory

- Responsibility for infrastructure is split between public and private organisations, as well as national, regional and local governance. The Infrastructure and Adaptation project should consider how best adaptation can be embedded as a result and what type of interventions are required (rather than a one size fits all approach).
- The current regulatory framework and other policy and guidance does not support long-term consideration and investment to adapt to climate change. The Infrastructure and Adaptation project should focus on how regulation and other frameworks could support long-term adaptation action in the sectors.

Technical & Operational

- Increased knowledge of infrastructure operational thresholds is required. A programme of research within each infrastructure sector, working with academia, is required to enable a robust understanding of these thresholds and possible trigger points.
- Increased understanding in business and professional bodies of how to use the range of probabilities and uncertainties contained within UKCP09 to enable businesses to apply the projections to their own specific operations.

	• New infrastructure should be designed and built so that it can be readily adapted. Industry, Government, engineers and planners need to work together to understand better how to do this on a consistent basis across all sectors. This should also consider ICT and interdependencies. • To increase information sharing, in particular of technical and operational risks and appropriate adaptation measures, the Infrastructure and Adaptation project, in partnership with infrastructure organisations, industry bodies and regulators, should set up a cross sector forum. • Increased understanding on the impact of climate change on infrastructure interdependencies is needed. The Infrastructure and Adaptation project, working with industry, academia and engineers needs to implement a programme of work that looks to test how climate change might increase infrastructure interdependencies, in particular in relation to increasing the threat of cascade failure. As part of this work, options to reduce the vulnerability of the infrastructure system as a whole to climate change needs to be developed. • As climate science continues to evolve and more data becomes available – in particular on wind and storms – industry needs to review the technical and operational risks from climate change on a regular (i.e. 3-5 years) basis to ensure infrastructure is resilient to long-term climate change.
Societal	• Industry, working with the relevant lead Government department and regulator, needs to implement a communication programme to: - Raise awareness of how climate change may affect infrastructure and delivery of essential services and their functionality. - Demonstrate how behavioural change can help reduce the impacts by reducing pressure on infrastructure/service demand. • Outside of the engineering and environmental disciplines, general awareness of the need to invest in adaptation measures is lacking. The Infrastructure and Adaptation project, working with engineers, industry and the finance sector, should develop a programme of engagement to address this.

Appendices

Appendix A
Glossary of terms

Glossary of terms

Abstraction (Water)	The process involves extracting water from any source, either temporarily or permanently. Sources may include: aquifers, surface water, rivers and reservoirs.
Adaption	The process or outcome of a process that leads to reduction in harm or risk, or a realisation of benefits associated with climate variability and climate change.
Carbon capture	This is a process of capturing carbon dioxide and storing it to prevent it from entering the atmosphere. The technology is normally applied to large stationary sources such as power stations and industrial plants.
Cascade failure	When one element of infrastructure fails (completely or partially) and causes failure or imposes pressure on other infrastructure simultaneously.
Central estimate	The projected change that has an equal probability of change being exceeded or not exceeded
Climate Change	Any change in climate over time, whether due to natural variability or as a result of human activity.
Climate projections	The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, based on simulations by climate models. Climate projections critically depend on the emissions/concentration/radiative forcing scenario used, and therefore on assumptions of future socio-economic and technological development.
Critical threshold	The point at which an impact to infrastructure will be observed. Beyond this point functionality may be altered, unless adaption measures have been implemented. For example, a power plant can operate to full capacity within a certain temperature range, outside this range, reduced efficiency can be expected.
Decarbonisation	Removal or reduction of carbon (in terms of emissions of carbon dioxide equivalents). For example using low carbon renewable technologies such as wind power to produce energy instead of fossil fuels results in removal of the carbon associated with energy production, also known as decarbonisation.
Downstream (oil production)	This term encapsulates the processes of refining crude oil and the selling and distribution of derived petroleum based products such as: gasoline, diesel oil, petroleum coke, liquefied petroleum gas (LPG), plastics and lubricants. The downstream sector includes oil refineries, petrochemical plants, petroleum product distribution, retail outlets and natural gas distribution companies.
Emissions scenario	A plausible future pathway of man-made emissions (e.g. greenhouse gases and other pollutants,) that can affect climate. These pathways are based on a coherent and internally consistent set of assumptions about determining factors (such as demographic and socio-economic development, technological change) and their key relationships.
Greenhouse Gas	A gas which absorbs and emits energy radiated by the earth, trapping some of it and thus warming the climate.
Impacts	The effect of climate change on natural and human systems.
Infrastructure	A physical asset central to the function of each of the three sectors.
Interconnectivity	The way in which different infrastructure sectors or components within a sector are linked together.

Interdependency	Where interconnections associated with the supply or receipt of a service (e.g. water) on which the receiving sector is reliant and an impact on this supply could be critical. For example water is essential for the cooling at power stations.
Low carbon economy	An economy which achieves higher productivity whilst using fewer natural resources and generating less emissions to the environment.
Mitigation	Action taken to reduce the impact of human activity on the climate system, primarily through reducing net greenhouse gas emissions, for example carbon dioxide.
Operational Issues	Concerning the functionality of infrastructure or components of infrastructure.
Potential impacts	All impacts that may occur given a projected change in climate, without considering adaption.
Regional convergences	Regional concentrations of infrastructure which, if impacted by a regional climate change event, could have consequences on functionality at a national scale in one more sectors.
Resilience	The ability to withstand the impacts of climate change.
Risk	A combination of the probability of an event and its consequences, with several ways of combining these two factors being possible. There may be more than one event, consequences can range from positive to negative, and risk can be measured qualitatively or quantitively.
Technical issue	Concerning the technologies used to facilitate the operation of the infrastructure component.
Transmission (gas and electricity)	The process of delivering/transferring gas or electricity to the consumer using a network of cables and substations (for electricity) and pipelines (for gas).
UKCIP	The UK Climate Impact Programme is funded by Defra and is responsible for promoting use of the UK Climate Projections, alongside other tools and guidance to help organisations to prepare for the unavoidable impacts of climate change.
UKCP09	The UK Climate Projections (UKCP09) give climate information for the UK up to the end of this century. Projections of future changes to our climate are provided, based on simulations from climate models. The UKCP09 were initially commissioned by the Defra and a consortium of organisations has been responsible for delivering its outputs including the Met Office Hadley Centre and the British Atmospheric Data Centre.
Upstream (oil production)	This term encapsulates the processes of searching and recovering crude oil and natural gas. Upstream operations may include searching for potential underground or underwater oil and gas fields, drilling of exploratory wells, and subsequently operating the wells that recover and bring the crude oil and/or raw natural gas to the surface.
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Appendix B
Stakeholder engagement

Climate change impacts on infrastructure

Stakeholder questionnaire

As the covering letter to this questionnaire makes clear, URS is undertaking a study looking at the long-term impacts on energy, transport and water infrastructure from long-term (20-90 years) climate change impacts. In particular, the work is looking at the technical and operational implications and how barriers to ensuring our new and existing infrastructure might be overcome and solutions implemented to achieve this.

To compliment our own thinking, we would welcome your expert input into the work by answering the following set of questions.

1 From your own work on how climate change impacts might affect your infrastructure and previous extreme weather events (heat waves, storms, floods, droughts):

   a. What were the direct effects of these climatic conditions on business operations?

   b. What were the indirect effects of these climatic conditions on business operations?

   c. Did this impact on supply and demand (e.g. loss of service, price impacts on customers)?

2 Are you aware of the new UK Climate Projections (launched June 2009) which set out the possible impacts of climate change on the UK to the end of the century?

3 Given the focus of this work is on the long-term (20-90 years), what do you see as:

   d. The biggest technical challenge to the infrastructure you are responsible for?

   e. The operational implications from these technical challenges and/or long-term impacts of climate change?

   f. The biggest challenge from long-term climate change – gradual change (e.g. higher average summer temperatures) or increased frequency and severity of extreme weather?

4 What do you see are the major barriers (eg regulatory, legislative, environmental or economic/investment) to increasing our new and existing infrastructure to long-term climate change?

5 Over what timescale do you feel that changes in operations (supply/demand) will need to be taken to adapt to long-term climate change? Are there any thresholds that would be critical to your operations if exceeded (e.g. average summer temperatures increase by more than 2℃)?

6 Have you undertaken any measures to adapt to the long-term impacts of climate change?

7 Are you aware of any good practice measures in your (or other sectors) domestically or internationally that would help adapt infrastructure to the long-term impacts of climate change?

8 Do you think new types of infrastructure will be required in your sector to ensure we are able to adapt to long-term climate change? If so, what and how?

9 Infrastructure risks are interconnected – a failure in one sector might cause another sector to also fail. Have you undertaken any work outside of your sector to understand these interconnected risks as a result of climate change impacts?

10 Parts of some infrastructure sectors are more vulnerable than others to long-term climate change impacts. Which parts of your infrastructure are more vulnerable, e.g. supply, demand, telecommunications, other?

11 Do you have any criteria for determining if new and/or existing infrastructure is resilient to the long-term impacts of climate change?

12 Have you undertaken any research into the effects of climate change on your business or are you aware of any relevant studies into the long-term impacts of climate change on your sector? If so, would you be able to make this available? Also what, if any, actions have you taken as a business as a result of carrying out this research?

