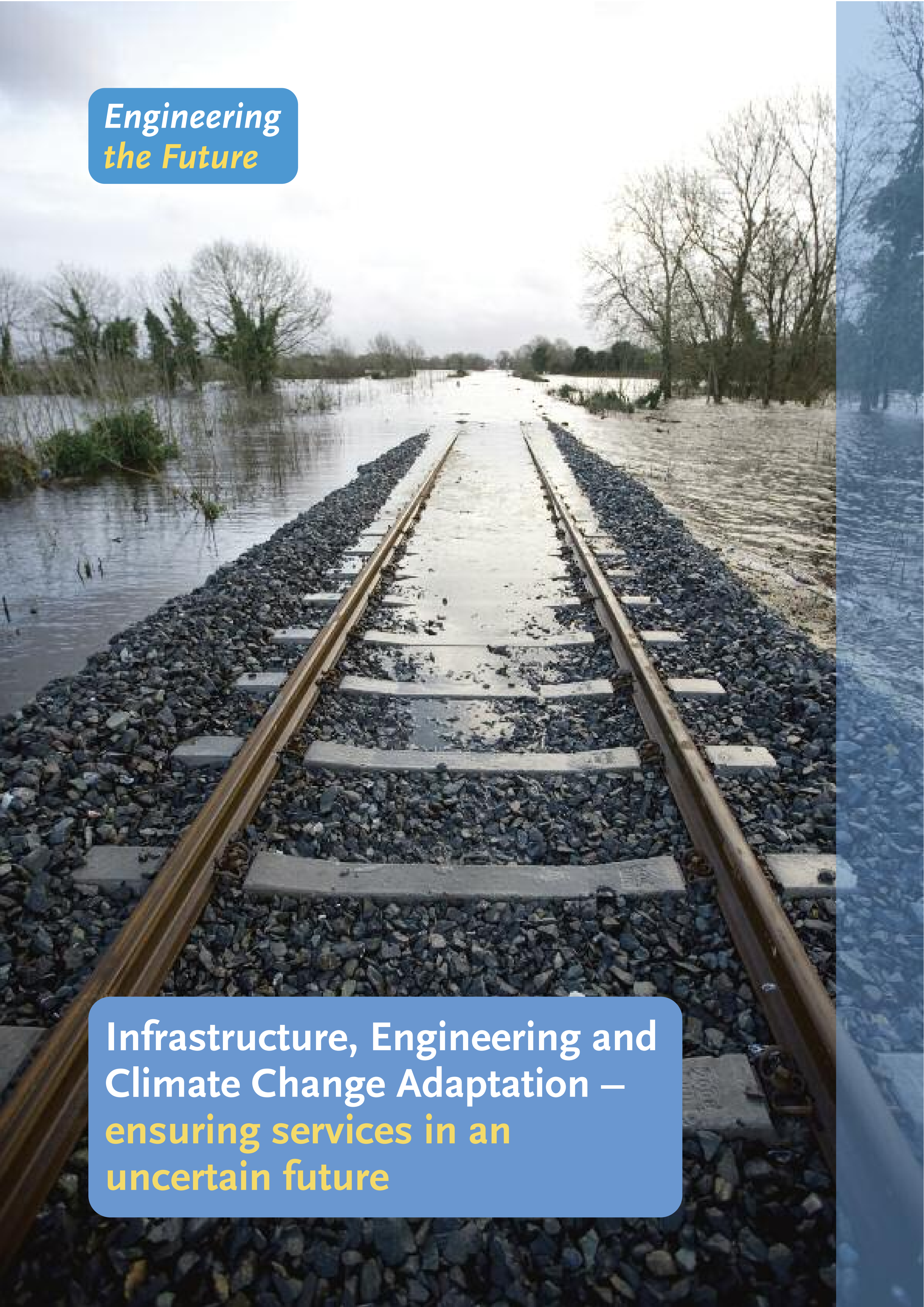

Engineering the Future

Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future

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Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future

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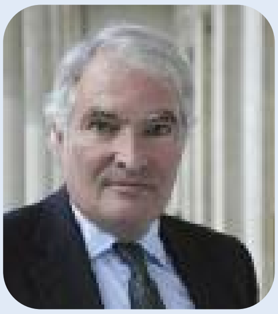
Foreword by the Rt Hon Lord Henley



Essential infrastructure which guarantees our energy and water supplies and enables safe and reliable use of road, rail and air transport is vulnerable to the effects of climate change.

We already have some insight into what a changing climate might mean for our infrastructure; high temperatures affecting rail lines leading to delays, floods affecting water infrastructure, closing motorways and damaging century old bridges, more extreme winter weather bringing costs and disruption to services.

And as our climate continues to change the difficulty in meeting the challenge of maintaining a robust and reliable infrastructure system increases.

This is especially true as our infrastructure sectors have developed into highly technical and interconnected systems. If one sector is at risk, so are the rest. If floods damage our energy supply, all other services can be affected, causing a cascade of failure.

To meet the challenge, we need an infrastructure system that is more resilient to climate change. This will require Government, the public and private sectors and professional sectors such as engineers to come together and proactively meet the challenge of creating a climate resilient infrastructure system for the country. This will reduce the risk of economic disruption to the country and enable the opportunities from well-adapted infrastructure to be maximised.

Through the creation of Infrastructure UK this government has highlighted the importance of infrastructure and it's crucial role in generating and sustaining economic growth. The UK's first ever National Infrastructure Plan, launched last year, underlines the importance of maintaining our transport, water and energy systems in the face of climate impacts. And in Spring 2011 the government will publish a report on Adapting National Infrastructure, emphasising the importance of well-adapted national infrastructure and outlining this Government's vision for moving forward.

The engineering profession has a crucial role to play. Engineers will be designing, building and maintaining our infrastructure to enable it to adapt. That is why I welcome this report from the *Engineering the Future* group, setting out how innovation and new engineering approaches can boost the climate resilience of our infrastructure.

Importantly, there is also an opportunity for UK engineers and leading engineering companies to develop innovative, cost effective and marketable solutions to climate threats for this country and abroad.

And Government will continue to work with the engineering profession to meet the challenge of adapting our infrastructure and help the profession take advantage of the opportunities a changing climate presents.

Foreword

Foreword by Lord Browne of Madingley

President, The Royal Academy of Engineering on behalf of *Engineering the Future*

Climate change is a reality. While efforts must continue towards mitigating its effects, there is a crucial need to adapt to the changing climatic conditions that are anticipated this Century. Extreme weather and long term climate change threaten critical national infrastructure and the UK economy, since a robust infrastructure is essential to economic functioning and growth.

Engineers will have a central role in adapting the UK's infrastructure for resilience to climate change. A holistic approach to the development and protection of infrastructure is essential, with an awareness of where failure in one sector can lead to a cascade of failures elsewhere. Engineers must use systems thinking to manage infrastructure in the light of new climate threats and to deal with systemic risks. An integrated approach to planning and managing infrastructure development is key. Government should take a systems approach to the processes of planning and regulation.

Adapting to climate change is not just a matter of managing the risks - it is about taking the opportunities it presents to develop new, innovative infrastructure systems and services. Adaptation to, and mitigation of, climate change provides opportunities in the new Green Economy. New opportunities in engineering design and manufacturing will come from the development of renewable energy technologies and the supply chains that will serve them. Building of resilience into existing infrastructure and designing new systems that are robust and efficient will do the same. If managed correctly, investment in infrastructure adaptation will create quality jobs, increasing the demand for skilled technicians to install, upgrade and maintain the new resilient infrastructure.

The adaptation programme needs Government to shape policy and regulation that will promote investment in infrastructure and encourage collaboration across sectors. It also requires individuals, organisations and businesses to take a realistic view of the future reliability of infrastructure based services, and to plan accordingly. Engineers will be critical to the adaptation challenge and the UK engineering profession is willing and eager to grasp the opportunities it presents.

Infrastructure, Engineering and Climate Change Adaptation –

ensuring services in an uncertain future

1. Executive summary

This study was an activity of the *Engineering the Future* partnership, carried out on behalf of Defra by The Royal Academy of Engineering, the Institution of Engineering and Technology, the Institution of Civil Engineers, the Institution of Mechanical Engineers and the Institution of Chemical Engineers. The conclusions of the study will feed into the Defra led cross-Government Infrastructure and Adaptation project. The study was carried out from the perspective of the engineering profession and the engineering response to the demands of climate change adaptation.

Engineers will be central to the process of adaptation, both ensuring that current infrastructure assets are protected from the long term and acute affects of climate change, and developing new infrastructure systems fit for changing climate conditions. Investing in engineering efforts to protect infrastructure is essential both to minimise risks to infrastructure, and thereby the public and the economy, due to climate change; and to maximise opportunities for the profession and the economy in developing cost-effective and marketable solutions to adaptation needs.

This report examines vulnerabilities in different sectors of the national infrastructure to the effects of climate change and the modifications that would be needed to increase resilience. It also considers vulnerabilities that affect the infrastructure system as a whole and which arise as a result of interdependencies between different sectors. The effects of climate change on infrastructure are not limited to changes in weather, but include the impact on infrastructure of efforts toward climate change mitigation, and climate induced changes in behaviour and demographics. These must be considered alongside other developments such as population growth and changes in the economic environment. The findings of the study are set out below.

Adaptation to climate change requires two forms of response: dealing with long term effects on the infrastructure such as rising sea levels, and developing resilience to acute and extreme weather events such as flash flooding. Extreme events highlight the interdependencies in infrastructure as they are liable to lead to 'cascade failure' where the failure of one aspect of infrastructure, such as flood defences, can lead to other failures, e.g. flooded power stations leading to power cuts which thereby affect telecommunications networks. The interdependencies in infrastructure therefore need to be managed well, especially as infrastructure is becoming more interdependent. For example, the smart grid will mean energy systems rely more on ICT, and the electrification of transport systems will mean transport is more reliant on the grid.

Resilience is thus required in all sectors to protect against cascade failure and to adapt the infrastructure against a slowly changing climate over the longer term. Managing national infrastructure is a systems issue, requiring collaboration, planning and sharing of information between sectors. Systems resilience, rather than sector resilience, is required to adapt to climate change. Current silos and boundaries must be broken down by culture and any other available levers used to build a picture of the state of the entire infrastructure system and local subsystems.

The infrastructure system also requires joined up management within Government, with long-term planning for adapting and maintaining infrastructure, and a regulatory and policy framework which provides the degree of certainty needed for investors. The need for a plan to manage the adaptation programme is urgent, but requires little cost and the plan can be implemented in a measured way over time. If the UK can implement a plan effectively, then there are opportunities for UK industry to meet both national needs and to export products and expertise.

Increased technical efficiency of the infrastructure should be valued, but a focus on economic efficiency can lead to reduced redundancy and diversity, thus reducing resilience. There are trade-offs between efficiency and resilience which must be addressed. Increased resilience comes at a cost, so given that there are limits on the extent to which Government and the public are likely to be willing to pay for resilience, failures cannot be avoided completely. As the climate changes and infrastructure systems are exposed to different and more extreme conditions, it is highly likely that degradation and interruption of vital services will occur at certain times. Therefore, there is a need to limit the consequences of failure and accelerate restoration capabilities, both through engineering solutions and by managing consumer expectations.

All users of these services must be consulted on acceptable service levels and the cost that customers are willing to pay for service at a given level. Communicating to the public the limits on resilience, and the need to modify demand on the infrastructure, is a major challenge for industry professionals and politicians alike. Resilient communities are needed as well as resilient infrastructure, with businesses and individuals involved in the efforts to deal with extreme weather. Greater understanding of demographic changes is also needed, including changes in the urban-rural relationship, the implications of an ageing society and a potential move to more homeworking.

Regulations and design standards are evidently in need of revision to reflect the uncertain climatic conditions that will be experienced in coming decades, setting probabilistic standards rather than absolute requirements for performance. Regulation must also be adapted to allow greater information sharing and collaboration across the supply chain to facilitate management of the infrastructure as a whole.

The engineering profession must respond to these challenges by working in new ways. Using systems thinking to plan, design and maintain infrastructure both at a national and local scale will deliver resilience at least cost. Innovation in developing infrastructure that can serve multiple purposes, such as reservoirs that can also be flood defences, will allow adaptation measures to be delivered in a cost-effective way. Adaptation will require new systems designed for the new climate, and UK businesses can capitalise if they can provide and demonstrate innovative solutions, taking a leading position globally in engineering for adaptation.

The adaptation challenge provides an opportunity for engineers in the UK, and meeting it will be essential for economic growth. It is, however, an opportunity that should be tackled alongside delivering mitigation measures, serving a growing and changing population and contributing to economic growth. The engineering profession must therefore be supported in developing the capacity and skills needed for adaptation.

Findings and recommendations

Planning for adaptation

F1: Methods for prioritisation of vulnerabilities in the infrastructure system are needed for effective planning. There will be a need to distinguish between the short term effects of climate change, such as flash flooding, which in some situations may reluctantly have to be tolerated, and those that are sustained or persistent, such as rivers running low, where it may be more realistic to introduce counter measures economically. Not all parts of the country face similar risk levels or similar impacts. Regional maps of severe weather impacts mapped against critical infrastructure elements would be useful.

F2: There are many interdependencies between the infrastructure sectors and failure in one area can very quickly lead to cascade failure. The interdependencies are in many cases quite straightforward: energy directly affects all other sectors which require power to function; workers in all sectors rely on transport to get to work and can only work if water supplies are maintained. However, the energy infrastructure is critical – all other sectors are reliant on a supply of electricity, especially ICT which is wholly dependent on it. Building a resilient energy infrastructure is therefore a priority, and it is a project that should be worked on across all sectors due to their interests and needs in this regard.

F3: Multipurpose infrastructure will be more cost effective and could be more resilient. When infrastructure developments are planned, additional uses should always be explored, such as reservoirs that can also act as flood defences.

F4: Carbon reduction targets will also have a significant impact on the infrastructure, both in terms of technical requirements and user behaviour, and these should be modelled in tandem with the effects of climate change. For example, the widespread adoption of electric vehicles will impact on the grid.

Regulation and governance

F5: Regulatory changes are needed to develop and implement necessary adaptation plans. In particular, regulations must be developed to deal with probabilistic rather than absolute scenarios. Adaptation to climate change requires a long term perspective and the suitability of quinquennial regulatory reviews focused on driving current efficiency should be reconsidered. The interaction with European and International regulation should also be recognised.

F6: The infrastructure should be dealt with as a system of systems. Mechanisms are required to enable Government to make strategic decisions about the infrastructure as a whole. Regulators will need to work together in planning changes required by climate change adaptation. Resilience in one sector is dependent on resilience in another, so modelling infrastructure systems and scenario planning is essential to ensure that vulnerabilities in one sector do not compromise others. Sharing of data and collaboration across the supply chain will be requisite for such systems-level planning.

F7: Standards should be adapted to allow resumption of a partial service after an emergency, where a full service is still unavailable. For example, when water systems are affected, getting a non-potable water supply online should be prioritised if the resumption of a potable supply is delayed, to provide water which can be used for washing and boiled for consumption, thus allowing some degree of normal functioning for home and business owners. In general, there must be greater preparedness for emergencies and disasters, with attention to resuming limited services as quickly as possible. Engineers need to develop skills in crisis management to deal with failures swiftly and effectively.

Technology and innovation

F8: The expected impacts of climate change in the UK will lead to conditions no more extreme than those currently experienced and dealt with elsewhere in the world. Technologies for adaptation exist in many of these locations, and given that many UK engineering firms, particularly within civil engineering, have worldwide experience, there are good opportunities to learn from both technologies and regulatory frameworks overseas.

F9: While there are few technical barriers to adaptation, the cost of adapting fully whilst maintaining current levels of service is almost certainly unaffordable. Adopting technologies from overseas for weather events experienced only rarely in the UK is not necessarily cost effective. Technologies employed overseas may also deliver service levels below those expected by UK consumers. Therefore, while some innovations can be adopted from overseas, engineers have a crucial role in identifying cost-effective technologies that are appropriate for the UK.

F10: Buildings (and their occupants) need to be considered as part of the infrastructure system. Retrofitting buildings for insulation and microgeneration, recycling water within a building, and the ‘greening’ of buildings, are adaptations that increase resilience and these need to be considered alongside changes to national and local infrastructure. Buildings should also be adapted to make them more resilient to extreme events.

F11: Better network management is essential for resilience. This can be supported by the roll out of a smart grid and smart meters, and the use of ‘intelligent pipework’ in water.

F12: Use of continuous monitoring to allow reactive and timely maintenance across all infrastructure can increase resilience. Sharing of this data for use in modelling infrastructure and scenario planning is of great value and should be facilitated, subject to security constraints.

Information and learning

F13: Research and experiences from each sector need to be shared. A catalogue of the key standards and process of coordination to bring together the existing knowledge would be beneficial in supporting planning and investment more effectively. A lot of research is being done thoroughly but with almost no coordination and information dissemination. There must be coordination of various adaptation investments, research and other activities. This depends in turn on common means for defining resilience and classifying vulnerabilities.