Appendix C
Risk evaluation

Table 1: Energy

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
Flooding of fuel supply infrastructure due to increased storminess and sea level rise	• Predominantly extreme events and to a lesser extent gradual sea level rise may cause severe disruptions to the fuel supply infrastructure as a result of floods from storm and storm surges. • The UK's oil and gas storage and pipeline infrastructure is mainly at low level and near to the coast and therefore is at particular risk from flood and extreme storm events. Oil storage is located primarily on portside whilst gas storage facilities are primarily located offshore, sub-sea; inland, underground or over-ground. • During flood events, sea levels are predicted to rise to levels beyond which infrastructure might not be able to be defended. • The predominant risk remains the flooding of internal docking facilities. • The risk of inland subsidence being on a scale sufficient to require a geotechnical or increased specification is felt to be low.	• There may be a requirement for the re-engineering of facilities to increase resilience by increasing the height of quayside and coastal protection • As a result of potential delays in fuel deliveries due to damage to supply infrastructure there may be a need for industry to install larger on-site fuel reserves to avoid operational disruptions. • Increased storage of fuels would have a cost implication. • Need for containment of materials on the jetty side. • With increased storms, deliveries may be delayed or re-routed to other ports. • The operating environment may become harsher and therefore require a risk management and monitoring approach to inland infrastructure.	• It is expected that by the 2030s significant areas of sea defences will need to be realigned or enhanced as illustrated by the Humber Estuary Shoreline Management Plan. • The typical design life of the infrastructure affected is 100 years. • Redesign of flood defences and coastal protection is already ongoing. • Delays to fuel deliveries is a short-term risk • Over the longer-term (2050s-2080s) there is a risk to portside facilities being overwhelmed by sea level rise and storm surge.	• The frequency and duration of extreme storm events determine the significance of this issue. • Frequency and duration of extreme storm events determine the significance of this issue. The risk of fuel supply disruption increases as sea storm intensity and duration increases. • There may be more risk associated with gas deliveries, and biomass imports may be particularly vulnerable if the duration of events disrupts landings. • This will remain a low risk for coal supply, as some alternative supplies exist in the UK. • The impact on port facilities might be considerable and lead to suspension of services for long periods of time. This would result in a requirement for facilities to move further inland or enhance existing inland ports. • Sea defences across wider areas do need considerable forethought, particularly if re-alignment is required. • Increased reliance on energy imports (oil, coal and biomass) will increase the use of ports. • Possible resource issues may require leaving some coastal areas to sea level rise encroachment, which in turn may put residential and agricultural land at risk. • More biomass imports may be particularly vulnerable if duration of events disrupts landings. • Port authorities will monitor such events and discern requirements as trends emerge. Re-enforcing and securing port infrastructure will be done rapidly if required. Fuel supplies may be diverted to other ports. • Lack of fuel supply would affect all sectors (only some for biomass fuels) and the impact is likely to be felt nationally, while only expected to cause a minor disruption as supply should be resumed after the storm event. • The impact of this risk is likely to be felt regionally at any one point in time but potentially flooding of exporting energy infrastructure will have a national impact with the potential to cause a major disruption.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
Flooding of fossil fuel and nuclear plants due to increasing precipitation and sea level rise	• Floods pose a particular risk for nuclear and fossil fuel power stations, especially those located near to the coast. • During flood events, sea levels are predicted to rise to levels beyond which infrastructure might not be able to be defended.	• Sites are at risk of flood.	• Nuclear and fossil fuel power station sites are already at risk of flood and present a high-risk scenario. This applies to both coastal and inland infrastructure. • The typical design life of the infrastructure affected is 40 years.	• Significant flood of generation sites can be catastrophic. Immediate close down procedures and de-electrification are required. Recovery will be lengthy. • In the case of nuclear plant, key safety measures require site power. Site power must be maintained and therefore all risks of climatic impact need full evaluation. • Sea defences across wider areas do need considerable forethought, particularly if re-alignment is required. • The impact of this risk is likely to be felt locally to regionally, unless a key region (such as Yorkshire and Humber) providing export energy to the rest of the country, in which case the effect would be national. • This impact could potentially cause a major disruption.
Loss of efficiency of fossil fuel power plants due to increased temperatures	• Temperature increases will decrease generating efficiency of power stations – particularly affecting combined cycle gas turbine (CCGT) plants. • With predicted fluctuations in rainfall patterns, affecting water supply, there will be an increasing risk, over time, of water resource problems, or a requirement to invest in dry cooling methods.	• Increased operating temperatures do present risk for stations requiring increased cooling options.	• It can be expected that there will be some reductions in thermal generation efficiency of fossil fuel power plants from 2010 as a result of rising air temperatures. • 2030 and onwards, increasing in severity. Additional wet or dry cooling will be required and potentially a method to cool air intake before combustion. • The typical design life of the infrastructure affected is 40 years.	• 5 degree increase in temperature will give a 3% decrease in efficiency. • The impact is likely to be felt locally to regionally. • This impact will impair service functionality. • Incremental inefficiency in the system will only cause disruption if the UK has not built enough capacity to cope with such and to cope with peaks in demand.
Loss of efficiency of, and storm damage to renewable energy sources due to increased storminess	• Renewable energy resources are prone to be vulnerable to both gradual climatic changes and extreme weather events.	• Increased cloud cover and rain will influence solar generation. Further enhancements will need to be made to photovoltaic and solar to secure energy even on overcast or rainy days. • Changing rain patterns will influence hydro, particularly micro installations. If rainfall patterns are disrupted this will cause operational problems,	• Not known. • The typical design life of the infrastructure affected is 40 years.	• Renewable energy sources remain a very small proportion of the overall UK energy mix, however with any significant increase it will mean that total availability may be more at risk than with conventional sources. Biomass supply will also be affected with increased disruption to shipping. • Wind will be the critical issue in determining significance of impact on wind turbines. If design cannot cope with increased wind speed then there will be potentially reduced wind source energy availability. • If photovoltaic and solar efficiencies are reduced significantly because of increased cloud cover, then solar sourced energy availability will be reduced.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
		particularly for micro-hydro. • Changing wind (i.e. direction, velocity, turbidity, duration) will influence turbines and extreme events may cause damage, particularly to turbines. Wind turbines will need design standards to cope with increased wind speeds, possibly retrofitting foundations for strength and protection against flooding/subsidence. • Sea surge may require enhanced specifications for wave and tidal energy infrastructure. • Increased rainfall may provide incentive for increased woodland cover for biomass. • Balancing the grid will require optimisation technology, good modelling and monitoring data as well as good ICT connections across the country. • New grid infrastructure will be required to optimise renewable energy generation areas.		• Renewable energy sources still represent a very small proportion of the overall UK energy mix, however with any significant increase it will mean that total availability may be more at risk than with conventional sources. • As increased demand on energy and electricity in particular is expected in the coming years, this issue will increase in significance. • As renewable mix increases, the UK will need to be able to model predicted supply under changing climatic conditions. • The impact from this risk is likely to be felt locally to nationally. • While it is likely to only cause a minor disruption on a national scale, it could mean substantial disruption at a local level if there is a particular heavy dependence on certain renewable energy sources.
Reduced capacity of distribution network due to increase temperatures and precipitation and storminess	• Energy distribution systems are particularly at risk from gradual climatic changes that will place increasing pressure on capacity thresholds as customers react to increasing temperatures and other demands for increased supply. • Extreme weather events also	• Increased loads for cooling will draw systems to threshold delivery capacity. Substations will likely overheat as well. • Pylons and overhead cables will be subject to storm damage but perhaps similar in intensity to current patterns. • Flooding can affect	• Capacity thresholds of distribution networks will be 100% overloaded in the 2080s and 65% overloaded in the 2020s at peak locations. • Until there is more specific experience of modelling, investments in strengthening infrastructure is unlikely to take place.	• Progress towards a Low Carbon Economy will encourage the development of more decentralised energy generation facilities, providing both heat and electricity. These, if sited correctly, will not be as prone to other energy distribution systems. • If cooling requirements increase as expected then capacity thresholds will be 100% overloaded in the 2080's; 65% overloaded in the 2020's at peak locations. • The distribution system requires careful analysis now, with substantial re-siting, re-engineering required. The technical implications are well understood but this will be a case of scale

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	have the potential to damage key infrastructure such as the flooding of Neepsend substation in 2007. • Energy storage remains a massive technological risk to the development of a distributed energy network.	substations as well as buried cables. Increasing risk is presented for those substations that are located on the urban fringe where temperature increases are likely to bring some elements of the substation infrastructure to capacity thresholds. • Combined with increased demand forecasts, new distribution systems will need specifications to manage both increased temperature and increased demand. • Storage such as pumped hydro and fuel cells will need careful design and siting to cope this risk.	• The distribution system requires careful analysis now, with substantial re-siting and re-engineering required. • The typical design life of the infrastructure affected is 40 years.	presenting challenges. • There are significant knock on effects to key users; vulnerable groups; water infrastructure and ICT. • The impact is likely to be felt regionally • Potentially flooding of energy infrastructure that provides export energy to the rest of the country will have a national impact as this is likely to cause a functionality and potential major disruption if society does not plan for this potential impact in peak areas. Without attention to the distribution system, all work elsewhere will be negated. • This impact is likely to cause a functionality and potential major disruption if society does not plan for this potential impact in peak areas. • Without attention to the distribution system, all work elsewhere will be negated. • The ability of major infrastructure to cope with incremental increases in temperature is more difficult to rectify quickly, once thresholds of capacity and risk have been exceeded. It is therefore apparent that for cables, substations and transformers the design period, compared against climatic predictions requires close attention to discern the most appropriate point at which significant re-investment is required to meet the challenges of the future. • There are also are significant knock on effects to key users, vulnerable groups, the water infrastructure, and ICT.

Table 2: Transport

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
Road				
Flooding from increased precipitation and/or storminess	• Increased number of intense rainfall events, such as those experienced during storms, and gradual greater winter rainfall are likely to lead to increased frequency in extensive flooding of the UK's road network. This is already being experienced and the risk will increase during the latter part of this century, leading to more frequent instances of roads being flooded or washed away. • Road infrastructure includes assets over 50 years old with design lives up to the end of the century and beyond. These will need to be assessed to determine if they are resilient to predicted increases in precipitation and frequency of storms.	• Delays and disruptions to users • Resources devoted to dealing with disruption, i.e. increasing deployment of emergency personnel and unplanned and uneconomic remedial activities. • Where roads carry statutory undertaker services, the operation of, and access to these services, may also be affected. • Major disruption somewhere on the road network each year on average due to erosion / washaways / flooding or combination. Disruption likely to be more frequent.	• The issue identified is likely to be realised immediately and likely to get more frequent and more serious with time.	• Potential "knock on" implications to other elements of infrastructure include the possible temporary collapse of road transport systems. The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Potential "knock on" implications to other elements of infrastructure include the possible modal shift from road to rail if particular routes become unreliable. • The issue could lead to the possible temporary collapse of surface transport systems • The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption • While the issue is likely to only have an implication where the increased precipitation occurs, and hence be regionally focused, all parts of the UK could be affected by such a flooding event. • The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption are likely to be significant, as shown by recent flooding events. • Experience in retrofitting drainage on M1 widening will be useful when this is needed elsewhere. Overseas experience will be useful. If implemented this may reduce the potential significance of this issue.
Scour of road bridges due to increased precipitation and/or storminess	• Bridges over water are at risk from increased flows due to their foundations being undermined by the energy of the flooded river. Over 4,000 on the network, 500 at higher risk (e.g. to scour). • The less well founded bridges are most vulnerable to scour.	• Bridge failures will lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities, often diverting resources from planned activities. • Requirement for more	• The issue identified is likely to be realised immediately and likely to get more frequent and more serious with time. • The typical design life of the infrastructure affected is up to 120 years +	• As the majority of road bridges carry services for statutory undertakers, the failure of a bridge will lead to failures in the services, often for significant periods, as access to fix them will also be curtailed. • Potential "knock on" implications to other elements of infrastructure include the possible modal shift from rail to road. • The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary and

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	• Bridges most at risk are those located on rivers receiving runoff from impermeable or steeply sloping terrain. • Extreme weather events and gradual greater winter rainfall are likely to lead to scour that in turn affect rail bridges. • Bridges have a 120 year design life. These will need to be assessed to determine if they are resilient to predicted increases in precipitation and frequency of storms. • The most vulnerable structures are perceived to be the early steel structures, which need high maintenance.	frequent inspections.		occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption are likely to be moderate owing to the localised and temporally limited nature of the disruption associated with a bridge collapse.
Rail				
Flooding from increased precipitation and/or storminess	• Increased number of intense rainfall events, such as those experienced during storms, and gradual greater winter rainfall are likely to lead to increased frequency in extensive flooding of the UK's rail network. This is already being experienced and the risk will increase during the latter part of this century, leading to more frequent instances of railways being flooded. • Rail infrastructure includes assets over 50 years old with design lives up to the end of the century and beyond. These will need to be assessed to determine if they are resilient to predicted increases in precipitation and	• Delays and disruptions to users • Resources devoted to dealing with disruption, i.e. increasing deployment of emergency personnel and unplanned and uneconomic remedial activities. • Rail services have to be shut if flood water rises 100mm above the top of rails. Particular problem at coastal sites. • Major disruption somewhere on the rail network each year on average due to erosion / washaways / flooding or combination. Disruption likely to be more frequent.	• The issue identified is likely to be realised immediately and likely to get more frequent and more serious with time.	• Potential "knock on" implications to other elements of infrastructure include the possible temporary collapse of rail transport systems. The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Potential "knock on" implications to other elements of infrastructure include the possible modal shift from rail to road if particular routes become unreliable. • The issue could lead to the possible temporary collapse of surface transport systems • The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption • While the issue is likely to only have an implication where the increased precipitation occurs, and hence be regionally focused, all parts of the UK could be affected by such a flooding event. • The implications identified are likely to result in the temporary and

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	frequency of storms.			occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption are likely to be significant, as shown by recent flooding events. • Experience in retrofitting drainage on WCML upgrade will be useful when this is needed elsewhere. Overseas experience will be useful. If implemented this may reduce the potential significance of this issue.
Scour of rail bridges due to increased precipitation and/or storminess	• Bridges over water are at risk from increased flows due to their foundations being undermined by the energy of the flooded river. Over 4,000 on the network, 500 at higher risk (e.g. to scour). • The less well founded bridges are most vulnerable to scour. • Bridges most at risk are those located on rivers receiving runoff from impermeable or steeply sloping terrain. • Extreme weather events and gradual greater winter rainfall are likely to lead to scour that in turn affect rail bridges. • Bridges have a 120 year design life. These will need to be assessed to determine if they are resilient to predicted increases in precipitation and frequency of storms. • The most vulnerable structures are perceived to be the early steel structures, which need high maintenance.	• Bridge failures will lead to significant disruption to services, increasing deployment of emergency personnel and unplanned and uneconomic remedial activities, often diverting resources from planned activities. • Requirement for more frequent inspections.	• The issue identified is likely to be realised immediately and likely to get more frequent and more serious with time. • The typical design life of the infrastructure affected is up to 120 years +	• Potential "knock on" implications to other elements of infrastructure include the possible modal shift from rail to road. • The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary and occasionally reversible failure of functionality of the infrastructure. • Cost of delays and disruption are likely to be moderate owing to the localised and temporally limited nature of the disruption associated with a bridge collapse.
Moisture fluctuation in rail embankments in SE England – due to wetter winters and drier summers	• Many of the railways and emanating from London are built on embankments of London Clay. Some date from the 19th century and	• More frequent inspections required • Main effect of settlement is to	• The issue identified is likely to be realised increasingly frequently. • Without adaptation, this is	• The issue is likely to have worst implications in the South and East of England. • The implications identified are likely to result in the temporary and

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	were not built to modern standards. During wet weather they absorb moisture which softens the clay, leading to settlement of the rail. In hot dry summers, there is a tendency for the clay to shrink and crack, also leading to movement. Although the movement is slow, not leading to sudden failures, it does affect the alignment of the rail, often requiring extensive maintenance to ensure a reliable service. • Gradual increase in winter rainfall and decrease in summer rainfall, coupled with greater summer temperatures may result in moisture fluctuations in railway embankments. This in turn could lead to instabilities in the embankments leading to their collapse, thereby causing disruptions to travel and requiring their reconstruction. • Embankments are at greater risk from wet / dry cycles (e.g. 150 year old clay embankments around London).	require speed restrictions.	likely to become a significant problem by the 2050s and severe by the 2080s, taking ever more resources to manage the problem.	occasionally reversible failure of functionality of the infrastructure. • Greater costs associated with unplanned emergency works. Greater disruption than for planned works.
Overheating of underground trains due to increased temperatures	• Gradual increase in summer temperatures is likely to lead to overheating of underground trains. • The exact mechanism between the outside air temperature, the duration of a hot spell of weather, and its effect on the temperature in	• Reduced efficiency as reduced demand • Underground services at risk from increasing temperature, as the tunnels overhead and it becomes increasingly hard to remove heat from them.	• It is considered that by the 2050s such episodes will be more frequent leading to disruptions to an acceptable service. • The typical design life of the infrastructure affected is Up to 120 years +	• Potential "knock on" implications to other elements of infrastructure include the possible increased demand in energy e.g. from cooling systems. • This issue is likely to primarily affect infrastructure in London. • The implications identified are likely to result in the temporary failure of functionality of the infrastructure. • major disruption if certain parts of the system have to be closed due

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	trains is not fully understood. • Underground trains are totally reliant on an electricity supply for their operation, and failure of supply will lead to train failure. If this were to happen on a hot day, the natural ventilation of the system by moving trains would cease and the temperature inside stations and trapped trains will rise yet further.			to health concerns
Ports				
High tides/storm surges & increased sea level rise at ports due to sea level rise	• Ports are at risk of disruption due to high tides or storm surges (and occasionally both together). These can curtail operations as the water level may be too high for berthing, embarking or loading, or the conditions may be too rough to allow these operations. • Storm events and gradual sea level rise leading to higher tides and increasing frequency of storm surges may result in damages to port infrastructure due to flooding. • The typical design life of the infrastructure affected is up to 100 years. This will need to be assessed to determine if it is resilient to increasingly high tides and storm surges.	• Diversion of services to other ports where possible.	• Predicted changes in sea level rise will start to take effect in the 2050s and become severe by the 2080s, especially considering high emission scenarios. • Need to design now for building on higher ground to guard against possible sea level rise (especially SE England – e.g. at Dover's new Western Ports Development).	• The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary failure of functionality of the infrastructure. • The risk of such events is unknown, due to the lack of certainty in future wind predictions. The risk will have to be revisited once more accurate predictions become available.
High winds at ports due to increase in storminess	• Extreme events may result in changes to the prevailing wind direction, as ports are sheltered from the prevailing wind, which in turn would affect the operation of ports. Docks in ports are usually	• Diversion of services to other ports where possible.	• Timeframes associated with the likely realisation of this issue are not known and more research needed. • The typical design life of the infrastructure affected is up to	• The issue is likely to have geographically widespread implications. • The implications identified are likely to result in the temporary failure of functionality of the infrastructure. • Delays and damage if there are strong winds from other than prevailing direction; also delays on approach roads.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	aligned to the prevailing wind direction, as shipping is more stable when moored into the wind. A change in prevailing wind direction will result in shipping being exposed to winds side on, increasing the risk of disruption and even damage. • The typical design life of the infrastructure affected is up to 100 years. This will need to be assessed to determine if it is resilient to increasingly high tides and storm surges.		100 years.	• The risk of such events is unknown, due to the lack of certainty in future wind predictions. The risk will have to be revisited once more accurate predictions become available.
Airports				
High winds at airports due to increased storminess	• Airports are potentially vulnerable to two different climate change impacts. The predicted increase and severity of stormy weather will create a risk that airports have to close more frequently due to aircraft not being able to fly in such conditions, or due to flash flooding of runways. The incidence of closure due to snow will probably decrease. • Runway orientations mostly E-W (e.g. Heathrow, Gatwick). Risk of significant disruption if prevailing winds change to a more southerly direction, as no practical alternative available. No guidance available on likelihood of this.	• Strong winds can disrupt aircraft movements. Risk of greater disruption due to more frequent and severe storms. • For local storms, this may only create local disruption as it will be possible to divert to other airports, but in major storms covering a whole region it could create significant disruption by closing several airports at once: south east England with its concentration of major airports being especially vulnerable. • Diversion of flights elsewhere. • Delays if winds prevent runway use.	• Timeframes associated with the likely realisation of this issue are not known and more research needed. • The typical design life of the infrastructure affected is up to 100 years. • Aircraft operators consider their business to be sufficiently short / medium term to be able to adapt as climate changes become more apparent. The exception is wind direction which could have a very severe effect.	• The issue is likely to have geographically widespread implications. The issue of possible change is direction would have most effect in SE England. • The implications identified are likely to result in the temporary failure of functionality of the infrastructure. • It is the lack of knowledge of future wind characteristics that makes it impossible to assess the risk of closure of airports due to even a slight change in wind direction and is a barrier to further action. This risk will have to be revisited once more accurate predictions become available. • It is potentially a significantly major risk, as there is the prospect of several of the major airports in south east England being affected. All of these have runways aligned to the prevailing west or south-west wind and construction of a cross runway is in many cases impracticable. Loss of capacity at these airports would create severe disruption.

Table 3: Water

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
Water Supply, Treatment and Distribution				
Reduced security of supply due to changing precipitation patterns and periods of drought	• Climate change poses a risk to water resources, water treatment & water distribution networks in terms of potential impact on availability and quality of water supply. • Changes to levels of precipitation and more variable rainfall patterns will affect the quantity and quality of water available for consumption for the reasons outlined below. • Drought will reduce water levels in water reservoirs which may not be designed for these new low levels. Low flows in the network may cause sedimentation problems. Groundwater levels may lower, thereby reducing the potential for abstraction. Water quality & chemistry will change as a result, causing changes to required treatment. • More frequent rain with increased intensity may cause increased siltation in reservoirs from runoff & erosion lowering the usable volume or impacting raw water quality. Soil dams may slip. Spillways may be improperly designed to handle flows. Flushing pipe network may mobilise silt deposits. Asset deterioration will hence result from increased demand and	• The operation of water resource management will be significantly impacted by this risk. • Balancing available supply with present and future demand will continue to be critical and potentially more unpredictable with climate change. • Changes in water quality would have to be addressed at the treatment plant, and flushing the network may be required to flush sediment deposits. • Watershed management may need to improve to protect resource • Utilities may need to find alternative sources of water or increase storage. • Requirement to upgrade existing and build new infrastructure. • Underground pipe networks typically have a design life of over 100 years. Above ground assets like pump stations or treatment works typically have a design life of 30-50 years, and reservoirs are designed to last hundreds of years. These will need to be assessed to determine if they are resilient to predicted changes in precipitation and	• Climate impact on the balance between water supply & demand is already an issue at present, although the twenty-five year water management plans for most utilities do not indicate any insurmountable challenges during this period. • This issue is likely to be realised when the frequency and severity of droughts and rain events significantly increase over current climate conditions. This is estimated to begin in the 2050s and become more prevalent in the 2080s. • No scientific basis other than existing water stress issues in summer.	• Water shortage is the primary implication if no action is taken. This may lead to potential population shifts bringing with it significant pressures on a number of key aspects of the economy and society at large • It is likely any changing quality issues associated with raw water can be addressed through catchment management or at the treatment plant, thereby reducing the significance of its impact on security of supply. • A water shortage will have implications to the general society at large, but may specifically impact transportation as potable water may need to be delivered by truck or rail to certain communities (interconnectivity with transport). • The increased levels of treatment potentially required and the increased pumping associated with intense precipitation events may result in an increase in energy consumption (interconnectivity with energy). • The level and extent of impact will be region specific, as each region has its own water resource management plan. Based on the climate change model, the most significant impact will likely occur in the Southeast which is already stressed for water resources to meet population demands. • Changes in water consumption patterns will impact timing and quantity of peak demand. Widespread implementation of water efficiency measures by both the utilities (reducing leaks) and general public (water conservation) could reduce peak demand. Public perception of water recycle/reuse may change making this an attractive alternative to finding new sources of water. These type of water efficiency measures could have a significant impact on reducing this risk. Conserving water will reduce demand for supply during drought allowing utilities to optimise resource utilisation. • There may be some minor disruptions associated with this issue, but the primary concern would be a failure of service as a res0lt of a water shortage.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	integrity problems in the network from soil movement. • Some water systems utilising groundwater near the coast may be impacted by saltwater intrusion. This will further reduce the available water resources. • Internal migration within the UK and associated population shifts as a result of climate change may also impact security of supply on a regional level as some regions may not have enough water resource to support large population increases.	temperature.		
Increased fluvial flooding due to increased precipitation and storm surges	• Many water infrastructure assets may be at risk from increased pluvial, fluvial and coastal flooding due to increased precipitation and storm surges as well as their physical proximity to watercourses.	• Assets impacted by flooding are difficult to access and can create health & safety hazards. • Water treatment plants may be flooded and inoperable for an extended period of time. • Bottled water may need to be provided as a potable water source for the public. • This could result in a disruption of service. • May impact security of supply if a water distribution networks were flooded. • Loss of potable water (majority of costs and broader impacts are regional, since water services are separate and drainage basins distinct).	• Flooding of water sector assets is already a major concern for utilities and the public. • Varying levels of flood protection have been included in the business plans of many utilities. • Adaptation to this climate change risk is currently in-progress. • Flooding will impact above ground assets typically with a design life of 30-50 years and below ground assets typically with a design life of 100 years.	• The main implication of the identified issue, if no action is taken, would be asset damage, disruption of service or service failure and risk to human health. • May specifically impact transportation, as potable water may need to be delivered by truck or rail to certain communities (interconnectivity with transport). • Many times large flood events also impact electrical power systems which would have a significant impact on all pumping and treatment assets. • Emergency generator back-up power may be damaged leaving assets vulnerable to disruptions in energy supply (interconnectivity with energy sector). • The level and extent of flooding will be region specific but the impact may be most predominant along the coast and south east England where both sea-level rise and intense rainfall increases are predicted to be greatest. • Public tolerance for flooding and service disruption due to 'acts of nature' may increase or decrease. Internal migration to drier climates or away from the coast would likely reduce risk. • The impact of flooding can range from a minor disruption to failure of service depending on the severity.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
Wastewater Collection, Treatment and Disposal				
Increased sewer (pluvial) flooding due to increased precipitation and storm surges	• Increases in the frequency and intensity of storms will put pressure on the capacity of the existing sewer drainage systems, which have a finite hydraulic capacity and may hence not be suitable to deal with the associated larger volumes of water resulting in sewer flood events. This is anticipated to lead to an increase in sewer flood events. • The use of existing combined sewer overflows (CSO) as a result of increased hydraulic pressures on the system will create more pollution events.	• Flow balancing and maintaining sufficient storage are examples of operational implications. • Assets impacted by sewer flooding are difficult to access and can create health & safety hazards. • The existing drainage system of collecting water and sending it to a central location is not sustainable. More sustainable drainage solutions that deal with control at the source will be required. • Below ground sewer infrastructure may have a design life of 100 years while above ground infrastructure is approximately 30-50 years. These will need to be assessed to determine if they are resilient to predicted changes in precipitation and temperature	• Sewer flooding is already a major concern for water utilities and the public. The existing drainage infrastructure is currently insufficient and non-sustainable in design. Adaptation to this climate change risk is currently in-progress.	• Insufficient drainage can cause property damage, flood streets, increase erosion, and cause excessive wear on pumping and transmission systems. It also presents a risk to human health. • Discharge from combined sewer overflows can negatively impact environmental water quality and the increased flow can overwhelm treatment systems. • Sewer flooding can have implications for wastewater treatment (exceed hydraulic capacity) and transportation (flooded roads from insufficient drainage). • Storm water management may require more sophisticated levels of telemetry and real-time monitoring and remote operation in order to optimise the flow of water throughout the drainage network. • The level and extent of sewer flooding will be region specific, as each region has its own drainage system. Based on the climate change model, the most significant risk will be in southern England where the level of intensity for precipitation events are predicted to increase. • This risk may lead to unsafe polluted communities and watercourses. • Public tolerance for flooding and service disruption due to ‘acts of nature’ may increase or decrease. Internal migration to drier climates would likely reduce risk. • There is likely to be shift in society to more sustainable drainage systems operated and maintained independent of the utilities. • The impact of sewer flooding can range from a minor disruption to failure of service depending on the severity.
Increased fluvial flooding due to increased precipitation and storm surges	• Many water infrastructure assets may be at risk from increased pluvial, fluvial and coastal flooding due to increased precipitation and storm surges as well as their physical proximity to watercourses.	• Assets impacted by flooding are difficult to access and can create health & safety hazards. • Wastewater treatment plants may be flooded and inoperable for an extended period of time. • This could result in a disruption of service. • May impact security of supply if a water treatment works	• Flooding of water sector assets is already a major concern for utilities and the public. • Varying levels of flood protection have been included in the business plans of many utilities. • Adaptation to this climate change risk is currently in-progress. • Flooding will impact above	• The main implication of the identified issue, if no action is taken, would be asset damage, disruption of service or service failure, risk of environmental pollution and risk to human health. • Many times large flood events also impact electrical power systems which would have a significant impact on all pumping and treatment assets. • Emergency generator back-up power may be damaged leaving assets vulnerable to disruptions in energy supply (interconnectivity with energy sector). • The level and extent of flooding will be region specific but the impact may be most predominant along the coast and south east England where both sea-level rise and intense rainfall increases are predicted