F14: There is a need for greater understanding of, and therefore research into, the behavioural changes which are likely as a result of climate change, within the context of changes in demographics and overall population levels. These will mean changes in the demands on the infrastructure. The net effects of, for example, increased homeworking on the energy, ICT and transport infrastructure, and their overall effects on carbon emissions are of significance, and research in this area should be developed further and shared.

Engineering profession and skills

F15: Engineers need to develop further their ability to embrace probabilistic methods and flexible solutions, and to deal with complex risk scenarios. There has been a lot of work on risk analysis but for the most part it has been simple, e.g. addressing just one risk element whereas future challenges involve a range of factors. Promoting the skills needed in engineering for adaptation is essential, as is using modelling techniques and the methods of scenario planning. The professional engineering bodies should lead on promoting and developing skills in systems thinking within the workforce.

F16: More engineers, with the skills to deal with complex infrastructure systems, will be needed to develop and implement adaptation measures. Adaptation, mitigation measures, and the demands of a growing population and economy all make demands on engineering capacity. There must be efforts both to balance these demands and expand capacity. Developing engineering expertise in adaptation will create marketable engineering skills and solutions for export.

F17: The changing climate may make the UK a more attractive and low risk location for business, especially ICT, compared to other countries which may be more vulnerable, provided that there are stable, long-term policy frameworks in place for both mitigation and adaptation. This presents an opportunity, but also will increase demand on infrastructure and the need for resilient systems to provide continuous service.

Public engagement and communication

F18: There must be expectation management as effects of changing weather on the infrastructure may lead to degradation of service. Improving resilience will come at a cost, and a completely robust infrastructure, if achievable, will cost considerably more.

F19: Openly addressing the issue of achievable and affordable levels of service quality is essential to manage the public's expectations and to provide certainty for investment decisions. Without certainty about the revised service levels, the private sector will be reluctant to invest and those investments that are made may be compromised.

F20: Extreme weather can affect infrastructure and services indirectly through peoples' behaviour and the advice they are given. Workers may not be able to get to critical places of work, e.g. power stations or hospitals, because the roads are not clear, or because schools are closed and they have childcare responsibilities. A better understanding of effects of weather on behaviour, and appropriate advice to give in such situations is needed, with planning to deal with the impacts of such events on critical workers.

2. Introduction

Background

The focus of this report is on adaptation and resilience of infrastructure to climate change, rather than mitigation of climate change effects through energy efficiency or carbon emissions reduction. It is about ensuring that the infrastructure system can cope with climatic changes predicted for the future and how efforts toward climate change mitigation may create new vulnerabilities that must be dealt with, such as those that may result from changes in patterns of supply and demand on the grid due to the uptake of electric vehicles and greater use of renewable energy generation. The concern of this report is to identify ways to ensure that infrastructure is resilient, the extent to which the effects of climate change need to be planned for and dealt with, and both the case for, and the economic limits on, a resilient infrastructure. It looks at bolstering the infrastructure against climate change threats in a cost-effective way, and at the opportunities presented by engineering for resilience. It will cover the engineering aspects of adaptation, as well as those regulatory and social responses, including expectation management, required to ensure that engineering solutions can be effective.

The assessments in this report of the impacts of climate change on infrastructure, and the consequent need for adaptation, were based on the UK Climate Projections (UKCP09). The Projections make the following key findings:

- Average UK summer temperature is likely to rise by 3-4°C by the 2080s. In general, greater warming is expected in the southeast than the northwest of the UK, and there may be more warming in the summer and autumn than winter and spring.
- Average summer rainfall across the UK may decrease by 11% to 27% by the 2080s. While this is the average, there will be a big change in rainfall between the seasons, with winters becoming wetter and summers drier.
- Sea levels are expected to rise. The central estimate (taking into account land movement) highlight sea level is projected to rise by 36cm in London by the 2080s.
- Extreme weather events are likely to become more common. For example, research published by the Met Office Hadley Centre suggests the summer heatwave we experienced in 2003 could become a normal event by the 2040s; by the 2060s, such a summer would be considered cool according to some models.[1]

Methodology

This report is based on the output of five workshops. Four workshops were held on the need and opportunities for adaptation in four infrastructure sectors: energy, transport, water and communications. Participants in these workshops were drawn from engineering industry, academia, regulators and government agencies.

[1] Taken from http://ww2.defra.gov.uk/environment/climate/science/. The emissions scenarios on which these findings are based are available here: http://ukclimateprojections.defra.gov.uk/content/view/2032/500/

Each sector group addressed the following questions:

- What are the long-term problems facing the sector from the impacts of climate change? What is the role of engineering?
- What are the long-term problems arising from interdependencies between the sectors from the impacts of climate change? What is the role of engineering?
- Does interdependency across the energy, telecommunications, transport and water sectors exacerbate or mitigate the problem? How can the risk of cascade failure be reduced? What are the potential 'single points of failure' that might trigger a 'cascade'? What opportunities might these interactions provide?
- How can the engineering sector help solve the problem? What are the opportunities for the sector as well as what is preventing action? What knowledge transfer activities are required?
- Who else needs to act?

The reports from each sector workshop (attached in full as appendices 6.1-6.4) cover the following issues:

- Expected vulnerabilities from climate change
- Critical "pinch points" with climate change vulnerability
- Adaptation measures
- Potential effects of vulnerabilities on other infrastructure and expected impacts of other infrastructure vulnerabilities paying particular attention to where there is the potential for cascade failures to be triggered.

A final workshop was held on interdependencies between sectors, cross-sector issues and the impact of climate change on the whole infrastructure system. The results of this workshop are included in chapter 4 below. A report of the interdependencies workshop is also attached as appendix 6.5.

3. Adaptations within infrastructure sectors

3.1 Energy

Climate Threats

The climate changes outlined in UKCP09 will affect the electricity, gas and oil infrastructure. There are a number of ways in which a changing climate can cause vulnerabilities in the energy infrastructure:

- Flooding could affect power stations particularly those close to rivers and on the coast, as a result of sea level rises, increased heavy rainfall, and greater probability of storm surges. This is a key risk in the energy sector.
- Flooding could also affect the fuel supply infrastructure.
- Drought could threaten the supply of cooling water to power stations.
- Discharge water flowing into rivers suffering reduced flow due to drought can cause ecological problems and has led to power stations being shut down.
- Summer heat or storms could affect the power distribution infrastructure by high temperatures reducing efficiency of transmission or storms causing power lines to touch and short circuit.
- Sea level rises could affect electricity substations in coastal regions.
- Soil shrinkage due to drought could affect oil and gas pipelines.
- Wind and wave power systems may suffer in extreme, stormy conditions, with wind turbines potentially having to shut down under very high winds.

Climate changes will also cause changes in behaviour and thereby changes in demands on the energy system. For example, high demand in summer created by the use of air conditioning has already created problems due to excessive strain on the grid.

Adaptations

There is no expectation of more extreme climatic conditions in the UK than currently experienced elsewhere in the world. Therefore, technologies needed for adaptation may already be in use overseas. However, this does not rule out opportunities for innovation, as the specific conditions in the UK and the design and condition of current infrastructure assets may rule out importing systems directly from overseas.

Smart meters and smart grids will play a part in managing variability of demand and supply, especially if they have the capability to cut off energy-intensive appliances remotely and automatically charge appliances when demand is low. In this way storage systems, in the form of chargeable batteries within appliances, can be relied on to facilitate load balancing to deal with uneven demand; e.g. that created by the take up of electric vehicles. When demand is low, devices can be charged so that they can rely on battery power when demand on the grid is high. Hydro-electric storage facilities will also be valuable for storing energy at periods of low demand and in deploying renewable energy generation effectively.

It remains likely, however, that there will be a need for greater generating capacity at times of peak demand. Developing distributed generating capacity and systems as part of the solution would lead to greater overall system resilience.

There are several obstacles to adaptation. Improving infrastructure brings significant costs. Even where adaptation measures can be implemented alongside routine maintenance, more exacting standards are likely to require more expensive materials, subject to more stringent testing. It may be difficult to match the costs to investors with the benefits of a more resilient infrastructure, which will be felt by the country as a whole. 'Just in case' capacity would not meet the usual investment criteria. Changes to current regulations may therefore be needed to require energy suppliers to provide this extra capacity, though costs are likely to be passed on to customers.

There will also need to be changes to regulation and legislation in order to allow the cooperation and coordination between companies necessary for improved resilience. Planning regulations in particular can also present obstacles, where local regulations may not match national needs.

Detailed risk assessments must be made for infrastructure assets under the likely conditions they will be exposed to. Design standards and building codes must be revised to ensure that they are appropriate for the extreme conditions expected, and design approaches to adaptation will need an understanding of the probabilities of specific climate conditions.

Energy infrastructure, from sourcing to delivery to the customer, must be considered as a whole. Operators must work together as far as legislation allows.

The UK has limited manufacturing capacity and engineers in the workforce to address these new challenges. There would need to be investment in both to increase the resilience of the energy infrastructure. This represents an opportunity for UK engineering and manufacturing. New engineers would need to be recruited and existing engineers trained in the skills required for designing in the light of probabilistic climate projections.

All of these adaptation needs present opportunities for the UK. In particular, developing energy storage systems to power ICT for long periods, and smart systems for allowing appliances to charge in off peak periods, could lead to marketable products. The UK is currently perceived as ahead of Europe in adaptation, but must work to stay in this position.

Interdependencies

Many of the threats to the energy infrastructure are directly a matter of interdependencies. One of the main concerns is floods that will directly affect power stations (due to their proximity to rivers to make use of water for cooling) or will affect the transport infrastructure used to deliver fuel to power stations.

Energy infrastructure is dependent on:

- water infrastructure for providing a cooling mechanism for power generation and oil and gas refining, as well as protecting energy installations from flooding and ensuring staff manning installations are able to work in a healthy, hygienic environment;
- ICT infrastructure for control and management systems, particularly smart grid and smart meter developments, and communications;
- transport infrastructure for the supply chain of fuel for power generation and the distribution of oil and gas products, as well as enabling access for staff.

Conversely, energy is required for:

- water, to run water treatment plants and pumping stations;
- ICT, to run all ICT equipment;
- transport, to drive all transport systems;
- energy infrastructure itself – e.g. to run gas control systems.

The energy infrastructure is therefore crucial to the functioning of all sectors of the infrastructure. Failure in this sector will undoubtedly cause 'cascade failures' and 'spirals' of failure; for example loss of energy will cause failure of ICT equipment which is essential to control and restore the energy network. For this reason, a resilient energy infrastructure is essential.

Shared vulnerabilities

Energy, water, ICT and transport infrastructure are often co-located: for instance, power cables may be laid below roads and beside communications cables, adjacent to water and gas mains and above sewers. Extreme weather events could conceivably affect all of these infrastructure assets simultaneously, though there are advantages in using water pipes as conduits for communications cabling to avoid multiple excavations in the same areas.

Smart Grids

The current electricity system is already in part a smart system, incorporating demand control and frequency control. Mitigation of climate change will have a major impact on the transmission system, so it needs to be smarter, and self-healing (switching automatically to different demand and power flows). Renewable generation and its intermittency require asset optimisation, two-way communications with assets and more control.

'Smart$_{er}$Grids' can help meet the challenges of intermittent generation, increased demand and need for more transmission by better managing the balance between demand and supply. They will be a catalyst for current green technologies (e.g. energy efficiency, demand response) and emerging green technologies (e.g. photovoltaics, energy storage, plug-in hybrid electric vehicles). Smart grids can provide customers with choice through control over how and when they use energy in their homes and businesses.

China is currently developing and rolling out a smart grid. This presents significant opportunities for knowledge share.

3.2 Transport

Threats

The transport system is very vulnerable to the impacts of climate change. The transport infrastructure comprises many different systems, and each is vulnerable to a range of climate threats, as set out below:

- Roads: storm surge; prolonged rainfall; flood; drought; snow; extreme wind; frost; fog; soil shrinkage
- Pedestrian route: snow
- Cycle paths: flood
- Surface rail: storm surge; prolonged rainfall; flood; snow; extreme wind; prolonged high temperatures; humidity affecting trackside equipment
- Underground rail: prolonged rainfall; high temperatures
- Airport: electric storm; flood; drought; snow; extreme wind; fog
- Airways: electric storm; extreme wind - (if wind direction changes then Heathrow runways will have to be redesigned.)
- Terminals: drought
- Coastal infrastructure: sea level rise; storm surge; flood; fog
- Seaports: sea level rise; storm surge; flood; drought; fog
- Inland waterways: storm surge; prolonged rainfall; flood; drought; frost; soil shrinkage
- Embankments: water table rise; storm surge; prolonged rainfall; flood
- Tunnels: flood
- Bridges: storm surge; prolonged rainfall; flood; change in wind direction and scour patterns
- Pipelines: prolonged rainfall; flood
- Control systems: storm surge; prolonged rainfall
- GPS: electric storm
- Oil Distribution: sea level rise; storm surge; flood
- Gas Distribution: sea level rise; storm surge; flood
- Electric car recharge network: electric storm; prolonged rainfall; flood
- CO_2 transport: flood

All sectors are aware of the potential impact of climate change, and generally are advanced in their planning for mitigation and adaptation. However, there is little cross-mode knowledge transfer.

There is little known about the impacts of climate change on aviation and on wind strength and direction, and further research is needed. Changes in wind are significant for sea ports.

Adaptations

As for energy, the climate change events likely to affect the transport infrastructure are already experienced elsewhere in the world. Therefore there is advantage in learning from other countries. The International Union of Railways (UIC) has matched various global locations in terms of current and projected climates, to enable lessons to be learned. The Highways Agency has already adopted French temperature standards for road surfaces.

Systematic risk assessment, by sharing and using accurate asset registers and information systems developed for other purposes, will be essential to assess risk from climate change. Complex risk analysis, rather than analysis of isolated parts of the infrastructure, or analysis of single risks, will be essential.

Amendments to design standards and operating practices will be required: e.g. it will be important to incorporate adaptation into business-as-usual maintenance routines; adapt to changing climate over the lifetime and replacement cycle of assets, e.g. road surfaces and rail tracks.

Adaptation measures should be incorporated into the routine maintenance processes and the lifecycle replacement of assets. Some major infrastructure may require significant investment to meet adaptation requirements, e.g. coastal rail tracks which cannot be moved and may require complex and costly adaptation. New infrastructure will need to be built consistently with adaptation requirements. Infrastructure procurement needs to take future climate and weather conditions into account.

Autonomous reporting of condition and availability of the infrastructure will be important. The use of sensor technology to track the condition of infrastructure assets will support this.

Little is understood of the impact of electric, hybrid and fuel cell vehicles and the infrastructure changes that may be required to enable them, e.g. recharging points and/or hydrogen fuelling stations. There needs to be consideration how these will affect transport and other infrastructure, in tandem with the effects of climate change.

There are also important regulatory, business and social aspects of adaptation. Uncertainty is a barrier to change. Currently the 'risk' of over-investment in unnecessary resilience is seen as greater than the risk of failure. However, some disruption to transport may be unavoidable. A risk/reward profile will be needed to assess an acceptable level of disruption and it may be necessary to accept increases in journey times in order to increase reliability. The franchise cycle of the railways may be inconsistent with the long term planning and investment needed for climate change adaptation.

Communication with passengers/consumers and other transport agencies will be a key adaptation strategy. It is important to understand how passenger and or consumer behaviour might change in relation to climate change. There must be more research on the behavioural response to climate change.

There must be coordination of knowledge across transport modes and common standards and treatment protocols for addressing issues common to different transport areas, e.g. drainage and subsidence. There is a need for a corpus of knowledge on disaster recovery.

There are a number of legal, administrative and institutional barriers to adaptation, for example constraints set by agencies such as English Heritage, Natural England and the Environment Agency, where works are close to sensitive sites. In many cases working on transport infrastructure requires compliance with the practices and standards of the owners of co-located services – eg most water supply companies have specified margins for closeness to main supply pipes which limit the freedom to adapt rail infrastructure.

It would be valuable to have more information about the regional affects of climate change, mapped against the location of critical infrastructure assets. Location of future flood risk is of critical importance.

Interdependencies

Transport is highly dependent on the other sectors – energy (eg electricity supply for trains or electric vehicles and control systems, power to buildings such as airports, electricity supply to fuel pumps, fuel for vehicles), water (eg flood prevention, water needed for operations), and ICT (eg control systems) for its continued operation and may suffer unforeseen consequences from assumptions of linearity and independence. Monitoring equipment is vulnerable during electrical power and telecommunications disruption.

There are many interdependencies within transport: e.g., rail workers may travel to work by road or underground. National rail networks link with local rail and underground networks, and local road networks link with the major roads controlled by the Highways Agency. If local roads fail in extreme weather, railway workers and bus drivers may not be able to get to their places of work.

Workers in all sectors depend on transport to get to work. This can cause significant problems if they are unable to access power stations or water treatment plants, which may require maintenance, particularly in times of extreme weather. Advice on whether and when to travel can have significant impact on travellers' behaviour and the ability of the infrastructure to cope.

Shared vulnerabilities

There are five major areas where rail and road have the same physical infrastructure issues but no organised information sharing appears to be taking place. These issues are: bridge scour, drainage, embankment and cutting stability, subsidence.