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
		were flooded. • Environmental degradation (majority of costs and broader impacts are regional, since water services are separate and drainage basins distinct).	ground assets typically with a design life of 30-50 years and below ground assets typically with a design life of 100 years.	to be greatest. • Public tolerance for flooding and service disruption due to 'acts of nature' may increase or decrease. Internal migration to drier climates or away from the coast would likely reduce risk. • The impact of flooding can range from a minor disruption to failure of service depending on the severity.
Increased pollution incidents due to changing precipitation patterns and periods of drought	• Summer droughts that cause lower flows in watercourses receiving treated wastewater effluent will lead to tighter environmental constraints on discharge which will lead to wastewater treatment plant infrastructure improvements in order to improve effluent quality and reduce the potential for a pollution incident. • This risk is indirectly related to gradual climate change but has significant implications for wastewater treatment. As a result of drier summers and more variable rainfall patterns during spring and autumn, reduced water levels in a watercourse receiving treated wastewater effluent will have less ability to dilute the discharge. Therefore to maintain a similar level of environmental protection, tighter discharge consent limits may be imposed on utilities requiring a higher standard of treatment in order to improve effluent quality. • Changes in temperatures and precipitation may also cause changes in the quantity and quality of wastewater sent to the treatment plant. During a drought wastewater is	• Higher levels of treatment typically require higher energy input and therefore greater carbon footprint. • Wastewater treatment and the production of sludge is a continuous process. It will be the responsibility of the treatment plant operators to keep treated effluent within consent limits with existing and/or new treatment technology; and it will be the responsibility of the entire water sector to determine environmentally acceptable sludge disposal options. • Requirement to upgrade existing and build new infrastructure.	• Changes in environmental regulations unrelated to climate change, such as the Water Framework Directive, have been implemented to improve water quality in the environment and will likely create stricter limits on utility discharge consents, which may cause a need for investment. • The likely impact of this risk as a result of climate change is estimated to be the 2030s (no scientific basis for this).	• The main implication of the identified issue, if no action is taken, would be a degradation of environmental water quality. • Improved wastewater treatment may require improved ICT in terms of smart telemetry and real-time monitoring to control remote assets. Improved treatment may also require an increased energy demand (interconnectivity with energy).. Also, most sites have limited sludge storage capacity, so alternative sludge disposal practices may rely on the transportation infrastructure (interconnectivity with transport). • The public's attitude towards environmental protection, along with the potential cost implications, may significantly affect this risk. • The level and extent of impact will be region specific, as each region has its own water resource management plan. Based on the climate change model, the most significant risk will be in southern and central England where summer rainfall is lowest. • Damage of the freshwater ecosystem. • Water utilities have a duty to protect the environmental and operate within consent limits; therefore this risk would lead to a failure of service.

Key Issue	Description of technical risk	Description of operational implications	Likely timeframe for issue to be realised	Potential Significance
	typically considered 'strong' with high organic loading but low flow. During a rain event wastewater is diluted but at high flows. Treatment plants will need to be designed to handle a wide variance in flow and load to remain in consent. • Changes in temperatures and precipitation may also have an impact on sludge treatment and disposal. Sludge is typically land spread as means of disposal. Higher intensity precipitation may increase run-off and erosion on land treated with sludge which would impact the local watercourse. Ground conditions may prevent land spreading (too muddy for trucks). Also agricultural demand for sludge may change with climate change creating a need for additional environmentally sound disposal options. • There are multiple components and processes within a wastewater treatment plant that have different design lives. Process equipment (pumps, blowers, etc) can range between 5 and 20 years, while concrete structures are typically 30-50 years. Ultimately the design life of a treatment plant is a function of design capacity. Once design capacity is exceeded the plant must be upgraded or replaced.			

Appendix D
Options appraisal

Table 1: Energy

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Risk Areas: Flooding and storm impacts on refineries, oil/gas storage and pipelines								
Technical options	Hard engineering – new / improved coastal flood defence systems near affected receptors	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts, possibly high financial costs	High	National	Irreversible	Gradual change – based on risk of flood profiles across the country	Short to long term
Technical options	Soft engineering – build controlled flood management zones, e.g. Alkborough on the River Humber, near affected receptors	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses. This offers high risk mitigation for the likely cost.	Land ownership / purchase cases long delays in securing this option. Possible rapid silting of new area, diminishing its effectiveness	High – a forward planning option that offers high risk mitigation	Local and regional locations	Irreversible	Gradual change – based on risk of flood profiles	Long term
Technical options	Containment of materials on the jetty side of ports/wharves – e.g. netting, barriers, dampening down of biomass, coal	Reduced risk of loss of port-side product and lower costs associated with effective forward planning rather than reactive responses	Difficult to provide adequate space portside. The scale of the supply would pose significant containment problems	Medium	Local to regional – depending on spread of storm weather and strong winds	Reversible	Step change – after trial and demonstration	Short term
Operational	Hold greater stocks of fuel on land to mitigate for supply disruption	Greater security of supply in the face of disruption and lower costs associated with effective forward planning rather than reactive responses	Greater expense of storing and holding stocks. Possible security implications	Medium – Supply shocks would cause disruption	Local to national	Reversible	Step change – to lessen impact of supply cut off	Short to medium term
Operational	Climatology – improve predictions of extreme and adverse weather conditions	Improved ability to manage adverse climate conditions and lower costs associated	Local climatology granulation difficult to achieve	Medium – improved accuracy will	Local to national	Reversible	Gradual change – based on	Short to long term

[1] Where 'high'= the option's potential benefits greatly outweigh the potential costs

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
		with effective forward planning rather than reactive responses		ensure greater efficiency and resilience			refinement of models	
Operational	Improve demand planning of each plant to maximise efficiencies from existing fuel stock	Greater security of supply and lower costs associated with effective forward planning rather than reactive responses. Will also allow for power re-routing and grid balancing if adverse conditions hit other areas	Possible technological, economic and operational constraints	Medium	Local to national	Reversible	Step change	Short to long term
Cultural	Widespread understanding and action by the population to manage their energy demands most efficiently	Reduced demand for energy, risks associated with energy disruption and lower costs associated with effective forward planning rather than reactive responses	Risk of not being successful if public don't change their behaviour	Medium	National	Reversible	Gradual change	Long term
Cultural	The population will also need a willingness to pay for security of supply in advance of an impending shortage.	Improved security of supply	Regulations may need to change to both accommodate and control 'price spikes'	High	National	Reversible	Gradual change	Long term
Regulatory	Include processing/power plants on the National Infrastructure Register. This will ensure periodic review for investment more closely aligned to Government policy and strategic interests.	Greater levels of investment in assets, greater security of supply with improved resistance to the adverse impacts of climate change, and lower costs associated with effective forward planning rather than reactive responses and lower costs associated with effective forward planning rather than reactive responses	Regulatory constraint of proposing to change the register. Possible economic constraint of increased costs	Medium	National	Reversible	Step change	Short term
Repair, Retrofit or Replace	Repair, upgrade existing costal defence systems near affected receptors	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts, possibly high financial costs	High	Local to national	Irreversible	Gradual change – based on flood and storm risk	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Repair, Retrofit or Replace	Repair, upgrade flood defences of refineries/ biomass and coal processing sites	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts, possibly high financial costs	High	Local to regional	Irreversible	Gradual change	Long term
Risk Area: Loss of efficiency of fossil fuel power plants due to increased temperatures								
Technical	Greater levels of cooling could be required to compensate for higher ambient temperatures	Regulatory compliance; reduced environmental damage	Reduced efficiencies, possibly high financial costs	Medium to high – temperature dependent	Regional to national	Reversible	Gradual change	Long term
Technical	Greater emphasis on siting new plants in locations that maximise advantages of sea / produced / poor quality water; cool air intake and lower temperatures.	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses. Ability to secure adequate cooling of plant and discharges.	Competition for water, possible environmental impacts	Medium	Regional to national	Irreversible	Gradual change	Long term
Operational	Climatology - improve predictions of extreme and adverse weather conditions.	Improved ability to manage adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses	Possible technological, economic and operational constraints. Local climatology granulation difficult to achieve.	Medium – improved accuracy will ensure greater efficiency and resilience	Local to national	Reversible	Gradual change – based on refinement of models	Short to long term
Operational	Improved water efficiencies in operational activities. Especially important for riverside locations where growing competition for water resource is anticipated.	Increased security supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts associated with levels of water abstraction or temperature of returned water.	Medium	Local to national	Reversible	Gradual change	Short to medium term
Cultural	Widespread understanding and action by the population to manage their energy demands more efficiently.	Reduced demand for energy and risks associated with energy disruption	Risk of not being successful if public don't change their behaviour.	High	National	Reversible	Gradual change	Long term
Cultural	The population will also need a willingness to pay for security of supply from	Improved security of supply and acceptance of varied	UK society will need to accommodate a varied portfolio of generation types	High	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	nuclear or fossil fuel generation.	energy generation sources.	and associated impacts on landscape and inherent pollution issues.					
Cultural	Proactive measures by the general public and Government to improve energy efficiency / use.	Reduced demands for energy of some 50 - 80% is required – thereby improved security of supply.	A range of fiscal, regulatory and technological initiatives need to be brought forward rapidly.	High	National	Reversible	Step change	Short to long term
Regulatory	The new Infrastructure Planning Commission should help ensure the timely construction of new power stations.	Quicker delivery of new power plants – thereby increasing the security of supply. Lower costs associated with effective forward planning rather than reactive responses.	Policy, social, environmental, economic are all potential constraints to delivery.	High	National	Irreversible	Step change	Long term
Risk Area: Flooding of fossil fuel and nuclear plants due to increasing precipitation and sea level rise								
Technical	Hard engineering – new / improved coastal flood defence systems near affected receptors	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts, possibly high financial costs.	High	Local to national	Irreversible	Gradual change – based on flood and storm risk	Short term
Technical	Soft engineering – build controlled flood management zones, e.g. Alkborough on the River Humber, near affected receptors.	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses.	Possible adverse environmental impacts, possibly high financial costs. Land ownership / purchase cases long delays in securing this option. Possible rapid silting of new area, diminishing its effectiveness.	High – a forward planning option that offers high risk mitigation	Local and regional locations	Irreversible	Gradual change – based on flood risk profiles	Short to long term
Operational	Climatology – improve predictions of extreme and adverse weather conditions	Improved ability to manage adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses	Possible technological, economic and operational constraints. Local climatology granulation difficult to achieve	Medium – improved accuracy will ensure greater efficiency and resilience	Local to national	Reversible	Gradual change – based on refinement of models	Short to long term
Cultural	Widespread understanding and action by the population	Reduced demand for energy, risks associated with energy	Risk of not being successful if public don't change their	Medium	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	to manage their energy demands most efficiently	disruption and lower costs associated with effective forward planning rather than reactive responses	behaviour					
Cultural	The population will also need a willingness to pay for security of supply from nuclear or fossil fuel generation in advance of an impending shortage.	Improved security of supply and acceptance of varied energy generation sources.	UK society will need to accommodate a varied portfolio of generation types and associated impacts on landscape and inherent pollution issues	High	National	Reversible	Gradual change	Long term
Cultural	Proactive measures by the general public and Government to improve energy efficiency / use	Reduced demands for energy of some 50 - 80% is required – thereby improved security of supply	A range of fiscal, regulatory and technological initiatives need to be brought forward rapidly	High	National	Reversible	Step change	Short to long term
Regulatory	The new Infrastructure Planning Commission should help ensure the timely construction of new power stations	Quicker delivery of new power plants – thereby increasing the security of supply. Lower costs associated with effective forward planning rather than reactive responses	Policy, social, environmental, economic are all potential constraints to delivery	High	National	Irreversible	Step change	Long term
Repair, Retrofit or Replace	Repair, upgrade existing costal defence systems near affected receptors	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts, possibly high financial costs	High	Local to regional	Irreversible	Gradual change	Short to long term
Risk Area: Loss of efficiency of fossil fuel power plants due to increased temperatures								
Technical	Greater levels of cooling could be required to compensate for higher ambient temperatures	Regulatory compliance; reduced environmental damage	Reduced efficiencies, possibly high financial costs	Medium to high – temperature dependent	Regional to national	Reversible	Gradual change	Long term
Technical	Greater emphasis on siting new plants in locations that maximise advantages of sea / produced / poor quality water; cool air intake and	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses. Ability to secure	Competition for water, possible environmental impacts	Medium	Regional to national	Irreversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	lower temperatures.	adequate cooling of plant and discharges.						
Operational	Climatology - improve predictions of extreme and adverse weather conditions.	Improved ability to manage adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses	Possible technological, economic and operational constraints. Local climatology granulation difficult to achieve.	Medium – improved accuracy will ensure greater efficiency and resilience	Local to national	Reversible	Gradual change – based on refinement of models	Short to long term
Operational	Improved water efficiencies in operational activities. Especially important for riverside locations where growing competition for water resource is anticipated.	Increased security supply and lower costs associated with effective forward planning rather than reactive responses	Possible adverse environmental impacts associated with levels of water abstraction or temperature of returned water.	Medium	Local to national	Reversible	Gradual change	Short to medium term
Cultural	Widespread understanding and action by the population to manage their energy demands more efficiently.	Reduced demand for energy and risks associated with energy disruption	Risk of not being successful if public don't change their behaviour.	High	National	Reversible	Gradual change	Long term
Cultural	The population will also need a willingness to pay for security of supply from nuclear or fossil fuel generation.	Improved security of supply and acceptance of varied energy generation sources.	UK society will need to accommodate a varied portfolio of generation types and associated impacts on landscape and inherent pollution issues.	High	National	Reversible	Gradual change	Long term
Cultural	Proactive measures by the general public and Government to improve energy efficiency / use.	Reduced demands for energy of some 50 - 80% is required – thereby improved security of supply.	A range of fiscal, regulatory and technological initiatives need to be brought forward rapidly.	High	National	Reversible	Step change	Short to long term
Regulatory	The new Infrastructure Planning Commission should help ensure the timely construction of new power stations.	Quicker delivery of new power plants – thereby increasing the security of supply. Lower costs associated with effective forward planning rather than reactive responses.	Policy, social, environmental, economic are all potential constraints to delivery.	High	National	Irreversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Risk Area: Loss of efficiency of, and storm damage to renewable energy sources due to increased storminess								
Technical	Increased use of renewable energy technologies, which are evolving with improved efficiencies.	Lower costs, greater productivity, diverse mixture of energy sources, increased security of supply, lower carbon footprint.	Social/cultural risks associated with greater employment of renewable technologies – e.g. adverse impacts on the landscape of windfarms.	High – particularly for increasing security of supply	National	Reversible	Gradual change	Short to long term
Technical	Regularly review the optimal mix of renewable energy sources contributing to the national grid. Certain technologies could prove to be more resistant to the adverse impacts of climate change than others.	Increased security of supply, lower carbon footprint.	Social/cultural risks associated with greater employment of renewable technologies – e.g. adverse impacts on the landscape of windfarms.	High	National	Reversible	Gradual change	Short to long term
Operational	Balance the grid with better information technology between inputs from renewable energy sources and other energy sources as climatic conditions vary, including with use of smart grid technology	Improved security of supply and efficiencies, thereby achieving lower costs.	Possible technological, economic and operational constraints.	High	National	Reversible	Step change	Short to long term
Operational	Spatial city wide energy and economic modelling required to establish viable operational portfolio	Direction to build a sustainable energy city plan available	Will require varied technology acceptance in the city and its fringes	High	National	Reversible	Step change	Short to long term
Operational	Climatology - improve predictions of extreme and adverse weather conditions.	Improved ability to manage adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses	Possible technological, economic and operational constraints. Local climatology granulation difficult to achieve.	Medium – improved accuracy will ensure greater efficiency and resilience	Local to national	Reversible	Gradual change – based on refinement of models	Short to long term
Cultural	Widespread understanding and action by the population to manage their energy demands more efficiently and	Reduced demand for energy and risks associated with energy disruption.	Risk of not being successful if public don't change their behaviour.	High	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	to adopt varied energy source portfolio.							
Cultural	Acceptance is needed of a varied mix of energy sources with possible adverse impacts on the landscape.	Increased security of supply with mix of energy sources, lower carbon footprint.	Cultural/social risk of public not accepting renewable energy due to adverse impacts on landscape etc.	Medium	National	Reversible	Gradual change	Long term
Financial	Provision of ROCs for biogas injection into gas network infrastructure.	Stimulate biogas technology deployment.	Waste to energy generation in or on the fringes of city and in the rural environment	High	National	Reversible	Step change	Long term
Regulatory	The new Infrastructure Planning Commission should help ensure the timely construction of new power generation.	Quicker delivery of new energy sources – thereby increasing the security of supply. Lower costs associated with effective forward planning rather than reactive responses.	Policy, social, environmental, economic are all potential constraints to delivery.	Medium	National	Irreversible	Step change	Long term
Regulatory	Amend ROCs to encourage those types more resistant to climate change to emerge.	Improved security of supply as resistant technologies are supported.	Technical, economic, policy	Medium	National	Reversible	Gradual change	Long term
Repair, Retrofit or Replace	Strengthening current facilities and energy generators may be required – e.g. improved foundations for wind turbines to cope with more adverse weather conditions.	Improved security of supply.	Economic, technical	Low/ Medium	National	Irreversible	Step change	Long term
Risk Area: Reduced capacity of distribution network due to increase temperatures and precipitation and storminess								
Technical	Evaluate which underground pipelines could be affected by land movement and/or water ingress if there is an increased risk of wet summers and dry winters	Increase security of supply and lower costs associated with effective forward planning rather than reactive responses.		Medium	National	Reversible	Gradual, prioritised to climatic risk	Long term
Technical	Cooling of electricity substations. Often situated in	Improved security of supply	Technical, economic	High	Regional	Irreversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	urban areas they are particularly vulnerable to temperature increases. Increased emphasis on cooling technologies, siting in favourable cool locations, shading, etc							
Technical	Decentralised energy systems with back-up access to the national grid	Improved security of supply	Policy, operational constraint of back-up access to the national grid, possible social constraints of public acceptance	High	National	Irreversible	Step change	Long term
Technical	Review the condition and location of existing distribution network and its resistance to adverse weather conditions	Improved security of supply	Economic, technological	Medium	National	Reversible	Gradual change	Long term
Technical	Higher specification cabling with greater resistance to increased temperatures and ground movement.	Improved security of supply.	Economic, technological	Medium	National	Irreversible	Gradual change	Long term
Operational	Balance the grid with better information technology between inputs from renewable energy sources and other energy sources as climatic conditions vary.	Greater efficiencies, lower carbon footprint as input from renewable energy sources is maximised	Technological, economic	High	National	Reversible	Gradual change	Long term
Operational	Climatology - improved predictions of extreme and adverse weather conditions.	Improved ability to manage adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses	None	Medium	National	Reversible	Gradual change	Long term
Operational	Plans should be established to enable re-routing in the event of disruption.	Improved security of supply	Technological, economic	High	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[1]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Cultural	Widespread understanding and action by the population to manage their energy demands more efficiently.	Reduced demand for energy and risks associated with energy disruption	Risk of not being successful if public don't change their behaviour.	High	National	Reversible	Gradual change	Long term
Cultural	Proactive measures by the general public and Government efficiency.	Reduced demand for energy and risks associated with energy disruption.	Risk of not being successful if public don't change their behaviour/ineffective Government policy.	High	National	Reversible	Gradual change	Long term
Cultural	Public acceptance of decentralised energy systems.	Greater security of supply.	Policy, operational constraint of back-up access to the national grid, public acceptance	High	National	Reversible	Gradual change	Long term
Regulatory	Advance planning by OFGEM to develop the financial plans needed to deliver a robust distribution system that is resistant to the adverse impacts of climate change.	Greater security of supply with more robust distribution network.	Policy, economic	Medium/ High	National	Reversible	Gradual change	Long term
Repair, retrofit and replace	Existing power distribution lines may need to be reinforced/replaced after review.	Greater security of supply with more robust distribution network.	Policy, economic	Medium	Regional	Irreversible	Step change	Long term
Repair, retrofit and replace	Substations may need to be retrofitted with cooling systems or new shading.	Greater security of supply with more robust distribution network.	Economic	High	Regional	Irreversible	Step change	Long term
Repair, retrofit and replace	Government policies to encourage the retrofitting of existing buildings with improved insulation and ventilations systems.	Greater security of supply as demand is managed.	Policy, social constraint if public are not proactive.	High	National	Irreversible	Step change	Long term
Repair, Retrofit or Replace	Reinforce/replace underground pipelines that are deemed to be vulnerable to land movement.	Increased security of supply and lower costs associated with effective forward planning.	Possible adverse environmental impacts, possibly high financial costs.	Medium	Local through to national	Irreversible	Gradual change	Short - long term

Table 2: Transport

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Flooding of roads or rail from increased precipitation and/or storminess								
Technical options	Review current bridges and roads for their ability to withstand the more extreme floods predicted as a result of climate change. Assessing the most vulnerable sites and prioritise the work needed to make them resilient.	Economic and social benefits associated with a more reliable road network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational, technological. Difficult process to obtain funding now to carry out improvements which may only have a benefit in several years time.	High	National	Reversible	Gradual change	Long term
Operational options	Improved regular inspection regime may be necessary to ensure that existing assets are coping with more extreme floods	Economic and social benefits associated with a more reliable road t network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational, technological. Lack of knowledge of some drainage details prevents a full analysis of the risk, and surveys will be needed.	High	National	Reversible	Gradual change	Long term
Operational options	Contingency planning with utilities companies for responses to disruption to power/telecommunications cabling associated with floods to transport infrastructure, e.g. bridges	Economic and social benefits associated with a better response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational	Medium	Regional	Reversible	Gradual change	Short term
Operational options	Climatology - improve predictions of extreme and adverse weather conditions	Improved ability to assess risk of adverse climate conditions and lower costs associated with effective forward planning rather than	Possible technological, economic and operational constraints. Current uncertainty of relevant climate change	Medium	National	Reversible	Gradual change	Long term

[2] Where 'high'= the option's potential benefits greatly outweigh the potential costs