3.3 Communications

Threats

ICT infrastructure is sensitive to climate effects in a number of ways. These fall into two classes: fast acting direct issues such as floods which may impact on local exchanges and overhead lines; slow acting direct issues. The infrastructure is also sensitive due to interdependencies. Some of the main issues are:

- high winds can affect telephone poles, causing problems as previously '1 in 150 years' events may become more frequent;
- change in rain density may cause attenuation of mobile phone signals;
- ground heave could affect buried cables;
- changes in wind speed or direction could have implications for the launching and stability of high altitude communications platforms;
- changes in vegetation density or building design (eg silvered windows) could disrupt wireless communication;
- humidity could increase tropospheric scintillation and interference;
- physical resources such as rare earth metals, which are essential components in much ICT equipment, are expected to become increasingly scarce, which may constrain the development and deployment of responses to climate change threats;
- solar storms have a potential impact on satellite communications, though these are not a consequence of climate change.

The ICT infrastructure can both facilitate and be affected by different behaviour patterns, which may be prompted or exacerbated by climate changes. It is important to track the impact of social change on networks to understand how the distribution of demand is shifting – e.g., increasing numbers of homeworkers may affect where and when networks experience the heaviest burdens. Cyber attack is an increasing threat and could capitalise on vulnerabilities created by climate change.

Adaptations

It is open to question whether the ICT system is sustainable in the light of a requirement of 60 60 24 7 cover – though it must be noted that businesses and increasingly individuals are becoming more reliant on continual ICT coverage. The resilience of the system is predominantly driven by the commercial imperative to maintain service. The cost of a completely robust network would be impossible to justify commercially, but it is necessary to encourage investment by suppliers in network infrastructure artefacts focussed on improving resilience.

Again, climate conditions anticipated are already experienced and managed elsewhere in the world. In fact, the changing climate in the UK may make it a more attractive (and lower risk) location for ICT operations and business currently operating in other, increasingly vulnerable, locations. In addition, the ‘refresh’ rate of end-user devices and network elements is more rapid than the rate of climate change, making this sector quite different to others, such as water.

In ICT resilience is created by diversity, with multiple, diverse systems providing back up should one system fail. Efficiency concerns can, however, reduce the degree of diversity in the system. Diversity declines closer to the end user; it is difficult to assess the diversity of an entire system.

Regulators of different aspects of the infrastructure might work together on questions of resilience. Because of internal interdependencies within the network, similar standards of resilience are required across the network.

In emergencies, there is frequently excess demand on communications, particularly the mobile networks. There has already been efforts to deal with this issue, with priority given to text to allow communications in periods of very heavy demand (such as experienced after the July 7th bombings in London).

ICT operators would benefit from an early warning system to highlight the potential of catastrophic weather events. Conversely, ICT networks provide a great opportunity for the provision of information in relation to climate change, including prediction of weather events.

Interdependencies

ICT is absolutely reliant on the continuing availability of electricity. Currently mobile and fixed network distribution and exchange points have only one hour battery back up. This makes ICT vulnerable in ‘cascade’ events, e.g. flooding could affect power supply thus making mobile networks vulnerable, and this could have an effect on broadcasting. Severe weather may make it difficult for engineers to reach fault locations.

Over the next 100 years the ICT infrastructure is likely to become more complex and more comprehensively networked, making it more difficult to diagnose and repair faults. It will also become more interdependent with the energy infrastructure; the development of smart meters and smart grids will mean that the power networks will rely on ICT to function adequately.

ICT, particularly the trend towards ‘cloud computing’, enables more home work, meaning less strain on the transport network, but with increased data traffic volumes. Net effects on carbon emissions are unknown; effects on population distribution and water and power use in the home are also unknown but could be significant.

Common vulnerabilities

ICT infrastructure could share groundworks with other infrastructure, e.g. running cables through water pipes, though this would render them vulnerable to the same threats (e.g. ground heave). Bridges carry communications infrastructure, which is vulnerable to damage when bridges are damaged, as learned in recent floods in Cumbria.

3.4 Water

Threats

The water infrastructure is directly affected by climate change. Changes in rainfall patterns will lead to reduced supplies from reservoirs and river flows, whilst increases in temperature will lead to increased demand from consumers.

Changes in precipitation will change the quality of raw water and increases in rainfall intensity will lead to increased water pollution incidents. Increases in the intensity of severe rain events will led to an increase in the frequency and severity of flooding.

Increases in periods of heavy rainfall will put drainage systems under stress leading to more frequent and more severe flooding, with more frequent flash floods. River overflow will also cause flooding as in Cockermouth in 2009. Floods will damage both water supply and waste systems.

Increased sea levels will lead to failure of or damage to flood defences in coastal and estuary areas. It will also cause saline intrusion into coastal aquifers and sewers. Planning and implementation of managed retreat for some communities and agriculture will be required.

Dry periods in combination with floods could change erosion and deposition patterns on river and canal banks, impacting on navigable waterways; changes in coastal erosion patterns could affect maritime navigation. Inland waterways are also directly affected by changes in water level due to drought and flood.

Hotter, drier summers will lead to changes in demand, including increased need for irrigation.

Higher mean water temperatures affect biological treatment processes and drinking water quality in distribution networks. Increased evaporation will lead to reductions in available yields in reservoirs, lakes and rivers.

These climate threats must be considered alongside population growth and demographic changes which also put pressure on the water infrastructure.

Adaptations

Climate threats are technologically manageable, as they will create conditions already experienced in other countries. Lessons to be learned from overseas include Singapore's use of recycled water and the Netherlands, experience of building on land at risk of floods.

Engineers need to focus on new inter-disciplinary methods as much as on new technologies, looking at social science and economics rather than using past engineering solutions, and embracing probabilistic methods and flexible solutions.

Lack of data is a hindrance to analysis of risks. Scenario-based approaches, developing projects on the basis of uncertainty and collecting data as a project progresses can make projects more flexible to cope with unfolding challenges.

There is a need for attitude changes in engineering and amongst other stakeholders. This will involve educating the public and developing appropriate policies and regulation regarding the level of service that will be possible at a particular cost, and necessary behaviour change in the light of climate change effects. There is a need to decide who pays, and how much they will pay, to protect communities from flooding.

The water infrastructure can gain resilience by a move from centralised water systems to distributed water treatment and storage. Water could be treated at point of use (within a property) to make it fit for a particular purpose, rather than treating all water to bring it to a potable standard. Distributed water systems are more likely to allow for meeting different needs at different times. Distributed water storage could be used for hydro power generation, to manage river flows, for irrigation or other purposes. There will be a need for increased local water storage due to shorter, higher intensity precipitation.

Water recycling may be able to serve 20-30% of usage, with reduced reliance on infrastructure. However there are energy implications from recycling water.

Different uses of existing water infrastructure should be explored, such as using reservoirs as flood defence.

Some development of new water supplies from new reservoirs or desalination plants may be necessary. Reservoir design could combine flood alleviation and river regulation functions where practical.

Demand can be decreased through low-flow appliances; more effective use of water in agricultural and industrial processes; smart meters and intelligent pipework to restrict access and reduce leakage; and metering and pricing strategies.

Incentives could be introduced to reduce water use. Planning regulations should be redesigned to deter building on flood planes and/or require buildings to be more resilient to flooding. Generally, regulation changes are needed to reflect the current situation of uncertainty regarding the climate and to allow for more flexibility in regulation. The costs of maintaining flood defences need to be debated, with the difficult questions of where to invest in flood defences, and managed retreat from at risk areas, addressed.

An increased degree of foul and surface water separation is needed for waste water systems. Solid waste could be separated and used as an energy source.

Key utilities and transport systems must be protected from flooding. Water and sewage treatment works require enhanced protection from flooding.

The cost of adaptation and rigid regulatory systems could be a barrier to adaptation. Engagement with the public is needed to develop new regimes that will allow adaptation at an acceptable cost. There are a number of ways in which regulation can be an impediment to adaptation, and the regulatory regime must be made more flexible and responsive to fit the demands of a changing climate. There must be better joining up of local and national planning regulations.

Interdependencies

Water is dependent on all aspects of infrastructure:

- Energy: water infrastructure is dependent on electricity to power its facilities, particularly pumping and water treatment, and its IT systems;
- ICT: water infrastructure is dependent on ICT to run its centralised IT systems and for communication;
- Transport: there is a dependency on road and rail transport for personnel and supplies to run its facilities, and for transport of waste;
- Water: an internal dependency on the water infrastructure, in that much of the infrastructure is susceptible to flooding, particularly for treatment works and waste water removal.

Water has significant impacts on other infrastructure:

- energy is dependent on water for cooling power generating and oil and gas processing plant; energy transmission infrastructure and plant is highly susceptible to flood damage;
- ICT cables are susceptible to flood damage;
- transport systems are also susceptible to flood damage.

In addition, any system or process dependent on human intervention is reliant on water for hygiene and drinking: without accessible water workers cannot remain on a site. Similarly, food production and processing is highly dependent on water.

Dual water and waste and water recycling

In the domestic context only 3% of water needs to be potable, with typically 30% of water supplied to customers used for flushing toilets. There is already some duality – with separate industrial and domestic supplies.

Local reuse of water has a real future as a means for reducing demand – roof and washing machine water could be used to flush toilets, for example. Recycling of water is most successful at the household and small area level, though even at the local scale some treatment of waste and grey water is needed.

It is valuable to consider the individual home or building as part of the infrastructure and to consider options for within-building water treatment. Indeed, technologies may make it feasible to pipe only non-potable water with purification to the required level within buildings. This would foster the use of alternative water supplies.

There is an argument for dual waste treatment. If foul and waste water can be separated and treated separately there are significant benefits. Solid human and food waste can be separated from the waste stream and solid waste treated by anaerobic digestion, and the treated waste used in composting or in biomass generators to produce energy.

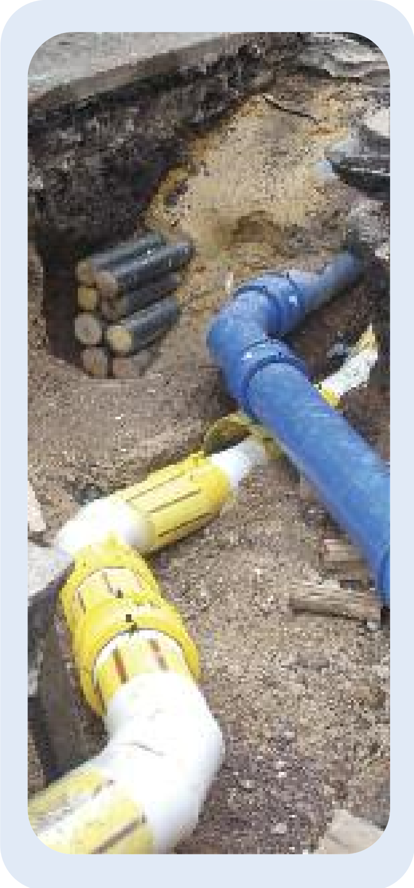
4. Interdependencies – a systems approach to infrastructure

This chapter examines all areas where individual sector reports have noted a reliance or effect on other sectors. It presents strategies for dealing with interdependencies arising as a result of climate change, be they technical, methodological, regulatory or social.

Identifying interdependencies and current solutions

The matrix below summarises the interdependencies identified within each sector. More detailed matrices are included in the sector reports attached as appendices 6.1-6.4

Sector	Dependencies on infrastructure	Dependencies on natural environment and population	Dependencies on overseas systems	Impacts on other sector
Energy	Water for cooling in power stations and fuel refining; ICT for control and management system of electricity and gas; Transport for the fuel supply chain and workforce	Substations and local distribution networks are vulnerable to flood; Coastal power stations vulnerable to flood, and most power stations are dependent on natural water supplies for cooling; Cables may be affected by extreme winds; Wind turbines may be affected by extreme weather	Dependent on interconnectors with France, the Netherlands and Ireland	ICT wholly dependent on energy; Transport dependent on fuel and increasingly electricity; Water dependent on energy for pumping and control systems
Transport	Energy infrastructure for fuel and increasingly electricity; ICT for management of services and networks; Drainage infrastructure to prevent flooding; Internally dependencies within and across modes (eg national rail dependent on connections with local rail)	Road and rail vulnerable to flood; Transport system sensitive to demographic changes and behaviour – eg, increased urban living and increased home working	Dependent on European air traffic and maritime control	All sectors depend on transport to carry workforce to sites; Food distribution depends on transport
Communications	Energy for all services; Transport for maintenance workers	ICT affected by demographic changes and user behaviour, such as increased home working	ICT is a global system, with many dependencies on systems overseas	All sectors increasingly dependent on ICT for control systems, especially the smart grid; Increasing dependence on ICT for sensing and reporting the condition of the infrastructure
Water	Energy for pumping and processing; ICT for control systems; Transport for workforce and supplies of chemicals for processing	Water infrastructure dependent on natural water and drainage systems for supply and flood defence; Water supply sensitive to changes in demographics and population numbers		All sectors vulnerable to effects of flood, either directly or via cascade; All workplaces require water for staff



A modern, efficient, networked infrastructure necessarily creates interdependencies between infrastructure sectors. Well managed energy, water and transport networks depend on ICT for control and monitoring of their condition, which entails dependency on energy. The ICT and energy infrastructure are becoming increasingly interdependent, since the smart grid needs ICT for control, and will soon not function without it. Commerce is also entirely dependent on ICT for financial transactions. The food supply will be impacted by climate change largely because of dependence on water in agriculture and food production.

There are interdependencies within sectors, for example the London Underground system is dependent on links with mainline rail and roads; power stations require a power supply to function. Local and national infrastructure also interconnect, especially in the transport sector.

Interdependency is therefore inevitable, but it creates vulnerability in that failure in one area can quickly cause a cascade of failure. It is therefore essential that all sectors of the infrastructure are invested in to ensure that they are resilient to an equivalent degree.

Dependence on systems outside the UK

Interdependencies also exist between UK infrastructure and systems overseas. ICT is a worldwide system, there is no UK ICT system as such. This increases its resilience since failure in one region can be compensated for.

The grid has an interconnector with France and there will shortly be one with the Netherlands and with Ireland. This is important for resilience, but potentially means a new vulnerability if the UK is reliant on these interconnectors. The UK is becoming more dependent on other countries for gas. All hydrocarbons depend on port and shipping infrastructure. All ports are dependent on electrical supply and some are very sensitive to the prevailing wind or sea level changes.

In transport, air traffic control is dependent on systems overseas and there is a move toward European air traffic control and maritime control.

Infrastructure is dependent on overseas supply chains. Rail rolling stock is manufactured from parts made overseas, and timescales in which overseas manufacturers can provide parts needed in an emergency are an issue. Climate change effects overseas can interrupt supply chains. Lithium will become a more important resource as electric vehicles become more prevalent, and its availability may be affected by climate change.

The infrastructure system

Each sector depends on other sectors for increased resilience, and while interdependencies can help to build resilience, these dependencies give rise to vulnerabilities. As the grid gains resilience by becoming smart, so it is more dependent on ICT. The infrastructure is therefore a complex system, with interdependencies occurring at different levels and emerging through the interactions between systems.

Systems resilience rather than sector resilience is required. If one sector is resilient to a certain degree whilst being dependent on a sector that is less resilient, then the systems put in place for resilience are wasted. A common, or commensurable, understanding of resilience and means of assessing vulnerability is needed for this to be possible. Resilience also requires a coordinated method for planning as it is a matter of planning for resilience across the whole system.

There is currently a lack of coordination of the various adaptation investments, research and other activities both within and across sectors. There should be a means of sharing information across sectors, and for sharing best practice. Data about the state of infrastructure assets needs to be shared within and across sectors for effective planning. However, there is a need for care about making information available, especially making it public, because of potential for terrorist threat. Local and regional resilience forums are needed, with data shared securely and in a limited way.

Current climate change projections have a resolution of 25km. More detailed resolution is needed to carry out detailed risk assessments of infrastructure systems, as vulnerabilities are often very localised.

The benefits of decentralised infrastructure should be assessed for all sectors, though there remains a need to keep in mind large scale issues and the value of joined up infrastructure. It is important to distinguish between infrastructure that can be delivered at a local level (e.g. water recycling) from that which must be planned and delivered as a large scale network (electricity, to some extent). Where benefits are available through decentralisation, these should be pursued. Water, in particular, may benefit from decentralised processing, as discussed in the box on page 23.

Collecting data and modelling infrastructure

There is a need to understand the performance and condition of infrastructure assets. It is only once performance and remaining lifetime of assets is understood that resilience can be assessed. The University of Cambridge is currently undertaking a large EPSRC/TSB funded project on smart infrastructure, looking in part at using sensors and data management to develop a detailed picture of the state of the infrastructure.

There is also need for research into the impacts of interdependency. The University of Newcastle received an EPSRC grant on long term dynamics of infrastructure systems. The aim is to develop a new generation of tools for analysing interdependent infrastructure systems, taking into account risks of failure, coevolution of infrastructure, land use and the economy. These will be used to develop strategies for infrastructure transition.

Categorisation and prioritisation of interdependencies

There are many vulnerabilities within the infrastructure system, and it is impossible to cover the cost of all adaptation measures needed for complete resilience. Therefore, it is necessary to prioritise the various 'pinch points' where resilience is needed. A precondition for this is a common method for categorising and prioritising vulnerability. However, resilience is understood in different ways in different sectors, which is a barrier to categorisation and prioritisation.

It is of benefit to consider resilience in terms of the ability of the infrastructure to function in a given set of scenarios. Whilst this method is already used within sectors, it is essential to use it to assess the resilience of infrastructure systems, where several infrastructure sectors are affected. Scenario planning for complex systems is essential for assessing resilience and therefore prioritising adaptation measures. Modelling of infrastructure systems, where possible, will also aid in assessing and prioritising vulnerabilities. Both of these methods require sharing of data about infrastructure assets.

Interdependencies can be immediate and acute (e.g. loss of ICT control for grid), leading to spirals of failure and cascade failure. For example, loss of energy can cause an outage of ICT based remote site control systems; this in turn will inhibit recovery of the energy supply, whilst also disabling control of water and gas supplies and the operation of transport systems. Thus one category of interdependencies is **emergencies** and rapidly cascading failures, caused by a number of sudden climate events such as floods and heat waves.

In planning adaptation measures it is essential to prioritise those 'pinch points' where cascade failures are likely to be initiated. Resilience, and the ability to recover from failures, should be built into the system at these points. On this basis, energy is a particular priority area for adaptation efforts, as failure in the energy infrastructure will inevitably cause failure elsewhere.

Another category of interdependencies is **trends** which require planning, management and adaptation. These include diminishing water resources and rising average temperatures. A further category is interdependencies due to mitigation-adaptation feedback. This would include new demands on the grid due to take up of low-carbon technologies such as electric vehicles or heat pumps.

Within these categories, the number of people likely to be affected by an infrastructure failure is an important criterion for prioritisation, and the length of time and costs needed to build a resilient solution will be a factor in setting priorities. The ability to respond to an emergency should also be taken into account. Social and economic objectives must be balanced when assessing which aspects of infrastructure must be protected. There should be public engagement on the issue of setting priorities, with dialogue on how to prioritise and the outcome of any prioritisation exercises.

Smart Buildings

The individual building is part of the infrastructure, and smart buildings are an important development in the building of a resilient infrastructure.

Smart buildings are responsive to occupants, regulating energy use on the basis of their behaviour. But buildings also interface with the city they are part of and have a significant impact on the microclimate of a city. They are an important part of the response to climate change impacts such as floods, and interact with transport, affecting and affected by noise and pollution.

Many existing buildings in the UK must be retrofitted as part of the mitigation effort. There is an opportunity in carrying out these works to make buildings smarter in relation to both the people in them and the city itself. Quite simple responses can have an impact, for example, changing facades by growing ivy for insulation can in turn reduce the city temperature at night and therefore energy consumption. Electric Vehicles may dominate by 2050, allowing more natural ventilation. Trees and natural vegetation, including food produce, on the roofs of buildings cool the city down because plants absorb sunlight, and can absorb rainwater to some extent.

Fuel cells can deliver 'no moving parts' CHP, ready for the houses of 2014. If we address heat loss and power consumption and use ground source heat pumps we can seriously reduce energy use.

There is a challenge in communicating the benefits of retrofitting, though there are significant opportunities. Incentives may be needed and must be communicated.

The Institute for Sustainability will carry out a community retrofit project including houses and infrastructure, at a scale of about 20,000 homes, to explore these interdependencies. This will demonstrate what an 80% reduction would be like using high tech systems relatively cheaply because of the scale of the project, and should demonstrate the savings that can be made in water and energy.

Dual use infrastructure

To engineer a resilient infrastructure in a cost effective way it will be essential to develop systems that perform diverse functions, with adaptation measures delivered alongside primary functions of infrastructure. Maximising opportunities for using underground space by running communications cables alongside water pipes is commonplace. Railway embankments currently also function as flood defences. More opportunities for dual purpose infrastructure should be actively sought, and infrastructure designed and built with these dual purposes at the fore.

However, dual use infrastructure systems only improve resilience if they add capacity and redundancy. If they are simply used to replace single use systems they can increase interdependencies and vulnerability. Multiple use of underground space also brings risks, since damage to water pipes will also damage communications cables. Therefore, dual use systems have to be planned, designed and implemented with care.

The Thames barrier is used to protect London from surges of sea water, but can also be raised to create a basin for water run-off in land floods. A new barrier could be used as a bridge, and a power station using hydropower. Reservoirs can serve as both flood defence and water supply. Roads can be used as flood pathways if properly designed.

If solid waste and wastewater can be treated separately it is easier to deal with the water. Food and human solid waste can then be treated by anaerobic digestion, and could then potentially be used for energy generation or for compost. Thus waste infrastructure can also become part of the energy infrastructure.

Buildings can realistically be used as power stations, given that photovoltaics are becoming cheaper and more efficient. Water can be used for energy storage, within localised, distributed infrastructure for water storage.

Human built infrastructure interfaces with the natural environment, and the dependencies between natural and artificial systems must be properly managed. For example, the consequences of building over natural land are reduced drainage and vulnerability to flood. Rivers allow natural drainage and these natural systems should be considered alongside built infrastructure.

Dual use infrastructure: the SMART tunnel

The Stormwater Management and Road Tunnel (SMART) is a unique solution to Kuala Lumpur's (KL) long-term traffic and stormwater management process. Conceived as a flood relief tunnel to divert the 1 in 100yr flood away from the KL city centre it was considered that the 11.8m id tunnel could be utilised in periods of low rain fall as a highway tunnel to alleviate the congested highway infrastructure.

Mott MacDonald was responsible for the feasibility study and for the detailed design of civil, mechanical, electrical, control and communication, hydraulic and highway aspects of the bored tunnel. Design also included junction boxes, gate houses and shafts structure, ventilation shafts and M&E services. SSP were responsible for the approach structures.

The overall scheme consists of 9.7km of bored tunnel with the central 3km having a twin deck road within. Complex water control gate structures are located at either end of the highway tunnel section to protect motorists. The 11.8m internal diameter tunnel required the specification of a tunnel boring machine which was one of the world's largest in diameter. A procurement strategy was developed and contract documents produced in order to allow the contractor to purchase two 13.2m external diameter machines. Two ventilation shafts are sited in the heart of Kuala Lumpur. These facilities are located in the Limestone rock, with the largest excavation being 180m in length, 20m wide and 28m deep. These shafts also serve as the launch sites for the Tunnel Boring Machines.

The exceptional nature of this innovative project required particular solutions in order to design out the complex conflicts between operation as a water tunnel and as a modern highway. The project was opened to traffic in May 2007, and the flood relief function has already been utilised on a number of occasions.

Text courtesy of Mott MacDonald

Mitigation and adaptation interactions

Efforts to reduce carbon emissions may create new interdependencies and vulnerabilities in the infrastructure system. Decarbonising transport means more electricity will be used, requiring a smart grid to deal with different loads. However, behaviour management, such as encouraging people to charge vehicles at night, can be used to flatten the daily load profile and lower the cost per unit of electricity. The smart grid should allow high energy consumption systems like electric vehicles and heat pumps to be shut down remotely when necessary.

Broadband will increase energy consumption. The increases in bit rates outstrip the reduction of energy per bit. It is likely that reduction in travel to work will increase reliance on and demand for broadband.

Regulation, design codes and standards

Standards in many sectors were designed to withstand really extreme conditions and in some cases may set sufficient standards to deal with climate change effects. However, in telecommunications for example, standards were never not initially developed with energy efficiency in mind. In Ofcom, regulatory impact analysis looks at the energy consumption of the technologies that are being regulated.

Smart grids need new standards. They also need smart meters with a user interface to allow high consumption items to be remotely controlled and chargeable appliances to be charged and switched to battery depending on demand on the grid. Implementation is currently being planned, and this functionality should be required.

Standards have to be developed to reflect the likely standards of service that are achievable. Realistic standards are needed to prevent frustrated investments. Absolute standards are a risk, potentially setting standards too high. It may be better to allow failure in systems, which can then be restored, rather than demand investment in a completely resilient system.

Standards required in the aftermath of an emergency should also be reconsidered. For example, it may be preferable to prioritise the delivery of a non-potable supply of water when the water supply is lost, rather than requiring that a potable supply be reinstated which may take much longer to achieve. Standards should allow partial services to be delivered when circumstances demand it.

Design codes and standards will be important in influencing behaviour. Standards can be put in place to limit the amount of water a building uses and require developers to incorporate microgeneration into buildings. Low energy light bulbs and HE boilers are an example where regulation has been successfully introduced to require lower energy systems to be used.

Incentives for adaptation can also be used in conjunction with regulation. In New York low flush toilets were introduced on a mass scale because suppliers paid for them to be installed. In Florida in the 1980s cheaper electricity was offered in return for allowing the power companies to shut down air conditioning remotely.

In Singapore education and financial incentives have been used to change behaviour. A visitor centre explaining water recycling open to school children was found to have a noticeable positive impact on reducing water use.

Providing some proportion of the cost of retrofitting buildings and publishing the energy use of buildings also has an impact. Government in the UK has started publishing energy ratings of buildings, which has had an impact on the behaviour of occupants (e.g. more lights turned off).

Regulation can stand in the way of information and data sharing. Sharing information about the condition of infrastructure assets and plans for adaptation both within and across sectors is necessary to plan adaptation effectively. Rethinking of regulation is needed where business regulation prevents such openness.

Users and investors

The DfT guidelines on cost–benefit measurement and the Treasury Green Book (Appraisal and Evaluation in Central Government) need to be developed to recognise climate change issues, especially the long time frame involved. Regulators are under pressure to deliver returns in a 5 year horizon. They need to be more focussed on the longer term. Stability encourages investors with need for a strategy for up to 40 years.

ETR 138, the programme of flood defences, costs £20M to protect substations against 1/100 yr flooding events. That cost will be passed on to the customer. Generally, the cost of adaptation has to be passed on to customers, therefore there may be some trade off between costs, and levels of service.

Since failure cannot be avoided without unreasonable cost, there must be an emphasis on reacting to failure to limit its consequences. This will involve preparing consumers for failures. Government and utility providers can help people to take individual action, to put their own flood defences up when severe weather is predicted. Where possible, warnings for customers, including the general public, businesses and local councils, are very important.

Expectations of systems is continually rising, with businesses, services and individuals depending on 24/7 service. This creates vulnerability, as there are often no contingency plans at local or individual business levels. Users of services must be consulted on the process of changing their demands and reliance on infrastructure, and their ability to respond in an emergency. Ways need to be found to convey the message that in extreme conditions– for example the consequences of the floods of 2007 – some disruption to services may be unavoidable. A risk/reward profile could be used to assess an “acceptable” level of disruption and degradation (for example slower journeys, reduced energy supply, slower broadband, reduced water pressure or intermittent supply) in order to increase overall reliability.

Adaptation requires financial engineering, finding means to charge the right people in the right way. Costs and benefits have to be presented together, to identify what people are prepared to pay for.

5. Next steps

Planning for adaptation

Government should follow up its National Infrastructure Plan with a detailed plan for adaptation measures across the whole infrastructure system. It is a matter of urgency to develop this plan, so that the adaptations to the system can then be delivered over time in a measured and economic way. A thorough plan will enable the development of policy and regulation that is essential for investment in the infrastructure. Infrastructure UK within the Treasury is currently carrying out work on maintaining the resilience of an interdependent infrastructure, and that work will be of considerable importance.

Regulation and governance

Regulatory changes are needed to allow the sharing of information across sectors, thus supporting a collaborative approach to infrastructure protection. Regulatory schemes should also be developed to reflect the reality of climate change and the effect it will have on the performance of the infrastructure. Standards should be revised to allow services to be delivered at a lower performance levels where essential, i.e. in response to an emergency, and to reflect the unpredictability of extreme weather. Setting absolute standards where only probabilistic predictions of the effects of climate change are available will not allow a cost-effective and achievable level of service. Regulation also needs to allow for longer term planning and to accommodate the potential failures that might arise from innovation.

A joined-up approach to governance is essential to manage the infrastructure system. Silos and sectors will have to be traversed to deliver system resilience. A centralised method of planning in Government will be key.

Technology and innovation

Whilst the UK can learn lessons from other countries where climate conditions expected for the UK are currently experienced, opportunities for innovation should still be grasped. Systems used overseas may not deliver the level of service that is relied on in the UK, and the frequency of extreme weather relative to other countries may not justify utilising the same systems. Therefore, there is an opportunity for innovation to develop effective, affordable and socially acceptable systems fit for climate change in the UK.

A greater degree of systems thinking, a focus on dual use infrastructure, and intelligent use of natural resources are all necessary to deliver adaptation measures. Climate change may threaten infrastructure but it presents an opportunity for innovative development of technology, which creates an opportunity for business and industry and can be a driver of economic growth.

Engineering profession and skills

The demands placed on the engineering profession by the need for infrastucture adaptation will be accompanied by further demands to deliver mitigation measures, to support economic growth and to serve a growing and changing population. This will put pressure on the capacity of the engineering profession to deliver on all of these demands, and there should be both efforts to extend capacity and skills in the profession and to prioritise between these different demands. There must be collaboration between Government and the professional engineering bodies to address these needs.

Again, there is an opportunity for the engineering profession here, with the potential to develop marketable and exportable skills. The professional engineering institutions and The Royal Academy of Engineering will have a significant role to play in promoting the opportunities for the engineering profession.

Public engagement and communication

Since they are likely to bear the burden of payment, the wider public must be consulted at all stages about the costs of delivering resilience, and the acceptability of resulting levels of service. Whilst engineers can deliver resilience, the effects of climate change will impact on the performance of infrastructure. Service users should be consulted on the acceptable balance between the costs of adaptation and the impacts of infrastructure degradation and failure. If we are to move to more localised infrastructure systems, then local communities will need to be more engaged in their development and operation.

Individuals have a significant part to play in protecting services, through curbing and managing their demands on them. Communicating the need to conserve water and to use less energy, and understanding better the impacts of climate change on behaviour, will be an essential aspect of the adaptation project.

6. Appendices

6.1 Energy sector report

ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY

Report of the Energy Sector Workshop July 2010

Summary

This report outlines the discussion and findings from a workshop on the adaptation of the UK's energy infrastructure to the projected changes in climate (set out in UKCP09). The workshop was one of a series on infrastructure sectors arranged by *Engineering the Future*, an alliance of engineering institutions, the Royal Academy of Engineering, Engineering UK, the Engineering Council and the Institute of Physics. The workshop was led by the Institution of Mechanical Engineers and the Institution of Chemical Engineers.

The key findings of the workshop were:

- The changes to climate outlined in UK climate projections (UKCP09) will have multiple effects on energy infrastructure.
- Electricity, oil and gas infrastructure will be affected.
- None of the potential climate impacts are new or unique problems for engineering.
- The flooding of electricity generating and transmitting infrastructure is a key risk.
- Renewable electricity generation might be affected by extreme conditions.
- There is a need for detailed risk assessment for each piece of infrastructure.
- A holistic risk assessment of each energy supply chain, from generation/importation to consumer is required.
- The management of electricity demand cycles will be more critical, relying on storage mechanisms and so called 'smart grids' to increase resilience.
- A strong case for investment in resilience measures and/or an increase in regulative requirements will be needed to create the required "just in case" facilities.
- Regulations and legislation will need to be changed to allow the co-ordination and co-operation between companies necessary to improve system resilience.
- Public opinion is critical to the acceptance of differing service standards and the provision of new adaptation related infrastructure.
- More engineers will be required and new skills will need to be disseminated throughout the energy industry.

- The potential opportunities arising from adapting the UK's energy infrastructure to climate change are similar to those related to climate change mitigation, although they might be harder to realise.
- Lessons could be learnt from the insurance industry, where they use methods for pricing risk for catastrophe insurance. Similar methods would help the energy industry to place a value on 'just in case' infrastructure investments.

Introduction

This document reports the discussion and findings of the Energy Infrastructure Adaptation to Climate Change Workshop held at the Institution of Mechanical Engineers on 8th July 2010. The event was chaired by Terence Tovey.

The workshop process was organised around the five key questions raised in the briefing document, commencing with a brainstorming session around the primary concerns and issues before considering options and choices.

Modern society in the UK depends on energy supplies 24 hours a day, 365 days a year, and expects to receive power whenever it is required, for whatever purpose.

The energy infrastructure covers the extraction and transmission of fossil fuels (coal, gas and oil), the generation and transmission of electricity from fossil fuels (gas and coal), nuclear power and renewable sources (including wind, wave, tidal and waste), and heating and cooling (both domestic and industrial).

The energy industry consists of both regulated, notably the supply of electricity and gas, and unregulated businesses. The impacts these face as a result of climate change and their responses to them may differ significantly.