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
		reactive responses	forecasts: particularly for more stormy weather.					
Operational options	Review emergency contingency plans to ensure that they are optimally organised for the areas most affected by floods	Economic and social benefits associated with a better response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational	High	Regional	Reversible	Gradual change	Short term
Cultural options	Manage expectations of the public to the disruptive effect of upgrades necessary to road infrastructure	Less pressure on a constrained road network	Social – risk of option not being effective unless adopted by the public	Medium	National	Reversible	Gradual change	Long term
Cultural options	Manage the demands placed by the public on the road network during extreme floods	Less pressure on a constrained road t network	Social – risk of option not being effective unless adopted by the public	Medium	National	Reversible	Gradual change	Long term
Regulatory options	Adapt the national performance indicators for the Highways Agency to reward for future-proof investments	Economic and social benefits associated with a more reliable road network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational	Medium	National	Reversible	Step change	Long term
Repair, Retrofit or Replace options	Following the review into the suitability of current road infrastructure assets, repair, replace, retrofit as necessary.	Economic and social benefits associated with a more reliable road network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses.	Financial costs – possibly too expensive until the effects of climate change are more understood	Medium	National	Irreversible	Gradual change	Long term
Scour of road or rail bridges due to increased precipitation and/or storminess								
Technical options	Review current rail infrastructure assets for their	Economic and social benefits associated with a more	Financial costs – possibly too expensive until the effects of	High	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	ability to withstand the more extreme weather conditions predicted as a result of climate change. Adaptation should begin with an inspection and assessment of vulnerable bridges, leading to a prioritisation of remedial works where necessary.	reliable transport network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses.	climate change are more understood, political, organisational, technological. Difficult process to obtain funding now to carry out improvements which may only have a benefit in several years time. As with the above example, the funding process is another barrier.					
Operational options	Improved regular inspection regime may be necessary to ensure that existing assets are coping with more extreme floods	Economic and social benefits associated with a more reliable road t network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational, technological. Lack of knowledge of some drainage details prevents a full analysis of the risk, and surveys will be needed.	High	National	Reversible	Gradual change	Long term
Operational options	Contingency planning with utilities companies for responses to disruption to power/telecommunications cabling associated with storm damage to rail infrastructure e.g. bridges.	Economic and social benefits associated with a better response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses.	Organisational	Medium	Regional	Reversible	Gradual change	Short term
Operational options	Climatology - improve predictions of extreme and adverse weather conditions.	Improved ability to assess risk of adverse climate conditions and lower costs associated with effective forward planning rather than reactive responses.	Possible technological, economic and operational constraints	Medium	National	Reversible	Gradual change	Long term
Operational options	Review emergency contingency plans to ensure that they are optimally organised for the areas most affected by extreme and	Economic and social benefits associated with a better response to emergencies. Lower costs over the long-term due to effective forward	Organisational	High	Regional	Reversible	Gradual change	Short term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	adverse weather conditions.	planning rather than reactive responses.						
Cultural options	Manage expectations of the public to the disruptive effect of upgrades necessary to rail infrastructure	Less pressure on a constrained rail network	Social – risk of option not being effective unless adopted by the public	Medium	National	Reversible	Gradual change	Long term
Regulatory options	Adapt the national performance indicators for National Rail to reward for future-proof investments	Economic and social benefits associated with a more reliable rail network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational	Medium	National	Reversible	Step change	Long term
Repair, Retrofit or Replace options	Following the review into the suitability of current rail infrastructure assets, repair, replace, retrofit as necessary	Economic and social benefits associated with a more reliable rail network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood	Medium	National	Irreversible	Gradual change	Long term
Moisture fluctuation in road and rail embankments in SE England – due to wetter winters and drier summers								
Technical options	Review current clay embankments not just for their current condition but also their ability to withstand more extreme temperature and weather conditions as the climate changes. Adaptation should incorporate local strengthening of embankments, as has been done already on some parts of the railway network.	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood	High	National	Reversible	Gradual change	Short term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Operational options	Improved regular inspection regime may be necessary to ensure that existing assets are coping with more extreme weather conditions.	Economic and social benefits associated with a more reliable transport network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses.	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational, technological. A significant barrier to remedial work is the lack of knowledge of the asset, stemming from a lack of assessments carried out on road and rail embankments, and assessments that are made very rarely use the forecast flows predicted by climate change.	High	National	Reversible	Gradual change	Long term
Operational options	Contingency planning to divert rail and road routes vulnerable to supports becoming insecure	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational	Medium	Regional	Reversible	Step change	Short term
Operational options	Improved regular inspection regime may be necessary to ensure that existing assets are coping with more extreme weather.	Economic and social benefits associated with a more reliable road network and response to emergencies. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood, political, organisational, technological.	High	National	Reversible	Gradual change	Long term
Repair, retrofit and replace options	Following the review, strengthen the embankments vulnerable to movement as necessary.	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive for lower risk locations until the effects of climate change are more understood.	Medium	Local	Irreversible	Step change	Short term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Overheating of underground trains due to increased temperatures								
Technical options	Carry out detailed study of the problem. It may be possible to introduce and utilise systems and technologies as they emerge to cool Underground infrastructure at certain stations.	Economic and social benefits associated with a more reliable rail network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood. Uncertainty over applicability; needs further research.	Medium	Local	Irreversible	Step change	Short term
Operational options	Contingency planning to reduce frequency of trains running during higher temperatures. Underground rail owners need to liaise closely with their electricity suppliers to reduce the risk of disruption to train operation and hence interruption of natural ventilation.	Economic and social benefits associated with a more reliable rail network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial – could be an expensive concession by the Underground operator	Medium	Local	Reversible	Gradual change	Long term
Operational options	Emergency planning for adverse health reactions from passengers.	Lower costs over the long-term due to effective forward planning rather than reactive responses. Duty to regard the health and safety of passengers	Organisational, financial costs – possibly too expensive until the effects of climate change are more understood	High	Local	Reversible	Gradual change	Long term
Operational options	Climatology - improved predictions of extreme and adverse weather conditions	Improved ability to manage adverse climate conditions	Possible technological, economic and operational constraints	Medium	National	Reversible	Gradual change	Long term
Regulatory options	Restrictions on the upper limits of temperatures allowed could make new cooling technologies more financially viable – if without the investment, train frequencies and income drop significantly	Health benefits for passengers, economic benefits by avoiding modal change	Financial – could be an expensive concession by the Underground operator	Medium	Local	Reversible	Gradual change	Long term
Repair, Retrofit or Replace	Cooling technologies can be	Health benefits for	Financial	Medium	Local	Irreversible	Gradual	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
options	more effectively employed at existing stations with enabling access	passengers, economic benefits by avoiding modal change					change	
High tides, high winds and changing wind direction at ports								
Technical options	The siting and location of new ports, docks and expansions need to consider greater tidal range. Planning for new infrastructure to be on higher ground will mitigate some of the effects, as is being done at Dover.	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Policy, social, environmental, economic are all potential constraints to delivery	High	Local	Irreversible	Step change	Long term
Technical options	Review defences to storms from other wind directions, not just south-westerly	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood. The risk of such events is unknown, due to the lack of certainty in future wind predictions and is a barrier to future action.	Low	Local	Reversible	Gradual change	Short term
Operational options	Contingency plan for greater limitations on operational times due to adverse tidal conditions	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational, financial costs – possibly too expensive until the effects of climate change are more understood	Medium	Local	Reversible	Gradual change	Short term
Operational options	Climatology - improved predictions of extreme and adverse weather conditions. Improved forecasting of imminent storm will also reduce the risks, as shipping can be safely moored, or diverted to ports where effects are likely to be less.	Improved ability to manage adverse climate conditions	Possible technological, economic and operational constraints	Medium	National	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Operational options	Contingency plan for the freight implications of dock closures e.g. 'Operation Stack' which uses the M20 as a lorry park during ferry closures	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational, financial costs –	High	Local	Reversible	Step change	Short term
Cultural options	People will need to become more flexible to changes in the ferry terminal they arrive and/or depart from	Less pressure on critical hubs eg Dover	Social – risk of option not being effective unless adopted by the public	Medium	Regional	Reversible	Gradual change	Long term
Regulatory options	The new Infrastructure Planning Commission should help ensure the timely construction of new ports	Lower costs associated with effective forward planning rather than reactive responses	Policy, social, environmental, economic are all potential constraints to delivery	High	Local	Irreversible	Step change	Long term
Repair, retrofit and replace options	Retrofit more resistant flood defences as required, including possible re-alignment of docks to minimise disruption caused by changing winds	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood	Medium	Local	Irreversible	Step change	Long term
High winds, storms, and changing wind direction at airports								
Technical options	New airports (e.g. Thames Estuary) will need to consider the implications of changing wind directions on runway layouts	Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood. Land, political, environmental, social constraints	Low	Local	Reversible	Gradual change	Long term
Technical options	Improved drainage to mitigate against flooding.	Lower costs over the long-term due to effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood. Land, political, environmental, social constraints	Medium	Local	Irreversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [2]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Operational options	Climatology - improved predictions of extreme and adverse weather conditions	Improved ability to manage adverse climate conditions	Possible technological, economic and operational constraints	Medium	National	Reversible	Gradual change	Long term
Operational options	Contingency plans are necessary to make best use of alternative airports if crosswinds at the intended airport make landing impossible	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational, national overview needed	Medium	Local	Reversible	Gradual change	Short term
Cultural options	People will need to become more flexible to changes in the airport they arrive and/or depart from	Less pressure on critical hubs eg Heathrow	Social – risk of option not being effective unless adopted by the public	Medium	National	Reversible	Gradual change	Long term
Regulatory options	Airport operators need to be made aware of this risk and consider their response	Economic and social benefits associated with a more reliable transport network. Lower costs over the long-term due to effective forward planning rather than reactive responses	Organisational, national overview needed	Low	Local	Reversible	Gradual change	Long term
Regulatory options	The new Infrastructure Planning Commission should help ensure the timely construction of new airports	Lower costs associated with effective forward planning rather than reactive responses	Policy, social, environmental, economic are all potential constraints to delivery	High	Local	Irreversible	Step change	Long term
Repair, retrofit and replace options	Possible re-orientation of existing runways	Lower costs associated with effective forward planning rather than reactive responses	Financial costs – possibly too expensive until the effects of climate change are more understood. Land, political, environmental, social constraints	Unknown	Local	Irreversible	Step change	Long term

Table 3: Water

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[3]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Reduced security of supply due to changing precipitation patterns and periods of drought								
Technical	Finding new water sources such as additional groundwater, or using resources outside of water company's regional boundaries from other water companies	Increase water supply	Impacts on environment & surrounding settlements, utility agreements	High	Regional	Irreversible	Step change	Long term
Technical	Desalination of sea water	Increase water supply	Significant capital and operating expenditure, power requirements	High	Regional	Irreversible	Step change	Long term
Technical	Building more water storage and more flexibility into the network could help avoid minor disruptions of service	Minimise disruptions to service,	Land availability, environmental impact of large storage	High	Regional	Irreversible	Step change	Long term
Technical	Providing erosion protection at key areas in the watershed could help reduce sediment loading from precipitation events	Reduce sediment loading (improve quality of water?), maintain storage capacity of reservoir	No major barriers; Land access	Low	Regional	Irreversible	Step change	Long term
Technical	Improving leakage performance would increase storage and promote efficiency	Increase water supply, maintain storage capacity	Financial cost, identifying all leaks	Medium	Regional	Irreversible	Gradual change	Long term
Technical	Dredging silt from reservoirs would increase storage and promote efficiency	Increase water supply, maintain storage capacity	Significant operating expenditure, identifying all leaks	Low	Regional	Irreversible	Step change	Short term
Technical	Modifying reservoir dams for	Increase water supply,	Would have to be done	Low	Regional	Irreversible	Step change	Long term

[3] Where 'high'= the option's potential benefits greatly outweigh the potential costs