The key questions that underpin these discussions were:

1. What are the issues/technical and operational impacts from climate change (focusing on the medium-term [to 2030] and long-term [to 2100] impacts) on the sector?
2. What are the potential adaptation options to address these issues/impacts? This should include consideration of engineering/design standards – do they need to change and if so why and how? For example should we allow regulators to operate beyond pure economic regulation; or incentivise cooperation between regulators? Or encourage investments outside the core business that are vital to improve resilience. Allow more resilient premium services?
3. What are the potential barriers to implementing these options (including consideration of the wider context within which engineering operates)?
4. What are the opportunities (e.g. skills, economic, innovation) from adapting our infrastructure, in particular to the engineering profession and engineering organisations? Whether opportunities could be brought out more, i.e. the potential for the ICT sector to provide technology to help the country/industry adapt.
5. What interdependencies does the sector have with the other three sectors and will climate change impacts exacerbate these (not to be examined in-depth but a list of issues will be useful to the interdependency group)? What about potential cascades of failure across the national infrastructure?

Impacts and operational challenges arising from climate change

The changes to climate outlined in UK climate projections (UKCP09) have multiple effects on energy infrastructure.

The URS report "Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change" (2010) identified the following high level risks to energy infrastructure.

Infrastructure components	Key risks
Fuel processing facilities/ storage of fuel/transport of fuel	Flooding of fuel supply infrastructure due to increased storminess and sea level rise/sea surges.
Power generation (fossil, nuclear and renewables)	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.

(source: URS, 2010. Page 3)

The 2007 floods in the Severn Valley saw the Walham sub-station at extreme risk of flooding[1], which would have damaged the electricity supplies to Gloucester and South Wales. With such sub-stations located in or near centres of population, and hence often on or near flood plains, the risk of flash flooding will increase with increased sudden rain storms and longer or more widespread rain events which may result in rivers bursting their banks. In coastal locations, increased high tides and storm surges may represent a significant risk to energy infrastructure.

Many electricity generating stations rely on river water for cooling. This means they too are often sited on or close to rivers, and may thus suffer from an increased risk of flooding. Conversely, greater fluctuations of rainfall may also lead to increased periods of drought during the summer months, when the continuity of a supply of water for cooling may not be guaranteed.

Increased air temperature may also reduce the efficiency of electricity generating and transmission infrastructure. Power stations become less efficient as the ambient temperature rises and cooling becomes less effective.

Current flowing through aerial transmission cables generates heat. The standard rating for transmission cables in the UK is 80°C. With higher air temperatures, less current will be transmitted before the cable reaches 80°C.

It is not clear whether transmission cables or pylons will suffer from wind damage per se. However, if parallel cables are swinging as a result of high wind, it is possible that they may touch resulting in a short circuit requiring repair. There is also a risk that, if climate change results in increased wind, cables may be increasingly damaged by, for instance, falling trees.

Rising sea levels may affect coastal installations such as conventional and nuclear power stations and oil and gas refining and storage facilities. These are frequently located in coastal areas for the ease of transport of fuel and the availability of water for cooling.

Oil and gas pipelines may be subject to damage by soil shrinkage as a result of drought.

More extreme conditions may affect renewable electricity generation. Under high winds, turbines utilising wind power need to decouple from their generators to prevent damaging them. Wave and tidal power generation may also be subject to restrictions due to extreme conditions.

The climate scenarios suggest that as well as factors influencing infrastructure, the effect of changing climate will change the patterns of demand for energy, with reduced winter usage resulting from higher average winter temperatures, increased summer energy usage as higher average temperatures leads to increased use of air-conditioning, and increased variability of demand.

Adaptation options to meet issues and challenges

It was observed that none of the potential weather impacts facing Britain in the foreseeable future are new or unique: they have all been experienced elsewhere in the world, and hence there are existing technologies which can be utilised to adapt to the changed conditions. There are no technological barriers to adaptation anticipated.

Primarily there is a need for detailed risk assessment for each piece of infrastructure under the likely conditions it will face so that adequate plans for adaptation and increasing resilience to meet those conditions can be prepared. Because the climatic conditions projected by UKCP09 are given in terms of probabilities, there is felt to be an increased need to develop training in probabilistic approaches to adequately assess the potential risks.

Revised design standards and building codes for the energy infrastructure need to be developed in anticipation of the conditions that the infrastructure is likely to face. Infrastructure could then be adapted as it comes up for refurbishment or replacement. Design approaches to adaptation will need an understanding of extreme of weather events and of the probabilities of specific climate conditions.

As well as a risk assessment of individual pieces of infrastructure, it would benefit operators and regulators (when appropriate) to envisage the energy supply chain between fuel supplies to delivery of energy to consumers in a holistic manner to identify pinchpoints or bottle-necks in the process which may limit resilience. It is suggested that utilisation of Sankey diagrams could accomplish this at national, regional and local levels.

This deeper understanding of the supply chain could facilitate greater co-ordination and integration between operators (where allowed by prevailing legal frameworks) to manage stresses on infrastructure by, for instance, co-ordinating when significant pieces of infrastructure such as generators are taken offstream for servicing and maintenance.

Despite the utilisation of these adaptation processes, it is possible that interruptions to energy supplies will occur. Using smart meters to manage the delivery of energy to consumers and developing a smart grid to ensure supplies to specific users or communities will enable suppliers to balance demand in times of stress.

Notwithstanding extremes caused by specific events, it is likely that there will be a requirement for greater electricity generating capacity at times of peak demand. This is best met through a variety of electricity generating sources and a broad portfolio of generating capacity. This will also increase the resilience of the electricity generating infrastructure by reducing reliance on any one source.

Using a variety of storage systems could also facilitate load balancing. The expected increase in the use of electric vehicles, for instance, could be managed through smart technology to charge vehicles' power supplies at times of low usage. Similarly, it would be possible for information technology systems such as personal computers and other networked equipment to use batteries charged during off-peak periods to provide power directly, removing the need to power the equipment during peak periods of energy demand.

Using hydro-electric facilities as a storage mechanism, pumping water during off-peak demand to generate electricity in peak periods, could manage peaks in electricity usage. Combining these with less predictable renewable supplies would enable the indirect use of renewable resources during peak periods. The system may be more resilient if the hydro-electric storage is managed on a local basis.

Developing other distributed energy systems and generating capacity would also increase the system resilience. Infrastructure such as small scale generators could work in many different, flexible ways, functioning as back-up systems for essential services, for specific customers or for local needs whilst having capability to provide energy to other users or the grid if and when required.

Barriers to implementing adaptation options

Many of the proposed adaptation mechanisms will require additional finance. Whilst incorporating the changes required into the design standards and building codes for infrastructure may enable the adaptation to be undertaken within the normal life-cycle of maintenance, refurbishment and replacement, it is likely that the standards will be more exacting in order to meet greater extremes. They may need increased quality materials, take longer to maintain, repair and replace and require more extensive testing to ensure revised standards are met. These inputs are therefore likely to increase the costs of infrastructure. Similarly, increasing the utilisation of hydro storage facilities and other distributed capacity will require investment.

The benefit of these investments may well be separated from the finance, particularly if the perceived benefit is to the nation as a whole through a more resilient infrastructure. The supply of such "just in case" capacity, which may be seen by investors as excess capacity, would not meet usual investment criteria in a commercial, market environment.

The development of distributed capacity by commercial users might become economical if the risk of power shortages were to increase. For instance, chemical processing plants, which can be energy intensive, require continuous energy supplies. If the risk to energy supplies increased, the costs associated with a power failure would increase and the investment in dedicated generating capacity to guarantee supplies may become uneconomic in older less efficient plants, thus precipitating their replacement in lower cost locations.

Regulation could also be used to require suppliers to provide 'just in case capacity'. If the regulated parts of the energy sector had a requirement to

provide energy to all consumers within specified standards, both the regulated and unregulated sectors would have economic reasons to comply – the regulated industry as part of their licence to operate, the unregulated industry to meet the needs of the regulated industry. However, the costs associated with this would probably be passed onto consumers. Some consumers may prefer to pay less for supply that met lower standards, i.e. supply which might be subject to outages.

Whilst the costs of incorporating smart energy management systems in new consumer goods such as electric vehicles may be absorbed, consumers may object to paying more for such systems in other electrical goods. Objections might be overcome through commercial mechanisms, for instance charging more for energy consumed at peak periods.

Regulation and legislation may also be barriers to the adaptation of infrastructure and the development of a more resilient system. Increased co-operation and co-ordination to meet the challenges of climate change may fall foul of regulatory and competition law.

In regulated businesses, there is often a focus on improved efficiency of the business within the regulatory regime, which would work against investing in spare capacity.

Existing environmental and planning legislation may also work against adaptation. This is particularly the case where national infrastructure needs are subject to local planning decisions. Local decisions can be inconsistent with national priorities, and there is no central body responsible for planning adaptation and resilience of national infrastructure. The current government's programme includes creating a presumption in favour of sustainable development in the planning system[2], but it is unclear whether this would include – or may even work against – increasing infrastructure resilience. There is a need for a broader approach to sustainability which balances economic, societal and environmental needs while simultaneously considering the legacy left to future generations.

Public opinion may also be a barrier to adapting and developing infrastructure. Whilst most people understand the need for continuity of energy supply in the abstract, they frequently object to local development – an example of NIMBYism[3]. Greater public understanding of the needs arising from climate change and the urgency of development may be required so that the public, politicians, suppliers and regulators can take part in an ongoing debate.

It is possible that the UK lacks the manufacturing base required to meet the future needs as a result of adaptation. A shortage of manufacturing capability may increase prices for infrastructure. This may be an opportunity for manufacturers.

It is not clear whether government, regulators, and businesses have sufficient information from climate projections for them to plan effectively for the effects of climate change. Although UKCP09 provides climate projections at 25km resolution (with further assessment being possible via the weather generator, which operates at 5km resolution), this information alone might not be sufficiently detailed to undertake a risk analysis of infrastructure. UKCP09 considers extreme events, which are those which might impact on infrastructure, as percentage changes rather than frequency changes. The weather generator provided in UKCP09 allows extremes associated with daily climate to be investigated[4]. UKCP09 has limited information on the effect of climate change on wind[5], which whilst not generally considered to have significant impact on energy infrastructure may impact specific pieces of infrastructure, particularly those involving renewable energy resources.

The skills and education of engineers will need to change to meet the demands required to fulfil the adaptation agenda. A skills mapping exercise for DECC indicated that an additional 35,000 engineers would be needed to meet the demands of the government's low carbon future – that is, mitigation of climate change. It is not certain how many engineers will be required to meet the needs of adaptation to climate change, but it is likely to be more than the number of engineers currently working in the energy sector. They will also need a different or additional skill set to deal with the probabilistic nature of the projections, rather different to the deterministic nature of traditional engineering education.

If adaptation is successful, the energy industry should be able to meet the nation's needs; however, it would then seem like the work was unnecessary: it is possible that it would take a crisis of some sort to demonstrate the need for adaptation. It might take considerable political will to undertake the investment and development potentially required to meet the adaptation agenda.

Interdependencies

Energy infrastructure is dependent on:

- water infrastructure for providing a cooling mechanism for power generation and oil and gas refining, as well as protecting energy installations from flooding and ensuring staff manning installations are able to work in a healthy, hygienic environment;
- ICT infrastructure for control and management systems, particularly smart grid and smart meter developments, and communications;
- transport infrastructure for the supply chain of fuel for power generation and the distribution of oil and gas products, as well as enabling access for staff.

Conversely, energy is required for:

- water, to run water treatment plants and pumping stations;
- ICT, to run all ICT equipment;
- transport, to drive all transport systems.

In addition, in urban environments energy, water, ICT and transport infrastructure are often co-located: for instance, power cables may be laid below roads and beside communications cables, adjacent to water and gas mains and above sewers. Failure of one form of infrastructure can lead directly to damage to another and damage can also occur inadvertently during repair infrastructure work.

Opportunities arising from adaptation to climate change

The opportunities arising from adaptation to climate change are likely to be large but may be hard to realise. They are similar to existing opportunities arising from strategies to mitigate climate change. In particular, developing more efficient energy systems such as power generation, power transmission and engines (electric or oil-based) would make energy infrastructure both more sustainable by reducing emissions and more resilient by making better use of the resources available.

Many of the adaptation options to climate change involve designing effective standards, codes and regulations for infrastructure. The expertise to develop these represents intellectual property which could be used elsewhere. The workshop perceived the UK as being ahead of rest of Europe on adaptation of its infrastructure, but needs to work to stay there. UK-based companies have experience of designing to these specifications currently and could capitalise on this experience.

The development of effective energy storage systems (either physical, eg storage of water for hydro schemes, or electrical) and distributed energy systems represent engineering and design opportunities. Developing both efficient storage capacity to power ICT systems for long periods and the smart systems to manage devices recharging during off-peak periods would be highly marketable.

The UK has extensive experience of renewable energy infrastructure, which is seen as important to reduce greenhouse emissions. Renewable facilities could also be central to developing distributed capacity, possibly community-based, again making the energy infrastructure more resilient.

Working with the built environment presents many opportunities. Incorporating systems to recycle waste heat from energy generation or industrial processes reduces energy consumption, helping to manage demand. The extensive infrastructure between the heat source and the buildings making use of the excess heat means that recycled heat is easier to implement in new build developments rather than existing urban areas. Similarly, incorporating thermal inertia heating/cooling systems into buildings functions as both an adaptation and mitigation strategy, improving working and living conditions under climate change whilst reducing power usage and greenhouse emissions.

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Energy Workshop Matrix

LIKELEY INTERACTIONS BETWEEN CLIMATE CHANGE FACTORS AND ENERGY

CLIMATE CHANGE POTENTIALLY IMPACTING TRANSPORT INFRASTRUCTURE																												
ENERGY INFRA-STRUCTURE AFFECTED	High temp		Low temp		Water table rise		Sea level rise		Storm surge		Prolonged Rainfall		Flood		Drought		Snow		Extreme Wind		Electric storm		Frost		Fog		Soil shrinkage	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
ELECTRICITY																												
Coal Power Stn	M	M	L	L	L	L	M	M	M	L	L	L	M	L	M	L	L	M	M	M	L	M	L	H	L	H	M	H
Oil Power Stn	M	M	L	L	L	L	M	M	M	L	L	L	M	L	M	L	L	M	M	M	L	M	L	H	L	H	M	H
Gas Power Stn	H	M	L	L	L	L	L	M	M	L	L	L	M	L	M	L	L	M	M	M	L	M	L	H	L	H	M	H
Transmission system	H	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	M	H	M	M	M	L	H	L	H	M	H
Distribution system	M	M	L	L	L	L	L	L	L	L	M	L	M	M	L	L	L	M	H*	M	H*	M	L	H	L	H	M	H
Sub Stations	M	M	L	L	M	L	M	L	L	L	M	M	H*	H*	L	L	M	M	M	M	H*	M	L	H	L	H	L	H
Power Stn Consumables	L	M	L	L	L	L	L	L	L	L	L	L	H*	M	L	L	H*	H	L	M	L	M	L	H	L	H	L	H
Communications/ control systems	M	M	L	L	L	L	L	L	L	L	L	L	M	M	L	L	L	M	L	M	H*	M	L	H	L	H	L	H
PRIMARY ENERGY																												
Coal supply UK	L	M	L	L	M	L	L	L	L	L	L	L	M	L	L	L	M	M	L	M	L	M	L	H	L	H	L	H
Coal Supply O/S	L	M	L	L	L	L	H	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	H	L	H
Oil supply UK	L	M	L	L	L	L	M	M	M	M	L	L	H*	M	L	L	L	L	L	L	L	L	L	H	L	H	L	H
Oil supply O/S	L	M	L	L	L	L	H	M	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	H	L	H
Gas supply UK	M	M	L	L	L	L	M	M	M	M	L	L	M*	M	L	L	L	L	L	L	L	L	L	H	L	H	L	H
Gas supply O/S	M	M	L	L	L	L	M	M	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	H	L	H

Likely Infrastructure **D**amage and **P**robability of a climate change-related impact are each scored as **H**igh **M**edium **L**ow

Cross cutting points:

- The impact from repeated or cumulative events will be different from that of a one-off event.
- Consistent adverse conditions will support mitigating investment but sporadic events, even if more extreme, will not.
- Impact from climate change is different in different geographic areas.
- Impact can be localised.
- Different types of infrastructure have different intrinsic resilience

ENERGY INTERDEPENDENCIES RELATIVE TO TELECOMS, WATER & TRANSPORT INFRASTRUCTURE M

	Telecoms				Water								Transport					
	Landline		Wireless		Drinking		Sewerage		Surface		Rivers		Rail		Road		Sea/Air	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
ELECTRICITY																		
Coal Power Stn	H	M	M	M	L	L	L	L	L	L	M	M	H	H	M	M	L	L
Oil Power Stn	H	M	M	M	L	L	L	L	L	L	M	M	L	L	M	M	L	L
Gas Power Stn	H	M	M	M	L	L	L	L	L	L	M	M	L	L	L	L	H	L
Transmission system	H	M	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Distribution system	H	M	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Sub Stations	H	H*	M	M	L	L	L	L	M	L	L	L	L	L	M	L	L	L
Power Stn Consumables	M	M	M	M	L	L	L	L	L	L	L	L	L	L	H	H*	M	M
Communications/ control systems	H	H	H	H	L	L	L	L	L	L	L	L	L	L	L	L	L	L
PRIMARY ENERGY																		
Coal supply UK	M	L	L	L	L	L	L	L	M	L	L	L	H	H*	M	M	L	L
Coal Supply O/S	L	L	L	L	L	L	L	L	L	L	L	L	M	M	M	M	H	M
Oil supply UK	M	L	L	L	L	L	L	L	L	L	L	L	L	L	M	M	L	L
Oil supply O/S	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	M
Gas supply UK	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Gas supply O/S	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

NOTES

- The impact from repeated or cumulative events will be different from that of a one-off event.
- Impact can be localised.

Likely Infrastructure **D**amage and **P**robability of an impact are each scored as **H**igh **M**edium

6.2 Transport sector report

ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY

Report of the Transport Sector Workshop July 2010

Summary

This report outlines the discussion and findings from a workshop on the adaptation of the UK's transport infrastructure to the projected changes in climate (set out in UKCP09). The workshop was one of a series on infrastructure sectors arranged by *Engineering the Future*, an alliance of engineering institutions, the Royal Academy of Engineering, Engineering UK, the Engineering Council and the Institute of Physics. The workshop was led by the Institution of Engineering and Technology.
The key findings of the workshop were:

- All transport sectors (national roads, local roads, rail, air and maritime) are aware of the potential implications of climate change on their businesses, are in general well advanced with their thinking on mitigation and adaptation, and are keen both to share their knowledge and to learn from others' efforts. However there is little organised cross-mode knowledge transfer to support their work.

- Little work is being done on the 'soft' issues of the impacts of climate change on culture and behaviour.

- Transport investment is subject to cost–benefit appraisal formulae that do not yet recognise climate change issues. In particular there is a need to invest in the short- or medium-term with the expectation of a very long-term benefit – something that may be inconsistent with, for example, the franchise cycle of the railways.

- A catalogue of the key standards and some sort of central information and coordination office would be beneficial in supporting research and investment more effectively.

- A lot of research is being done and done thoroughly but with almost no intra-or inter-mode coordination and information dissemination. Consequently there is probably duplication, and inefficiency in the use of resources. We identified three key gaps in the current research:
  - the effect of climate change on aviation;
  - the effect of climate change on wind strength and direction (potentially a key issue for ports and airports);
  - interdependency of transport with other elements of the infrastructure.

- There is a very strong case for some central funding to bring together the existing knowledge and present it as common standards, treatment protocols and techniques for addressing bridge scour, drainage, embankment and cutting stability, and subsidence which are common to many areas of road and rail engineering.

- There has been a lot of work on risk analysis but for the most part it has been simple i.e. addressing just one risk element. There is a need for

more work on complex risk assessment when two or more different classes of risk coincide.

- There has been some innovative research on transport as a complex system but more needs to be done to look at transport and climate change as a multi-mode complex system with links to energy, ICT, and water infrastructure systems.
- The ten effects posing the biggest risks to Local Authority highway networks are:
  - Pavement failure from prolonged high temperatures;
  - Increased length of the growing season leading to prolonged and/or more rapid growth of the soft estate;
  - Lack of capacity in the drainage system and flooding of the network;
  - Surface damage to structures from hotter and drier summers;
  - Scour to structures from more intense rainfall;
  - Damage to pavement surface layers from more intense rainfall;
  - Subsidence and heave on the highway from more intense rainfall;
  - Scour and damage to structures as a result of stronger winds and more storminess;
  - Severe damage to light-weight structures from stronger winds;
  - Less disruption by snow and ice due to warmer winters.

Introduction

This report summarises the processes and outputs of the workshop held on 14 July 2010 under the chairmanship of Professor Eric Sampson. The 36 participants at the workshop considered the likely impacts of climate change on transport infrastructure. Discussion was stimulated by a series of presentations covering Integrated Transport, the Strategic Road Network, the Rail Network, Airports and Ports while CIRIA considered the impact of natural hazards across a broader front. Written material was also taken into account from discussions with Leicestershire County Council who were unable to be present.

The key questions that underpin the discussion are:

1. What are the issues/technical and operational impacts from climate change (focusing on the medium-term [to 2030] and long-term [to 2100] impacts) on the sector?
2. What are the potential adaptation options to address these issues/impacts? This should include consideration of engineering/design standards – do they need to change and if so why and how? For example should we allow regulators to operate beyond pure economic regulation; or incentivise cooperation between regulators? Or encourage investments outside the core business that are vital to improve resilience. Allow more resilient premium services?
3. What are the potential barriers to implementing these options (including consideration of the wider context within which engineering operates)?
4. What are the opportunities (e.g. skills, economic, innovation) from adapting our infrastructure, in particular to the engineering profession and engineering organisations? Whether opportunities could be

brought out more, i.e. the potential for the ICT sector to provide technology to help the country/industry adapt.

5. What interdependencies does the sector have with the other three sectors and will climate change impacts exacerbate these? What about potential cascades of failure across the national infrastructure?

This report focuses on the principal discussions and findings as follows:

- Not enough work is being done on 'soft' issues, behavioural response to climate change (especially temperature).
- the DfT guidelines on cost–benefit measurement and the Treasury Green Book (Appraisal and Evaluation in Central Government) need to be developed to recognise climate change issues especially the long time frame involved.
- hidden or unintended consequences of adaptation activity: e.g. possible increases in cycling fatalities linked to temperature-induced behaviour change.
- Adaptation, interdependencies and risk assessments need to be considered as total systems and in at least three ways:
    - within a sector (e.g. vulnerability of roads networks where local authorities (LAs) and the Highways Agency have different approaches and standards);
    - within transport (i.e. the linking of the different modes);
    - Interdependencies of transport with energy, ICT, water etc.
- Internal transport interdependencies can be systemically fatal;
    - the rail network might be resilient and virtually fully available but if local roads and bus services collapse then railway workers might not be able to get to work to provide the rail service.
- Not enough work being is done on instrumenting infrastructure to enable autonomous reporting of condition and availability. Work is also needed to ensure maintenance of monitoring capability during electrical power and telecoms disruption.
- Most sectors have considerable records of data and information that might potentially benefit adaptation studies but until very recently this material was not collected and stored with climate change in mind. Some exploratory work on data recovery and data mining looks like a sound investment.
- Buildings seem not to be considered a part of infrastructure but they are a key element for sea and air ports and public transport network interchanges.
- Not enough research is being done on the effect of climate change on aviation.
- Not enough research is being done on the effect of climate change on wind strength and direction (potentially a key issue for ports and airports).

- Climate change work so far has assumed no radical change in the UK's economic make-up. There seems to be a strong case for exploring whether there would be significantly different issues and interdependencies if major change happened e.g., doubling or halving the UK manufacturing base, rail moved to a predominantly electric or a predominantly diesel energy regime or the importation of substantial proportion of electrical energy.
- Funding adaptation work could be impeded if some Regulator powers and responsibilities are not amended to reflect the new operating regime.
- There is no coordination of the various adaptation investments, research and other activities – much of which is believed to be happening somewhere. Some are proceeding too slowly because of inadequate funding. Adaptation research work needs a central 'clearing house' logging all initiatives by the numerous bodies in this area to help reduce overlap of activity and duplication.
- There has been a lot of work on risk analysis but for the most part it has been simple i.e. addressing just one risk element. There is a need for more work on complex risk assessment when two or more different classes of risk coincide. Local Authority Emergency Planning scenarios might be a usable base for this.
- It was recognised that funding for adaptation work will be in short supply. It would be useful to compile an initial list of the top 25 or so items of 'most critical' transport infrastructure, assume that they will be protected and the necessary work funded; then examine infrastructure items 'below the line' to see how failure in these areas might impact on water, energy, ICT.
- Concern was expressed about the pricing of data and research work by the Meteorological Office. There was a strong feeling that the Office was lagging behind other Departments in opening up data and information collected at public expense (the Cabinet Office 'Berners-Lee' liberalisation initiative) which was inhibiting experimental work and creating a near-monopoly for research in this area.

Issues and operational challenges arising from climate change

A number of likely impacts of climate change on transport infrastructure have been drawn from Annex C of the Engineering, Infrastructure and Climate Change Adaptation Conference Report, December 2009 (Defra). The summary list below shows transport related infrastructure marked with high potential for damage by severe weather conditions and medium or high likelihood of occurring.

1. Roads: storm surge; prolonged rainfall; flood; drought; snow; extreme wind; frost; fog; soil shrinkage
2. Pedestrian route: snow
3. Cycle paths: flood
4. Surface rail: storm surge; prolonged rainfall; flood; snow; extreme wind
5. Underground rail: prolonged rainfall

6. Airport: electric storm; flood; drought; snow; extreme wind; fog
7. Airways: electric storm; extreme wind
8. Terminals: drought
9. Coastal infrastructure: sea level rise; storm surge; flood; fog
10. Seaports: sea level rise; storm surge; flood; drought; fog
11. Inland waterways: storm surge; prolonged rainfall; flood; drought; frost; soil shrinkage
12. Embankments: water table rise; storm surge; prolonged rainfall; flood
13. Tunnels: flood
14. Bridges: storm surge; prolonged rainfall; flood
15. Pipelines: prolonged rainfall; flood
16. Control systems: storm surge; prolonged rainfall
17. SatNav: electric storm
18. Oil Distribution: sea level rise; storm surge; flood
19. Gas Distribution: sea level rise; storm surge; flood
20. Electric car recharge network: electric storm; prolonged rainfall; flood
21. CO_2 transport: flood

Adaptation options to meet issues and challenges

- Systematic risk assessment:
  - dependent on up-to-date, accurate asset registers;
  - using information systems developed for other purposes to assess risk from climate change.
- Amendments to design standards and operating practices will be required:
  - incorporate adaptation into business-as-usual maintenance routines;
  - drainage systems;
  - earthworks.
- Some simple measures can be cheap and effective:
  - New buildings, especially stations, are making increased use of reflective and/or shaded glass.
  - Quick wins are possible e.g. redesigning culverts in embankments can help to prevent landslips, painting bus roofs white can reduce the risk of overheating. Degrading service frequency and quality might be a useful adaptation technique in some circumstances.
  - Adapt to changing climate over the life-time and replacement cycle of assets e.g. road surfaces, rail tracks.
  - Learn from:
    - each other;
    - other systems – the types of UK weather expected to result from climate change are found elsewhere in the world now.

- Some major infrastructure may require significant investment to meet adaptation requirements e.g. coastal rail tracks cannot be moved, and so may need significant and costly adaptation.
- New infrastructure will need to be built consistently with adaptation requirements e.g. ports. This approach will 'future proof' current investment.
- It is important not to reduce specifications of new build due to financial pressures. Infrastructure procurement needs to take future climate and weather conditions into account (possibly even those of currently unlikely weather conditions as mitigation measures appear to be lagging behind).
- Communication with passengers/consumers and other transport agencies will be a key adaptation strategy. There is a need to understand how passenger and/or consumer behaviour might change in relation to climate change.
- Some disruption to transport may be unavoidable – as now (e.g. floods of 2007):
    - A risk/reward profile will be needed to assess an "acceptable" level of disruption and it may be necessary to accept slower journeys (increases in journey times) in order to increase reliability.
    - It may be that reducing service frequency on the railway might be appropriate; (this has already been considered for the London Underground to cope with higher tunnel temperatures). Customer expectations would need to be carefully managed.
    - Contingency planning will be required to manage extreme weather events and emergencies.
    - Local authority emergency planning may need to be extended.
- A major assumption is that vehicles using the infrastructure are separate from it:
    - Vehicles have shorter lifespan than the infrastructure on which they travel (e.g. average age of UK train rolling stock in 2006/07was c.16 years[6]).
    - It is assumed that vehicle operators will ensure their vehicles are adapted to changing climate as they are replaced but this may need to be enforced through regulation and/or legislation.

Sector summaries

Each organisation presenting has taken its own approach to these challenges and so, although brought together here, each section will emphasise those matters perceived as important by the host organisation.

(a). Transport for London

Transport for London has the challenge of operating and sustaining an integrated transport system (bus, underground, tram. DLR, overground, river, traffic management), and has responsibility for promoting both cycling and walking. TfL operations are vulnerable to a range of hazards including flooding, drought, over-heating, air quality (a legal requirement), subsidence and ground heave and wind storms.

TfL has developed a number of adaptation mechanisms including detailed risk assessments and adaptation costing, securing road drainage, changing infrastructure specifications (bus design, tube, Crossrail), and installing ground water pumping. It has integrated adaptation into its business continuity planning and the ongoing maintenance and replacement of assets. TfL recognises communication with customers, employers and employees and between transport services is essential.

(b). The Highways Agency

The Highways Agency is responsible for the Strategic Road Network in England. While only 2% of road network is regarded as national infrastructure it carries 25% of all traffic and almost 50% of HGV traffic so there are nonetheless significant risks. These include the reduction in asset condition and safety from climate change and reduced network availability and/or functionality. The cost of maintaining a safe and serviceable network is likely to increase and there is increased safety risk to road workers with increased programme and quality risks due to required changes in construction activities. Not all of the current Agency internal operational procedures are appropriate to the future and dealing with climate change will incur increased business management costs.

The primary impacts of climate change are through the increase in average and maximum temperatures, increased winter and decreased summer rainfall with an increase in extreme rainfall events – giving particular challenges in relation to drainage capacity and flooding.

Secondary impacts are likely to be felt through a longer growing season coupled to reduction in soil moisture and changes in groundwater level. Flooding is expected to be an increasing problem. Winter is expected to see reductions in the numbers of days with fog or ice but a potential increase in the frequency of storm surges. The current Government Chief Scientific Adviser, Professor Sir John Beddington, is conducting a study into the case for increased resilience in the transport sector against severe winters.

A particular concern raised was the issue of wind effect on road signs. It was felt that wind change effect is not sufficiently covered in CP09 and that road signs which are vulnerable to this may be heavily impacted.

The HA is undertaking risk assessments and considering the future challenges. Adaptations are likely to include future-proofing new designs such that they are able to deal with the range of conditions expected, retrofitting necessary solutions to the existing road network and developing contingency plans. The HA recognises the need to update its operating procedures, to monitor what is happening and to continue appropriate research.

Changes to standards and specifications are already being considered or applied and these include thermal action, thermal range and wind action (loads) applied to superstructures. The HA has already adopted French temperature standards for road surfaces and these are performing well. There is however an issue with standing water if present for more than a week. Design requirements are being changed through modifying temperature and wind maps (National annex Eurocode) as is the design of structure drainage, the use of temperature sensitive components or materials in construction and rehabilitation and the design of bearings and expansion joints.

Business processes are being changed to incorporate risk assessment of and adaptation to climate change. The whole is recognised as an iterative process of assessment and adaptation to risks.

The road network must be recognised and managed as a single network of assets. While it is not totally dependent on energy, in the sense that the network continues to function without signage, emergency signals etc, the capacity of the system will be greatly reduced and traffic may be unable to enter or leave if traffic signals on local feeder roads lose power.

The renewal cycle for major routes is 30 years, with a third of the network resurfaced every 10 years. Bridge structures are designed for 120 year life (although some structures are significantly older) and it may be that some design expectations will need to be revisited in the light of changes to wind patterns and forces, and potentially changes in scour patterns from altered water flow.

Road user behaviour is also expected to change and generate new challenges. Not enough is known about the possible impact of changes in weather on driver behaviour. It is possible that both hot and cold extremes will increase road traffic while driver responses to the changing situations may lead to increase in accidents and delays.

Vehicles are, in this context, assumed to be relatively short-lived artefacts (5-10 years typically) and it is considered that they will be adapted by manufacturers. However, little is understood of the impact of electric, hybrid and fuel cell vehicles and the infrastructure changes that may be required to enable them, e.g. recharging points and/or hydrogen fuelling stations.

(c). Construction Industry Research and Information Association (CIRIA)

Prompted by recent flood events CIRIA has undertaken research to consider the resilience of transport infrastructure to flooding which has benchmarked UK critical infrastructure. The objectives of the research were to collect and collate information on currently available flood resilience and resistance measures, to identify approaches to improve the adaptation to flood risk and promote cross-sector collaboration and consensus. The project recognises the complexity of both the regulatory context and the public/private sector mix and that it has complex interdependencies. A framework has been proposed for the development of standards based on risk and criticality based priority.

The study recommended that flood resilience measures should be implemented as an integral part of organisations' business continuity management processes, whole life asset management plans and climate change adaptation strategies. It also noted that smarter investment planning would be required together with 'joined-up thinking' and a greater emphasis on whole of life project costing.

The ensuing discussion highlighted a number of requirements:

- to understand the behavioural impacts of climate change;
- to consider what people will do differently following climate change, for example how work patterns might change and the consequences for usage of infrastructure;
- to assess how increased homeworking and/or telecommuting may reduce the need to travel to work and that dependency on infrastructure;
- to research how technology may enable both internal migration and changes in immigration patterns;
- to elevate awareness of economic aspects for adaptation to drive investment.

It was also recognised that there is a huge dependence on electricity for transport, to power small but increasing numbers of electric vehicles, for trains, for fuelling pumps for vehicles, aircraft and ships and to operate the control systems that enable them all to operate safely.