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	new reservoir low levels and/or high levels	maximise use of existing assets	during periods of low water levels in reservoir					
Technical	Designing new infrastructure to account for possible climate change	Flexibility in water network, increase access to existing supply	No major barriers, potentially land access, financial cost	High	Regional	Irreversible	Gradual change	Long term
Technical	Water reuse treatment plants (treating wastewater effluent to drinking water quality) are a technically feasible option.	Increase water supply, reduce waste	Capital and operating expenditure, power requirements	High	Regional	Irreversible	Step change	Long term
Operational	Better demand forecasting	Better planning for water demand	Uncertainty associated with forecasting	High	Regional	Reversible	Gradual change	Long term
Operational	Improved watershed management	Increase water supply quantity & quality	Have to have comprehensive control of watershed	Medium	Regional	Reversible	Gradual change	Long term
Operational	Incentivise demand reduction (compulsory metering)	Decrease demand	Large number of homes requiring metering	Medium	Regional	Reversible	Gradual change	Long term
Operational	Support for localised resources (rainwater harvesting) and grey water recycling	Increase water supply Less waste water	Out of utilities control, less regulated since localised control	Medium	Regional	Reversible	Gradual change	Long term
Operational	Industries create the largest water demand, supplying them a source of non-potable water could be an option, which would entail non-potable distribution network (technical challenge)	Less water treatment required hence less energy demand, higher water quality	Major distribution infrastructure cost/challenger	Low	Regional	Irreversible	Step change	Long term
Operational	Partnering with bordering utilities to share resources and increase flexibility	Increase access to water supply	Contractual relationships between utilities	High	Regional	Reversible	Step change	Long term
Cultural	Widespread and effective water efficiency measures	Reduce water consumption	Cultural barriers Lack of awareness	High	Regional	Reversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Cultural	Utilising rainwater harvesting and grey water recycling	Reduce water consumption	Health concerns / perceptions of greywater	Medium	Regional	Reversible	Gradual change	Long term
Cultural	Accepting water reuse	Reduce water consumption and reduced waste	Health concerns / perceptions of greywater	High	Regional	Reversible	Gradual change	Long term
Cultural	The population will also need a willingness to pay for security of supply in advance of an impending shortage	Proactive approach rather than reactive	Cultural spending habits, i.e. willingness to pay; Regulations may need to change to both accommodate and control 'price spikes'	High	Regional	Reversible	Step change	Long term
Financial	The UK water industry is a 'quasi' public entity and utility finances are directly related to regulatory control. Raising customer rates for water services is an option to offset the cost of climate change adaptation	Financial resource to implement adaptation measures	Regulations may need to change to both accommodate and control 'price spikes' Public and Political resistance to change	High	National	Reversible	Step change	Long term
Regulatory	Utilities currently submit a 25-year Water Resources Management Plan to Ofwat every 5 years. Ofwat could require utilities to consider a greater impact from climate change in these plans and in their asset management plans or set climate change adaptation targets. A regulatory method for approving adaptation plans may be required	Gives incentives to utilities to be proactive in climate change adaptation	Increased prices likely to be passed onto consumers (question if adaptation is a newt benefits to utility or to customer? No established rule yet)	High	National	Reversible	Step change	Long term
Repair, Retrofit or Replace	Adaptation to climate change in the water sector will require all three of repairing, retrofitting and replacing	Retrofit typically cheaper than replacing and not always need to replace with most expensive option	Significant capital and operating expenditure	High	Regional	Irreversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Increased sewer flooding due to increased precipitation and storm surge								
Technical	Increasing storage in the system, and increasing the capacity of the existing system are technical options for adaptation.	Reduces pollution events through reduced sewer flooding; Protects community property	Significant capital expenditure	High	Regional	Irreversible	Step change	Long term
Technical	New sewers should be designed with climate change figured into the design standards. Many new storm sewers are designed with consideration for climate change forecasts of storm events in 2080.	Same as above for security of supply. More sustainable design standards, proactive approach to adaptation	Defining appropriate design standards	High	Regional	Reversible	Gradual change	Long term
Technical	A more applicable approach may be controlling drainage at the source through sustainable urban drainage systems (SUDS) to keep stormwater out of the sewer system.	Less pressure on centralised treatment plants, more sustainable drainage	Flexibility	High	Regional	Irreversible	Gradual change	Long term
Technical	Persuade/prepare the public to accept a higher risk of sewer flooding. Encourage rainwater harvesting	Less pressure on utility to provide high quality effluent	Negative environmental impacts	Low	National	Reversible	Gradual change	Long term
Operational	Maximise capacity within existing assets	Relatively easy to do, low cost, proactive approach	Potentially has minimal effect. Need to have awareness to forecast storm event within certain time constraints	High	Regional	Reversible	Step change	Short term
Operational	Widespread and effective use of SUDS would be a cultural option. Utilising rainwater harvesting would also be a cultural option.	Asset and community property protection	The population will also need a willingness to pay for reduced flood risk in advance of a significant flood event.	High	Regional	Irreversible	Gradual change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority)[3]	Criteria to assess/prioritise net impacts			
					National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Cultural	The UK water industry is a 'quasi' public entity and utility finances are directly related to regulatory control. Creating tariffs to provide incentives for the public to reduce stormwater from entering sewerage systems.	Financial resource to implement adaptation measures	Regulations may need to change to both accommodate and control 'price spikes' Public and Political resistance to change All infrastructure spending must be approved by regulators Socioeconomic issues need to be considered – what will the impact be on poorer members of society? Note that 'fuel poverty' is an issue in the UK and 'water poverty' could become an issue of the future.	High	National	Reversible	Step change	Long term
Financial	Planning permits for buildings restricting freedom to increase hard surfaces and regulatory requirements to implement and/or retrofit existing drainage to SUDS.	More sustainable form of surface water drainage, less pressure on centralised treatment facilities	Changing planning controls at the local authority level likely to be arduous and time consuming. Incorporating into national Planning Policy Statements more helpful.	High	National	Reversible	Gradual change	Long term
Regulatory	A regulatory method for approving adaptation plans despite the uncertainty associated with climate change predictions may be required.	Gives incentives to utilities to be proactive in climate change adaptation	Increased prices likely to be passed onto consumers (question if adaptation is a newt benefits to utility or to customer? No established rule yet)	High	National	Reversible	Step change	Long term
Repair, Retrofit or Replace	Adaptation to climate change in the water sector will require all three	Retrofit typically cheaper than replacing and not always need to replace with most expensive option	Significant capital and operating expenditure	High	Regional	Irreversible	Gradual change	Long term
Increased flood risk due to increased precipitation and storm surge								
Technical	Flood proof strategic assets; relocate vulnerable assets to	Protection of flood plain for other development, reduction	Significant capital and operating expenditure; No	High	Regional	Irreversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	areas of lower flood risk	in pollution events, protection of assets, proactive approach	regulatory method in place to approve flood protection on non-critical assets					
Operational	Provide emergency pump capacity	Dewater assets within available time	Not sustainable, minimal impact	Low	Regional	Reversible	Step change	Long term
Cultural	The population may need a willingness to pay for increased flood protection in advance of a significant flood event.	Less pressure on centralised treatment facilities, may contribute to sustainable development	Cultural resistance	High	National	Reversible	Gradual change	Long term
Financial	The UK water industry is a ‘quasi’ public entity and utility finances are directly related to regulatory control.	Financial resource to implement adaptation measures	Although 100% flood protection may be technically possible, it is unlikely to be feasible. Obtaining funding to flood proof assets can be difficult if they are not strategic for providing public potable water. There are also other financial barriers in that people typically do not want to pay more for water and sewer services. Regulations may need to change to both accommodate and control ‘price spikes’ Public and Political resistance to change All infrastructure spending must be approved by regulators Socioeconomic issues need to be considered – what will the impact be on poorer members of society? Note that ‘fuel poverty’ is an issue in the UK and ‘water poverty’ could become an issue of the future.	High	National	Reversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Regulatory	A regulatory method for approving adaptation plans or requiring increased flood protection of strategic assets despite the uncertainty associated with climate change predictions may be required.	More sustainable form of surface water drainage, less pressure on centralised treatment facilities	Currently regulations do not specify requirements for flood protection. Changing planning controls at the local authority level likely to be arduous and time consuming. Incorporating into national Planning Policy Statements more helpful.	High	National	Reversible	Gradual change	Long term
Repair, Retrofit or Replace	Adaptation to climate change in the water sector will require all three	Retrofit typically cheaper than replacing and not always need to replace with most expensive option	Significant capital and operating expenditure	High	Regional	Irreversible	Gradual change	Long term
Pollution incidents due to changing precipitation patters and periods of drought								
Technical	There are numerous technical options for treating wastewater to a higher standard. Membrane technology is one example of a treatment process that can produce high quality effluent.	Opportunity to recycle waste water (reduce potable water consumption), Improved environmental protection	Significant capital and operating expenditure, power consumption, carbon footprint	Medium	Regional	Irreversible	Step change	Long term
Technical	There are also numerous technical options to adapt treatment plants to various flow rates, such as increased storage during high flow and recycling during low flow	Higher flexibility to meet minor variations in flow and load as result of climate change	Significant capital and operating expenditure, flexibility of asset modification	Medium	Regional	Irreversible	Step change	Long term
Technical	Numerous technical options also exist for sludge disposal. Two options have the potential to generate energy.: 1.Anaerobic digestions of sludge creates a biogas (methane) suitable for localised consumption. 2.Incinerate sludge can provide combined heat and	Increased options for sludge disposal, potential to generate localised and sustainable energy	Significant capital and operating expenditure, specialised technology that water companies might not be qualified to install, potential emissions issues with CHP	Medium	Regional	Irreversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
	power (CHP) that can also be utilised on-site							
Technical	The use of sustainable urban drainage systems (SUDS) to keep stormwater out of sewers will also reduce risk	Asset and community property protection	Responsibility for payment	High	Regional	Irreversible	Gradual change	Long term
Operational	Operations at wastewater treatment plants will evolve with changing wastewater influent, treatment technologies and consent limits. Utilities could require industrial customers to limit and/or pre-treat their effluent prior to discharging in the sewer in order to alleviate capacity issues at the treatment plant.	Less pressure on centralised waste water treatment facilities	Willingness of industrial customers to pay for the additional on site treatment,	Low	Local	Reversible	Step change	Long term
Operational	Decentralised treatment systems, including more private systems, could also reduce pressure on capacity at the wastewater treatment plant, but the increased number of effluent discharge points may increase the risk of a pollution incident.	Less pressure on centralised waste water treatment facilities	Difficult to regulate, every decentralised system would need own effluent discharge permit which would have to be environmentally feasible	Low	Local	Irreversible	Step change	Short term
Technical	The use of sustainable urban drainage systems (SUDS) to keep stormwater out of sewers will also reduce risk	Asset and community property protection	Responsibility for payment	High	National	Reversible	Gradual change	Long term
Cultural	The public's acceptance and support of wastewater effluent reuse could significantly reduce the risk of a pollution incident by essentially creating a 'closed-loop' system.	Sustainable water use	Regulatory barrier and public resistance	High	National	Reversible	Step change	Long term

	Possible mitigation options	Benefits of options	Barriers to implementation	Net impact of option (i.e. priority) [3]	Criteria to assess/prioritise net impacts: National, regional or local impact	Reversible or irreversible impact	Gradual or a step change	Short or long term impact
Financial	The UK water industry is a 'quasi' public entity and utility finances are directly related to regulatory control. Raising customer rates for water services is an option to offset the cost of climate change adaptation.	Financial resource to implement adaptation measures	Regulations may need to change to both accommodate and control 'price spikes' Public and political resistance to change All infrastructure spending must be approved by regulators Socioeconomic issues need to be considered – what will the impact be on poorer members of society? Note that 'fuel poverty' is an issue in the UK and 'water poverty' could become an issue of the future.	Low	National	Reversible	Step change	
Regulatory	Less stringent controls over effluent discharge would obviously reduce the number of pollution events.	Less pressure on utility to provide high quality effluent	Negative environmental impacts	High	National	Reversible	Step change	Long term
Regulatory	A regulatory method for approving adaptation plans despite the uncertainty associated with climate change predictions may be required.	Being proactive in implementing adaptation measures	No regulatory method to do so	High	Regional	Irreversible	Gradual change	Long term
Repair, Retrofit or Replace	Adaptation to climate change in the water sector will require all three	Retrofit typically cheaper than replacing and not always need to replace with most expensive option	Significant capital and operating expenditure	Medium	Regional	Irreversible	Step change	Long term

Appendix E
Workshop report

Workshop on Increasing the Resilience of Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change

4th November 2009 at Defra Innovation Centre, Reading

1. Introduction

1) In April this year the Domestic Adaptation Programme Board set up the Infrastructure and Adaptation project as a high-level, two year project (to March 2011) to look at adaptation issues relating to infrastructure within the energy, transport and water sectors.

2) The project's remit is to examine and identify strategic solutions to 'improve the long-term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts'. As well as examining the three sectors, the project also considers:
   - The role of ICT and Telecommunications within and across the sectors.
   - The interconnectivity between and within the sectors.

3) As an important first part of the project, the firm URS have been commissioned to undertake a project to focus on the technical implications from climate change on the infrastructure in the three sectors and what this means operationally, including supply and demand. Additionally, the work will consider interconnectivity across the three sectors as well as possible new or modified future infrastructure that may be required due to climate change.

4) The workshop, held on 4th November, brought together industry, government representatives and URS to discuss the project (a full list of workshop attendees is in Annex A). It presented an opportunity to test emerging findings from the work with sector experts and to get views on barriers and possible options for overcoming these. A particular focus of the workshop was on the issue of interconnectivity between and within the sectors (i.e. energy sector and water sector or aviation and rail) – an issue that is still a relatively new consideration.

2. Presentations

1) Mark Filley gave a presentation to the workshop on the work currently being undertaken by the ACC programme and the Infrastructure and Adaptation Project.

2) Sally Vivian gave a presentation on the emerging findings from the project as well as possible barriers to increasing the resilience of the infrastructure in the three sectors to long-term climate change.

3) Both Mark's and Sally's presentations are separately attached.

4) The majority of the day was focused on discussing a number of issues which are summarised in the following sections.

3. Summary of Discussion on Emerging Findings Per Sector

Poster	**Emerging Findings**	**Workshop Response**
Water Infrastructure	*Infrastructure including: Reservoirs, Water & Sewer Networks, Treatment Works etc.* • Near term concern (2030s) = Drainage & Flooding • Longer term priority = Availability & Quality of Water Resources • Asset Adaptation Technology Exists • Water Infrastructure is a Single Integrated System • Efficiency vs Adaptation	*Clarification Needed* • Further details needed on efficiency vs adaptation. *Additions* • Report should include consideration of the future demand for water. • River systems are integral to water supply and waste water management and will be impacted by climate change. *Concerns* • The assumption that asset adaptation technology already exists might prevent development of technology needed to deal with longer terms impacts. • Greater education is needed to increase understanding of the cost of water. • As resources become more stressed, there will be increasing competition, especially from the energy sector for water. • Water companies need to clarify minimum supply standards. *Other Comments* • Water impacts including flooding, availability and increased carbon from treatment is being felt now.
Energy Infrastructure	*Infrastructure including: National Grid, Oil Refineries, Wind Farms, Fossil and Nuclear Power Stations, Pipelines etc.* • Demand forecasting • Flood damage to coastal and floodplain infrastructure • Design thresholds for transformers	*Clarification Needed* • Report should be clear about the timescales involved in planning energy infrastructure. *Additions* • Report should consider the work already undertaken by the energy network companies alongside the EA to consider flooding risks. • Increased growing season is causing trees to grow into overhead lines and is already increasing costs. • Renewable energy systems will have a large impact on network design.