It was felt that despite incorporating changes required for adaptation in future standards, pressure on funds means some elements of adaptation are likely to be put off until infrastructure fails. It was noted that there does not appear to be a catalogue of the key standards. While CIRIA are considered to have documents that nearly fit that description and the Highways Agency has extensive Design Manuals for infrastructure, these are not written from a weather resistance perspective and there has been no prior proposal that this should be done. It is suggested that this would have potential for significant improvements in efficiency and effectiveness for Local Authorities – and generate cost savings.

(d). Network Rail

Network Rail operates with a fixed infrastructure, it cannot easily move rails away from coastal areas, flood plains or other impacted areas. Using the West Coast Mainline as a model Network Rail adopted new standards for adaptive resilience in May 2008 and December 2010. These standards affect new build projects not current infrastructure and include, for example, increases in drainage channel capacity to allow a 20% increased flow with a 20% added margin. Track is now replaced on a 10 year cycle and, with an enormous legacy infrastructure, a risk management approach is in use based on asset registers.

The workshop discussed a number of issues. There is additional risk to trackside equipment from increased humidity and although track is pre-tensioned to match a 27°C ambient temperature it is vulnerable to sustained higher temperatures. Overhead line equipment is tensioned by weights and is considered safe up to around 38°C but it might be necessary to increase the standard line tension to increase resilience to changing wind strengths. The Channel Tunnel and High-Speed One being relatively new build are assumed to be resilient.

Although rolling-stock has a 30 year life (approximately) it is assumed that the impact of climate change will be accommodated as 'business as usual' in future design and that existing rolling stock will replaced before the effect of climate change impacts. The question of infrastructure failure as a result of current weather on rolling stock, e.g. Channel Tunnel breakdowns of December 2009, was raised although it was recognised that these were failures of power/traction unit and not the permanent way.

It was suggested that the structure of the industry, particularly Regulatory and economic model and short franchise periods, might act as inhibitors to adaptation – it is already recognised that the franchise periods inhibit normal investment by franchise holders.

The table below shows the likely impacts of climate change and consequences for the UK rail network.

Ongoing availability of electricity is clearly a key risk area but is not included in this table as it is outside the scope of management of Network Rail and will be picked up as one of the key interdependencies.

(e). Airports

Turning now to airports, specifically Heathrow, it is recognised that there will be impacts on buildings, operations and passengers. Buildings will

Climate Impact Group	Cluster	Consequence
Heat	Track	Management of track buckle risk
Heat	Track	Reduced window of opportunity to carry out maintenance/ renewals work due to heat
Heat	People	Passenger health and impact on freight from train failure in extreme temperatures, including heat and cold
Heat	People	Staff working conditions, eg: use of heat watchmen
Heat	Power/ Telecoms/ Signalling	Floating electrical earth leading to stray earth currents caused by dry ground/ low groundwater; heat (solar gain) affecting lineside equipment; sag in tethered overhead line systems at terminal stations
Rainfall	Fluvial flood	Track and lineside equipment Failure
Rainfall	Groundwater flood	Track and lineside equipment Failure
Rainfall	Pluvial flood	Track and lineside equipment Failure
Rainfall	Fluvial flood	Scour and water effects at bridges
Rainfall	Fluvial flood	Scour at embankments due to high river levels and culvert washout
Rainfall	Fluvial flood	Safety of workforce carrying out inspections during an extreme flood event
Rainfall	Pluvial flood	Landslips
Rainfall	Fluvial flood	Accessibility of fleet and of maintenance depots
Insolation/ heat/ rainfall/ wind	Vegetation	Change in type, falling trees causing obstructions, poor adhesion, and track-circuit non-activation
Sea level rise and storms	Coastal and estuarine defences	Wave overtopping and flooding at defended coastal and estuarine railways

face increased cooling demand for both terminals and aircraft and there are likely to be shortages of power, fuel and water. Flooding of terminals and the airfield under certain circumstances are considered possible.

From an operational perspective it is possible that exceptional climate change may lead to payload limitation and/or a need for longer runways – a practical impossibility at Heathrow, while slower climb rates may mean the need for airspace redesign. Sustained higher temperatures could lead to diversion of incoming aircraft if temperatures were to become too high for safe landings, while, as yet un-forecast changes in prevailing wind conditions would affect optimal runway orientation.

Increased temperature might reduce the need for de-icing which would represent a cost saving, but might increase bird hazards; while there may be seasonal changes to passenger demand and other shifts related to road, rail or tube disruption.

The workshop was unclear whether water was an essential item for safe airport operation, i.e. what would be the impact on Heathrow of the loss, failure or closure of adjacent reservoirs?

(f). Ports

Ports have a reporting requirement only in relation to wetside infrastructure. There is no requirement for reporting dryside issues. However, in practice, strategic ports (those carrying more than 10M tonnes cargo per annum) report on all facilities for which they are responsible. Climate change is considered likely to affect road surfaces, rail lines, sewage treatment, power supply efficiency, and IT systems through higher temperatures. Drought and pressure on water supplies, especially in the south east, are likely to have an impact while flooding and sea level rise generate higher risks for transport, water treatment, electricity substations and power stations. Storms will affect power and telecommunications networks and operations at ports and airports. Sea-level rise per se is likely to be a benefit for most ports as it enables larger ships to be moved and reduces the need for dredging. It is suggested that sea level rise can be factored into port planning and harmonise with the 20-30 year investment cycle in this sector.

Adaptation is being commenced with revised operating practices to protect staff working outside while specifications for new build already exceed the range of conditions required for adaptation – although this is seen as a happy accident rather than good design. As with all things commercial, the needs and demands of customers are the strongest drivers of adaptation e.g. refrigerated units.

The workshop also considered that while wind can interrupt functioning of a port and so is already a constraint upon operation and expansion it is not necessarily forecast to increase.

It was noted that most buildings at ports are owned by private companies and do not currently come under any obligations to be resilient to climate change or to report on their ability to cope.

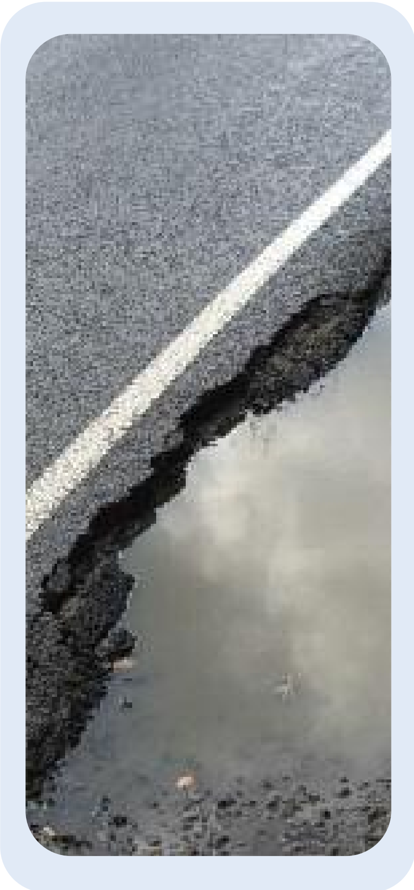
(g). Local Authority roads

The position with regard to Local Authority roads is complex. In 2007 the Audit Commission issued a series of national performance indicators (NIs) for Local Authorities. NI 188, Planning to Adapt to Climate Change, states: "To ensure local authority preparedness to manage risks to service delivery, the public, local communities, local infrastructure, businesses and the natural environment from a changing climate, and to make the most of new opportunities. The indicator measures progress on assessing and managing climate risks and opportunities, and incorporating appropriate action into local authority and partners' strategic planning."

Leicestershire, Derbyshire and Nottinghamshire acting as the 3 Counties Alliance Partnership (3CAP) began work in 2008 to assess the effect of climate change on their highways policies and standards. The project took predictions by the UK Climate Impacts Programme 2002 (UKCIP02), and developed an adaptation plan using a risk and probability management approach based on predictions made for the year 2050. The results indicated significant impacts on the construction and maintenance of local authority highways.

The ten effects posing the biggest risks from climate change to the highway network are:

- pavement failure from prolonged high temperatures;
- increased length of the growing season leading to prolonged and/or more rapid growth of the soft estate;
- lack of capacity in the drainage system and flooding of the network;
- surface damage to structures from hotter and drier summers;
- scour to structures from more intense rainfall;



- damage to pavement surface layers from more intense rainfall;
- subsidence and heave on the highway from more intense rainfall;
- scour and damage to structures as a result of stronger winds and more storminess;
- severe damage to light-weight structures from stronger winds;
- less disruption by snow and ice due to warmer winters.

The 3CAP region looks to be ahead of many others in terms of predicting changes and implementing plans to tackle both the causes and effects of climate change. This project has identified responses to achieve Level 2 of National Indicator 188 [Comprehensive Risk Assessment] and the adaptation action plan developed by 3CAP to address the biggest risks achieves Level 3 [Comprehensive action plan and prioritised action in priority areas]. An outline timescale has been agreed for implementation of this adaptation action plan which would move the 3CAP councils towards achieving Level 4 of NI188 [Implement an adaptation action plan and establish a process for monitoring and review to ensure progress].

Work is starting to see to what extent the work done so far needs to be modified to incorporate UKCIP09; there looks to be a strong case for seeing whether the 3CAP work is sufficiently generic to be adopted by a much wider range of LAs.

Barriers to implementing adaptation options

Uncertainty is perceived as the biggest single barrier to change. Currently the 'risk' of over-investment in unnecessary resilience is seen as greater than the risk and consequences of failure. This situation is probably not helped by relatively short-term investment appraisals and high uncertainty in job security – and the rate of job turnover amongst Senior Executives. The need for a better understanding of traveller behaviour has already been flagged; both this and the impact of climate change on national demographics need to be studied from a base of "hard", quantified climate data (which is in short supply).

There are a large number of climate effects which are not properly understood or are not yet quantified at a sufficient level of certainty to support any specific changes in infrastructure, e.g. wind direction. While there are forecasts and models provided by the Environment Agency and the Meteorological Office, there are computational limits on processing data for climate forecasts – particularly given the processor hungry nature of the models that are currently being constructed.

Availability of funding is as ever a challenge and the current and future economic circumstances in which infrastructure will exist is highly uncertain. From a regulatory perspective, it was suggested that standards need to be agile to remain relevant and that there is little support or sponsorship from Government to enable a standards setting process. This was contrasted with the evidence from France where it is reported that the Government sponsors travel costs for delegates to accredited standards bodies.

Businesses within the sector tend to be organised in silos with climate change expertise often in one specific business area and not seen as central to operations. Meanwhile the transport industry itself is highly segmented (e.g. 24 train operating companies, innumerable Bus and Coach operators) and only marginally profitable in many situations. It is not an industry generating surpluses which are available for investment in projects of uncertain value and/or return.

Transport is highly dependent on the other industries – energy, water (e.g. flood prevention, water needed for operations), and ICT for its continued operation and may suffer unforeseen consequences from assumptions of linearity and independence.

A scoping study before the workshop involving a number of the participants identified a number of issues that are already inhibiting engineering work on infrastructure.

Legal, administrative and institutional:

- Adapting a significant part of rail infrastructure will require Town and Country Planning Act consents or English Heritage approvals (or both) which are usually slow processes.
- Rail has had a number of cases where remedial work has been subject to mutually contradictory constraints by the Environmental Agency and Natural England.
- Some rail and road earthworks likely to need attention are adjacent to Sites of Special Scientific Interest or similar designation so an additional approvals will be required.
- In most cases adapting rail infrastructure will have implications for the Regulatory framework.
- Adaptation at a national level could require very wide-impact moves which would be socially unacceptable for example a ban on car air conditioning.
- There is little experience of disaster recovery management techniques and no recognised corpus of knowledge and training based on documenting previous incidents.
- Resilience teams are primarily focused on the very short term, however, their expertise is highly valuable in understanding how infrastructure can be made more resilient and how interdependent sectors are impacted by incidents.
- There is not a generous funding allocation for adaptation work under current budgets, which are likely to be reduced in view of pressures at national level.
- There is a significant risk of duplication or gaps (or both) in the absence of any one central reference and coordinating body responsible for maintaining a list of known or emerging engineering standards, research activities etc.
- Addressing climate change issues is essentially meeting a long-term need; however benefit–cost appraisal models give inadequate weight to benefits so far in the future.
- There is no central 'clearing house' logging all initiatives by the numerous bodies in this area with the result that there is overlap of activity and almost certainly duplication.

Technical:

- In most areas there is no shortage of underpinning science to take forward adaptation projects. However it is likely that a significant amount of that scholarship is in archived reports, and the knowledge within them has not yet been used to write standards or design engineering products and processes, because of resource limitations.
- Adapting infrastructure while it is in service will either involve partial removal of capacity or full closures / blockades; all of which are most unpopular with travellers.
- Dealing with significant adaptation projects is likely to require project and programme management experience, together with knowledge and skills in areas such as drainage techniques, geotechnical engineering, all of which are in short supply.
- In many cases working on transport infrastructure requires compliance with the practices and standards of the owners of co-located services – for example most water supply companies have specified margins for closeness to their main supply pipes which limit the freedom of action to adapt the rail infrastructure.

A final major barrier is that of information sharing and co-ordination. Whilst recognising that there may be issues of commercial confidentiality, it is suggested that an information co-ordinating body – a nexus that brings together people and information at a single point of contact would have significant benefits. OLEV was offered as a model for this. An example of where such knowledge sharing could be valuable is in the stocks of disaster mitigation equipment. There is no central repository of such information and apparently no organised sharing of this information at a national level. It is considered that this inhibits sharing of plant and equipment and inhibits the response to emergencies and disasters.

Interdependencies

There are significant and major interdependencies within the transport sector. Transport workers and managers must themselves travel to and from work, while the vehicles depend on the provision of energy – most commonly liquid fuel, delivery of which typically relies on road vehicles. There are interdependencies between transport and ICT with management systems, control systems and communications systems all relying on provision of power and for electricity – to run transport infrastructure (e.g. electric trains) and management systems.

There appears to be very little joint working between modes of transport, although when the opportunity is created there is much enthusiasm for sharing information. However, the workshop identified five areas where rail and road have the same physical infrastructure issues but could see no organised information sharing taking place. These issues are: bridge scour, drainage, embankment and cutting stability, subsidence. Recent events have highlighted the scour issue.

	Telecoms		Water				Energy		
	Landline	Wireless	Drinking	Sewerage	Surface	Rivers	Electricity	Gas	Oil
Roads	✓				✓	✓			
Pedestrian routes					✓				
Cycling paths					✓				
Surface rail					✓	✓	✓		
U/G rail	✓						✓		
Airport	✓					✓	✓		
Airways		✓							✓
Terminals			✓				✓		
Coastal infrastructure	✓	✓							
Seaports						✓			
Inland waterways					✓	✓			
Embankments					✓	✓			
Tunnels						✓	✓		
Bridges						✓			
Pipelines							✓		
Control systems	✓	✓					✓	✓	
SatNav		✓							
Oil Distribution					✓		✓		
Gas Distribution					✓		✓		
Electric car recharge network		✓					✓		
CO_2 transport					✓		✓		

Derived from Annex C, Engineering, Infrastructure and Climate Change Adaptation Conference (Defra, 2009) – likely damage rated "high" and probability rated "medium "or "high"

Opportunities arising from climate change

Given that the UK transport sector has taken a lead in responding to the emergent threat from Climate Change there are a number of potential business opportunities arising. These include inward tourism, refrigerated transport systems and, significantly, the export of intellectual property and consulting know-how in solving the problems identified.

Other developments might include internet-enabled maps indicating weather/climate and likelihood of weather events at specific locations (based on Met Office data to 25km^2) over different time periods, integrating data from different systems and acting as a knowledge sharing nexus.

While increased use of remote monitoring would improve prioritisation this in turn increases dependency on ICT and raises the possibility that warning signals may be lost in the increasing noise resulting from increased monitoring. The tools and skills to discriminate useful and meaningful information will be key.

The workshop raised concerns over the number of engineers available and of bottlenecks in engineering skills available to meet the challenge of climate change (*A National Infrastructure for the 21st Century*. Council for Science and Technology, 2009). They recognise that the UK has world-leading capability in climate change, and that nearly all the technology required to meet challenges of climate change already exists, here or elsewhere in the world. It is suggested that commercialisation of the Meteorological Office has hindered knowledge sharing as it is charging for essential data and the government needs to free up that data. It was further noted that the Environment Agency charges for access to data on rivers. Chapter 8 of the CST Report: "A National Infrastructure for the 21st Century" considered the issue of skills in greater depth and an extract from that form appendix 1 to this report.