<table>
<tr><td></td><td>expected to be exceeded
Decreases to efficiency of thermal generation
Impacts to longer cable routes (efficiency & resilience as well as extreme events)</td><td>Concerns
The energy sector needs certainty of water supply.
Other Comments
The EA is piloting sits-by-site flood warnings for energy companies. This programme could be rolled out to all critical infrastructure providers.
The report should recognise that the energy sector has three elements – Generators, Transport and Distribution.</td></tr>
<tr><td>Transport Infrastructure</td><td>Infrastructure including: Roads, Rail (network, signals, stations), Airports (runways/terminals/aircraft) and Ports.
Greatest risk for infrastructure with longest design life (e.g. earthworks and drainage 60 years, structures 120 years)
Road, rail and tunnel flooding
High-reliance on electricity and ICT for functioning of transport network
Storm damage to critical infrastructure (e.g. airports, ports)</td><td>Clarification Needed
Who is responsible for resilient energy network to the transport sector? Is this the energy supplier, the transport sector or both?
Additions
The energy sector is vulnerable to storms (power lines down, trees block routes, subsistence of embankments).
Flooding and inundation of coastal infrastructure is a significant risk to the transport sector.
Concerns
There is a potential gap in knowledge over the performance of some parts of the existing infrastructure to floods and increases in temperature.
Uncertainty over predictions of extreme climate events.
Some specifications might become outdated – changes in these will need to keep pace with climate change.
Problem of overheating on underground train networks.
Other Comments
Should investigate the possibility of using new transport infrastructure (especially earthworks) as a part of flood defence.
Plans for future infrastructure should consider the types of materials that will be available in a low carbon world.</td></tr>
</table>

4. Summary of Discussion on Infrastructure Interconnectivity and Role of ICT

<table>
<tr>
<td>Infrastructure Interconnectivity</td>
<td>Water
○ Road, rail and tunnel flooding
○ Transport for deliveries, staff, sludge removal

Energy
○ Water is critical for cooling
○ Transport of materials and staff

Transport
○ Airports and Ports reliant on Road and Rail
○ Energy for rail and electrical signage</td>
<td>Clarification Needed
• How do tipping points in one sector impact on other sectors? Will thresholds and tipping points be met and exceeded suddenly or gradually?

Additions
• Extreme weather conditions are the priority concern.
• All sectors are wholly reliant on each other operationally.
• ICT is integral to all sectors and should be considered as a shared resource.

Concerns
• There is a different level of climate change and adaptation knowledge in the three sectors and no real inter-sector dialogue.
• A route map of cross sector reliance is needed. Analysis of individual supply chains could be a good first step. Cross sector co-ordination is required.
• Should consider uses of resource in other sectors that are non-essential/ unsustainable (for example – cleaning of trains with water).

Other Comments
• New Infrastructure Planning Commission could ensure capital projects consider cross-sectoral adaptation issues at the planning stage.</td>
</tr>
<tr>
<td>Role of ICT</td>
<td>Water
○ ICT Important for operation of remote assets
○ Emergence of smart telemetry will enable “self adjustment” of networks

Energy
○ Sector itself has a major reliance on ICT
○ Operation of ICT requires energy for all aspects of the network

Transport
○ Operation (ports, air and rail in particular are reliant on ICT
○ Local overloading in event of emergency.</td>
<td>Clarification Needed
• What changes will take place in the ICT sector that will impact on the other three sectors?
• Is the question about the use of ICT as an adaptation option or the vulnerability of ICT and the impact of its failure on the other three sectors?

Additions
• Simpler systems may be more resilient as they are easier to repair; however more complex systems can be more robust/ efficient as they are harder to ‘knock off’.

Other Comments
• ICT is perceived to have a short term life – is it relevant to long term climate change?</td>
</tr>
</table>

5. Summary of Discussion on Barriers to Effective Long-term Adaptation

Barriers to Effective Adaptation	*Barriers include:* • Uncertainty of climate projections (e.g. investment and energy demand forecasting) • Current regulatory and investment mechanisms (e.g. AMP funding cycle, need for return on investment) • Current business/operational structures/systems tend to focus on shorter timeframes (e.g. 6-12 year) windows – limits longer term investment planning	*Sector Complexity* • Most adaptation options involve the input of more than one sector – for example sustainable drainage. • Reliance upon other organisations or sectors for ensuring supply chain is sufficiently adapted. • Different sector regulators and differences between national and regional cultures pose a significant barrier. *Existing regulatory/ legislative structures* • Costs are short term and easily measureable in terms of capital outlay whereas benefits are long term, uncertain and often intangible involving. Additionally benefits are often shared. • Existing planning policy for water infrastructure does not consider climate change adaptation sufficiently. • Shortness of funding cycles limits long term investment. *Organisational barriers* • Whilst there is good buy-in at working level, senior individuals in organisations are still not being put under pressure to take action to adapt. • Possibility of organisations using risks and uncertainties as an excuse not to adapt. • Decision makers need to cascade the need for an adaptation plan, and customers and staff need to put pressure on the decision makers to adopt and take action towards the adaptation plan. *Knowledge gap/ communication* • There is a need to increase understanding among the public of their role in changing behaviour. • Planners are often "siloed" in the decision making process. There is a need to ensure planners are involved in the process alongside policy makers, operators and the end user. *Other Comments* • Customer expectations are high – customers do not expect interruptions to supply, restrictions on use or loss of quality but demand low costs. This is not the case in other countries that are faces with resource shortage. • Climate change should not be treated as a separate issue. It should be embedded into existing risk management practices.

6. Summary of Discussion on Possible New Infrastructure

New Infrastructure and the Low Carbon Transition	New infrastructure will be wide ranging but could include: • Electrical vehicles – results in a changing balance of energy demand • Smart telemetry - remote management of water network could enable more efficient response (but requires reliance on ICT) • Low carbon generation (e.g. nuclear, increased wind, tidal etc) – opportunities to design in resilience, but with critical operational requirements e.g. cooling water for nuclear, wind power etc)	*Clarification Needed* • What sort of electric vehicles should be planned for - Plug in; Swap batteries; Constant pick-up (rails, magnetic)? • How does climate change affect the design life of new technologies? *Additions* • Smart water and waste water grids. • Should be encouraging simple, non-carbon new infrastructure such as walking and cycling. *Concerns* • There is a need to re-engineering the 20th Century grid to enable low carbon generation and to create the capacity. • The interaction between mitigation and adaptation should be considered. Win – win or no/low regret options should be identified as the preferred approach. • Increased energy demand exacerbates problems associated with the interconnectivity of the energy sector and other sectors. *Other Comments* • The design process is not expected to change, but the parameters being designed for will.

7. Summary of Discussion on Possible Adaptation Options including a "World with no Barriers"

Adaptation Options	From your organisation's experience of considering climate change risks, how would you: • Increase long term resilience • Reduce long term technical risks	*Increase long term resilience* • Encourage cultural change within organisations – getting senior managers to 'sign-up to long terms problems'. *Reduce long term technical risks* • Specific engineering solutions on a short term basis – driving ingenuity. • Improve connectivity so that the organisation is not dependent on one source of supply. *General* • Flexibility of solutions that are constantly evolving – this allows the ability to deal with uncertainty.
A World With No Barriers	*What are your aspirations?* • Water infrastructure would be able to adapt by ... • Energy infrastructure would be able to adapt by ... • Transport infrastructure would be able to adapt by ...	*In a world with no barriers...* • ... surface water would be kept out of sewers. • ... treatment plans would be self powered. • ... the sectors would identify the main risks and any new solutions • ... there would be a constant renewal of all infrastructure assets – signals, tracks, buildings etc.. • ... Home Video-Conferencing and virtual offices would remove the need to travel to the office. • ... there would be a root and branch review of regulations that prohibit adaptation and • ... there would be higher standards in design and resource efficiency. • ... planners would know exactly what future climates would be like and would have access to more accurate climate predictions with greater levels of certainty. • ... there would be a greater understanding of mal-adaptation. • ... planning legislation would be developed that prohibits building in sensitive areas such as floodplains and promotes sustainable infrastructure. • ... there would be a rationalisation of the use of resources with a view to reduce the impacts of their use. • ... behaviours promoting adaptation would be incentivised for regulated companies. • ... people would accept the need to modify behaviour for the sake of the environment. • ... short terms gains would not come at the expense of long term benefits.

8. Possible Case Studies

Case Studies	• Do you have an example of a case study where an organisation (in the UK or internationally) has considered the technical/operational risks to a piece of its infrastructure? • Do you have any good examples of infrastructure in other countries that may be appropriate in this country due to long term climate change?	*Examples of UK Case Studies* • 25 Year Water Resource Plans that include impacts of climate change on both supply and demand. • Energy Network companies have assessed flooding risk to all grid and power substations and forwarded recommendations for remedial action. Costain have submitted plans to Ofgem with price controls. • Highways Agency is changing standards and specifications for drainage on motorways. Currently they are building in an extra 20% capacity. • Skanska built an electricity substation on stilts in a flood vulnerable area *Examples of Overseas Case Studies* • STFC has looked at Water, Energy and Transport in Chile for the ESA project. [S Webb] • Large drains in cities in far east to cope with sudden downpours • Sweden – use of biogas and advanced digestion of sludge. (Easier in some countries due to municipal structure). • 2004 Tsunami – the location of mobile phone masts meant this infrastructure continued to work while other localised infrastructure failed. *Examples of 'Practical Action' Case Studies* • The West Coast Main Line has conducted a pilot study with the HADLEY centre through the Rail Safety and Standards Board. • Flood mapping of the rail network in the valleys of South Wales. *Examples of Adaptation in Mitigation Case Studies* • Hammarby – a residential eco-town development in Stockholm.

9. **Summary of 'Challenge' Session**
Delegates were asked to formulate a challenge, and identify possible options to address the challenge.

1) Single Issue Focus

   Challenge:

   How do we ensure that new legislation does not have a single issue focus *so that* it looks at wider issues and implications in other sectors or areas in the long term *even though* there is likely to be a single required outcome?

   Recommended option

   Introduce a requirement in the development of new legislation that it should have a consideration of other sectors. Regulating bodies should look at existing legislation to identify areas that have a single issue focus but that could be broadened to include considerations of other sectors.

   Remaining problems

   This approach should, if properly followed through, ensure that single issue focus is not a problem for new regulation. However problems with a single issue focus in existing regulation and legislation may not be solved.

2) Interconnected Infrastructure Vulnerabilities

   Challenge:

   How do we identify vulnerabilities in our interconnected infrastructure systems *so that* the system delivers a specified service/performance with an appropriate reliability *even though* we face an uncertain future in terms of climate, demand and technologies?

   Recommended option

   It would be worth investigating the development of a probabilistically based working model of all interconnected national infrastructure networks together with a model of the associated interacting human behaviour to create an ensemble of potential scenarios for testing failure models and adaptation strategies.

   Remaining problems

   This is an extremely complicated issue and developing a working model within useful ranges of uncertainty would be very difficult. A good first step would be to identify interdependencies where there is a danger of cascade failure and then identify the thresholds that might bring this failure about.

3) Uncertainty in the UK Climate Projections

   Challenge:

   How do we ensure the users of the UK Climate Projections understand future climate science in sufficient detail *so that* appropriate and proportionate decisions are made *even though* there remain uncertainty and residual risks?

   Recommended option

   A rolling programme of sector led training by professional bodies. This would be accompanied with and complimented by guidance on key trigger points and thresholds and what levels of risk are acceptable for specified types of infrastructure.

   Remaining problems

Concerns over whether there is sufficient knowledge among the trade associations to carry through this type of training. However, this was identified as being a positive sector-lead solution.

4) Short term Nature of Funding Framework.

   Challenge:

   How do we establish an investment framework *so that* long term benefits are considered *even though* projects are funded by short-term costs?

   Recommended option

   Greater guidance is needed from government so that funding for projects includes an accurate assessment of long term costs.

   Remaining problems

   Still no guarantee that planning and funding decisions will accurately assess the potential for long term cost so that over investment or 'white elephants' as well as under investment are avoided. It was suggested that it might be worth considering encouraging a lowering of expectations so that lower standards are deemed acceptable.

10. Summary and Next Steps

In summing up, Mark Filley thanked all attendees for their participation which made for an interesting day. Mark mentioned that:

1) There was a great deal of enthusiasm for continuing this group especially in the light of the shortage of other inter-sector forum on climate change adaptation. Defra's Adaptation Team will consider how this can be addressed.
2) URS will use the workshop to feed into their final report. This workshop report will be included as an annex to the final report.
3) All delegates will be sent a copy of the final report that URS delivers to the Infrastructure & Adaptation Steering Group.
4) Delegates are invited to contact the Adapting to Climate Change programme (ACCInfrastructure@defra.gsi.gov.uk) if they have any additions or amendment.

Annex A
Details of Confirmed Attendees

Name	Organisation
Andrew Sinclair	International Power
Bruce Horton	Water UK
Brian Haddock	Network Rail
John Dora	Network Rail
Mark Langdon	Network Rail
David Quincey	Anglian Water
Caroline Leatherdale	Skanska
Mike Keil	Ofwat
Penny Tomlinson	RWE Npower
David Whensley	Energy Networks Association
Sean Wilkinson	Tyndall Centre
Brian Morrow	United Utilities
Mark Ellis-Jones	Environment Agency
Phil Lawton	DECC
Michelle Witton-Smith	DfT
Sarah Webb	BIS
Mark Filley	Defra
Will Lochhead	Defra
Richard Smith	Defra
Peter Newman	Defra
Saminder Gaheer	Defra
Sally Vivian	URS
Will Rogers	URS
Mike Smith	URS
Steve Ashton	URS
Alex Tosetti	URS
Greg Blais	URS