Unsolved problems

It was recognised that, going beyond previous discussions there is a need to consider:

- The potential for co-incident (or 'cascade') events, e.g. a "double whammy" of, say, flood and heat; snow followed by mist and so on. This should also extend to 'cascade failure' – for example loss of energy causes outage of ICT based remote site control systems which in turn will inhibit recovery of the energy supply, whilst also disabling control of water and gas supplies and the operation of other transport systems. Such an event would severely impact on the electrified railways as they depend on the availability of electricity for both the rolling stock and the signalling system. Failure of either prevents the safe operation of the railway.
- It was suggested that not all parts of the country face similar risk levels or similar impacts. Regional maps of severe weather impacts mapped against critical infrastructure elements would be useful.
- Location of future flood risk is a matter of critical importance which is not as well understood as it needs to be.
- The impact on human behaviour of climate change overarches everything else, is not at all understood, and needs to be properly researched and studied.
- A better understanding of the current and future economic scenarios and their interactions with climate change and adaptation needs to be developed in order to provide more reliable information for the sector.
- Currently conventional modelling and simulation systems present significant and costly computational challenges. They may slow down modelling process and inhibit capacity.

Appendix 1

Extract from CST Report

"The Sector Skills Councils and other bodies representing industry and professions, such as learned societies, professional associations, higher and further education institutes, need to continue working together to provide the Government and the devolved administrations with this essential information. But the lead must be with the employers themselves, and in a co-ordinated way.

Encouraging the supply of science, technology, engineering and mathematics graduates should continue to be a Government priority. Putting in place more high-level apprenticeships and training and development of technician engineers should be an important component of the skills mix needed. The development of multidisciplinary skills sets to design, install, operate and maintain the NI will be essential.

There is a question of whether a more focused approach to skills training is needed for strategically important sectors such as the low carbon economy, and major infrastructure projects such as nuclear build and retrofitting of low-carbon solutions. There are other skills bottlenecks needing urgent attention, for example in transport planning and operational research. The economic and Social Research Council will have an important role in ensuring that these skills and the relevant research is undertaken to support a modernised national infrastructure.

Social science skills will be essential at many stages of planning and implementing change in the NI. These include:

- researching, and gathering together the findings from existing research, on the social
- dimensions of modernising the NI
- informing modelling and simulation on a more interconnected NI
- operational management of the NI systems in a way which takes the social dimensions fully into account
- managing public engagement" (p49)

Appendix 2

Presentations received

Helen Woolston	Transport for London
D Kerwick-Chrisp	Highways Agency
B Kidd	CIRIA
John Dora	Network Rail
Graham Earl	Heathrow Airport
Gary Wilson	Port of Felixstowe

Appendix 3 Transport Workshop Matrix (from Dec 2009)

(1) LIKELEY INTERACTIONS BETWEEN CLIMATE CHANGE FACTORS AND TRANSPORT INFRASTRUCTURE

ENERGY INFRA-STRUCTURE AFFECTED	CLIMATE CHANGE POTENTIALLY IMPACTING TRANSPORT INFRASTRUCTURE																											
	High temp		Low temp		Water table rise		Sea level rise		Storm surge		Prolonged Rainfall		Flood		Drought		Snow		Extreme Wind		Electric storm		Frost		Fog		Soil shrinkage	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Roads	M	H	M	L	M	M	M	L	H	H	H	H	H	M	H	M	H	H	H	M	L	L	H	M	H	M	H	H
Pedestrian routes	L	L	M	L	L	L	L	L	L	L	L	L	H	L	L	M	H	H	L	L	L	L	M	M	L	M	L	M
Cycling paths	L	L	M	L	L	L	L	L	L	L	L	L	H	M	L	M	M	H	L	L	L	L	M	M	L	M	L	M
Surface rail	L	H	L	L	M	M	M	M	H	M	H	H	H	M	L	M	H	H	H	M	L	L	M	M	M	M	M	M
U/G rail	L	M	L	L	L	M	L	L	M	M	H	M	M	M	L	M	H	L	L	L	L	L	L	L	L	L	M	M
Airport	M	H	M	M	L	M	L	L	M	M	M	M	H	M	H	M	H	M	H	M	H	M	M	M	H	M	M	M
Air ways	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	H	H	L	L	M	M	L	L
Terminals	L	L	L	L	M	M	L	L	M	M	M	M	M	M	H	M	M	M	L	L	L	L	L	L	M	L	L	L
Coastal infrastructure	L	L	L	L	M	H	H	H	H	H	M	L	H	H	L	L	L	L	M	M	L	L	L	L	H	M	L	L
Seaports	L	L	L	L	L	M	H	H	H	H	M	M	H	M	H	M	L	L	L	L	L	L	L	L	H	H	L	L
Inland waterways	L	L	M	L	L	M	M	M	H	M	H	H	H	M	H	M	L	L	L	L	L	L	H	M	L	L	H	M
Embankments	L	L	L	L	H	M	L	L	H	M	H	H	H	M	M	M	M	M	L	L	L	L	M	M	L	L	H	H
Tunnels	L	L	L	L	M	M	L	L	M	M	M	M	H	M	L	M	L	L	L	L	L	L	L	L	L	L	M	L
Bridges	M	H	M	L	L	M	L	L	H	M	H	M	H	M	M	M	M	L	M	H	L	L	L	L	L	L	M	L
Pipelines	L	L	L	L	L	M	L	L	H	L	H	M	H	M	L	M	L	L	L	L	L	L	L	L	L	L	M	M
Control systems	M	M	L	L	L	M	M	M	H	M	H	M	M	M	L	M	L	L	L	M	M	M	L	L	L	L	L	L
SatNav	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	L	L	L	L	L	L
Oil Distribution	L	L	L	L	M	L	H	M	H	M	M	M	H	M	L	L	M	M	L	L	L	L	L	L	L	L	L	L
Gas Distribution	L	L	L	L	M	L	H	M	H	M	M	M	H	M	L	L	M	M	L	L	L	L	L	L	L	L	L	L
Electric car recharge network	L	L	L	L	L	L	L	L	M	M	H	M	H	H	M	M	M	L	L	L	H	M	L	L	L	L	L	L
CO_2 transport	M	M	L	L	M	M	L	L	M	M	M	M	H	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Likely Infrastructure Damage and Probability of a climate change-related impact are each scored as High Medium Low

Cross cutting points:

- The impact from repeated or cumulative events will be different from that of a one-off event.
- Consistent adverse conditions will support mitigating investment but sporadic events, even if more extreme, will not.
- Impact from climate change is different in different geographic areas.
- Different types of infrastructure have different intrinsic resilience e.g. diversion around a damaged road is far easier than around a damaged airport.
- Climate change might lead to changes in vegetation which in turn might impact on infrastructure, while seasonal demand on infrastructure might add to stress.
- Climate change might lead to changes in land use which in turn might require infrastructure changes.

(2) TRANSPORT INTERDEPENDENCIES RELATIVE TO TELECOMS, WATER & ENERGY INFRASTRUCTURE

	Telecoms				Water								Energy					
	Landline		Wireless		Drinking		Sewerage		Surface		Rivers		Electricity		Gas		Oil	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Roads	H	M	L	L	L	L	M	M	H	H	H	H	M	M	L	M	L	M
Pedestrian routes	L	L	L	L	L	L	H	L	H	M	L	L	L	L	L	L	L	L
Cycling paths	L	L	L	L	L	L	H	L	H	M	L	L	L	L	L	L	L	L
Surface rail	L	L	L	L	L	L	L	L	H	M	H	M	H	H	L	M	L	M
U/G rail	H	M	M	L	L	L	M	L	M	M	M	M	H	H	L	M	L	M
Airport	H	M	H	M	M	M	H	L	M	M	H	M	H	H	L	M	H	H
Air ways	L	L	H	H	L	L	L	L	L	L	L	L	L	L	L	L	H	H
Terminals	M	M	M	M	H	M	H	L	M	M	M	M	H	M	L	M	L	M
Coastal infrastructure	H	M	H	M	M	M	M	M	M	L	L	L	H	L	L	L	L	L
Seaports	L	L	L	M	H	L	H	M	M	M	H	M	M	M	L	M	L	M
Inland waterways	L	L	L	M	L	L	L	L	H	M	H	M	L	M	L	M	L	M
Embankments	L	L	L	L	L	L	M	M	H	M	H	M	L	L	L	L	L	L
Tunnels	L	L	L	M	L	L	L	L	M	M	H	M	H	M	L	M	L	M
Bridges	L	L	L	L	L	L	L	L	L	L	H	M	L	M	L	M	L	M
Pipelines	H	L	H	L	L	L	L	L	M	M	L	M	H	M	L	M	L	M
Control systems	H	M	H	M	L	L	L	L	M	M	M	M	H	M	H	H	L	M
SatNav	M	M	H	H	L	L	L	L	L	L	L	L	H	L	L	L	L	L
Oil Distribution	M	M	H	L	L	L	L	L	H	M	L	L	H	M	L	L	L	L
Gas Distribution	M	M	H	L	L	L	L	L	H	M	L	L	H	M	L	L	L	L
Electric car recharge network	H	H	H	H	L	L	L	L	M	M	L	L	H	M	L	L	L	L
CO_2 transport	M	M	M	M	L	L	L	L	H	M	L	L	H	M	L	L	L	L

NOTES

- If oil distribution networks are damaged transport is severely impacted but the infrastructure remains intact.
- There are interdependencies within interdependencies e.g. loss of gas supplies leads to a high impact on the electricity infrastructure.
- Surface transport will be more electricity dependent and so more vulnerable in future years than now.

Likely Infrastructure Damage and Probability of an impact are each scored as High, Medium, Low.

6.3 Communications sector report

Summary

This report outlines the discussion and findings from a workshop on the adaptation of the UK's communications infrastructure to the projected changes in climate (set out in UKCP09). The workshop was one of a series on infrastructure sectors arranged by *Engineering the Future*, an alliance of engineering institutions, the Royal Academy of Engineering, Engineering UK, the Engineering Council and the Institute of Physics. The workshop was led by the Institution of Engineering and Technology.

The ICT sector by its very nature represents a rapidly changing environment influenced heavily by developments and technologies across the globe. Typical lifetime of equipment including the development phase can be from as little as 18 months through to several decades for infrastructure items such as satellite, submarine systems and long haul wireline. Consequently the impact and dependency profiles of the infrastructure supporting the sector can be markedly different from the traditional sectors such as energy, water and transport.

In order to assist in the analytical process an attempt was made to break down the likely scenarios caused by slow and fast moving effects.

It is still not widely appreciated by many just how reliant we are on the ICT infrastructure, the services it provides or carries and the impact of failure has on both every day lives and society as we know it. Underlying this infrastructure lies the absolute dependency on energy in the form of electricity. Some parts of the infrastructure deemed critical is supplied by standby power should the need arise, but in many cases in the private sector it is not apparent what arrangements exist and what sorts of autonomy time can be relied upon. Even with critical infrastructure up and running, normal every day life for the public is heavily reliant on local communications systems functioning, many of which will not work in the event of power failure, or in the case on mobile base stations may only have an autonomy time of a few hours.

As one may expect the impact on the ICT infrastructure is thought to be low as a consequence of climate change. What is highlighted however is the indirect high dependence on many other aspects such as supply chain, transport, trained workforce and physical access to the infrastructure for maintenance.

Another underlying issue is that many systems are engineered only to meet a particular service delivery model. It is not clear at present who would fund appropriate levels of infrastructure resilience should there be a requirement to guarantee service availability for any scenario.

A table has been constructed at the end of the document to summarise dependencies and envisaged probability of impact as a result of climatic change. In some instances further research is required to address additional levels of detail – these are marked as U - Unknown.

Introduction

This document reports the discussion and findings of the ICT Infrastructure Adaptation to Climate Change Workshop held at the IET on 6th July 2010. The event was chaired by Prof. Will Stewart.

The workshop process was organised around the five key questions raised in the briefing document:

1. What are the issues/technical and operational impacts from climate change (focusing on the medium-term [to 2030] and long-term [to 2100] impacts) on the sector?
2. What are the potential adaptation options to address these issues/impacts? This should include consideration of engineering/design standards – do they need to change and if so why and how? For example should we allow regulators to operate beyond pure economic regulation; or incentivise cooperation between regulators? Or encourage investments outside the core business that are vital to improve resilience. Allow more resilient premium services?
3. What are the potential barriers to implementing these options (including consideration of the wider context within which engineering operates)?
4. What are the opportunities (e.g. skills, economic, innovation) from adapting our infrastructure, in particular to the engineering profession and engineering organisations? Whether opportunities could be brought out more, i.e. the potential for the ICT sector to provide technology to help the country/industry adapt.
5. What interdependencies does the sector have with the other three sectors and will climate change impacts exacerbate these. What about potential cascades of failure across the national infrastructure?

The work shop commenced with a brainstorming session around the primary concerns and issues before considering options and choices.

Issues and operational challenges arising from climate change

Following a brief presentation on the climate change implications for telephony, a round-table discussion identified and considered a variety of issues.

Fast acting, direct issues

Fast acting direct issues such as extreme weather events (storms, rainfall, floods) may have an impact on one or more of the 6000+ local telephone exchanges and myriad overhead cables and antennae. A particular concern is the effect of storm force winds on telephone poles (already an issue in exposed areas) and it was suggested that there may be an increasing vulnerability as the frequency of historically 1 in 150 year events increases. Wind loading on satellite earth stations was also considered a risk area together with the possible impact of ice storms. Flooding may impact on the ability to sustain broadcasting due to loss of energy supply, and mobile networks are similarly vulnerable having only 1 hour battery back up. The effects of precipitation on transmission capability and mobile backhaul could lead to an increase in service outages.

The resilience of non-BT exchanges, data-centres and other key installations was not fully understood and these are subject to the same risks. BT Exchanges are protected against power outages having both emergency generators and batteries – and have fire, flood and gas detectors in addition to lightning conductors. Such protection is regarded as a necessity for commercial reasons, and it is likely (although not certain) that other ICT operators have similar protection in place.

Although beyond human control and arguably beyond the scope of this workshop, solar storms and other sources of extreme radiation have a potential impact on satellite communications, including those for GPS – a system which is increasingly relied upon in both the transport and other sectors. It was recognised that protection and shielding of such devices would have a substantial lifetime cost.

Finally, there is an inter-dependence of ICT on and with other elements of the infrastructure, and weather events directly affecting these other elements may have consequences for ICT.

Slow acting direct issues

There were a number of potential effects of climate change that may have longer term, less immediate impacts on the ICT infrastructure. These particularly include effects on cables, transmission devices and transmission capability.

There could be ground heave effects, particularly on buried cables and ducting although this could also affect buildings and towers, and there may be impacts from rising or falling ground water and/or rising sea levels in particular geographic locations. Similarly, changes in wind speed or direction could have implications for both the launching and stability of high altitude communications platforms. Mobile wireless communications could be disrupted by changes in vegetation levels and density and by changes in building design, for example the use of silvered windows.

In terms of building design, there may be a modest amelioration from the use of 'free air cooling' (as is used in parts of the Middle East) and through building density. BT exchanges are already designed to utilise free air cooling and are able to function at 30°C, although the precise upper limit of functioning is not known.

Large buildings generally are considered to have unknown resilience. There is no single view of their operations and the inflow/outflow of data and whilst each individual business within a multi-occupied building may have taken a view on its own business continuity arrangements, it is unlikely that a view has been taken of the whole building and its interdependencies. Such a view should be useful both to the organisations themselves and to the 'first-responder' community.

Humidity was seen as a particular challenge, increasing tropospheric scintillation and interference. It is recognised that this effect can be modelled and there is a need to determine whether the effect can be mitigated.

It may also be the case that some organisations may be providing services of a critical nature to maintenance of community and that their vulnerabilities and importance are not understood.

Whilst outside the scope of human control the impact of solar storms on radio based communications was considered important.

A stronger concern was the recognition that as the availability and reliability of telecommunications equipment increases, the skills available to manage, support and repair them are in decline. The working environment for engineers may become increasingly difficult as extreme weather events are also likely to be the cause of increasing numbers of call outs, i.e. the reliability of the systems is such that at the few times an engineer is needed it may not be possible to reach the fault location and/or the working conditions may be hazardous or impossible.

Interdependencies

The dominant interdependency identified is the absolute reliance of ICT on the continuing availability of electricity. This will become a more complex issue with the development of smart metering and smart power networks within the energy sector, which are reliant on ICT to function adequately.

Mobile and fixed network distribution and exchange points are believed to only have one hour battery back up in the event of main supply power loss.

Extreme rain events, flood and flash flood will have an impact on the capability of antennae to operate, and the forecast from UKCP09 that rain density and size of raindrops will increase may cause attenuation of mobile signals. Changes in flood patterns may have an impact on population locations – although this is a relatively long term effect. Should the population relocate from coastal areas to higher ground there will be a need to relocate or extend the ICT infrastructure in those locations. Forecasts of population growth and location will be important to this issue.

The panel also raised the question of the impact of changes in ocean levels and behaviour on undersea cables, particularly where they emerge onto land.

Overall the panel suggest that loss of power supply is likely to be more of a cause of failure than the ICT networks themselves.

Extreme weather events can hamper communication about the event itself, reducing the ability of the responders to deal with events as they unfold. Resilience and continued operation of the communications networks are then vital to both real-time management and to continued business as usual.

Diversity and Resilience

This as a significant area of concern with the change from copper wire to fibre optic infrastructure and the impact of indirect reliability issues. There may be network instabilities beyond the 'official' critical infrastructure and the commercial imperative for efficiency may drive down the level of diversity in the overall system.

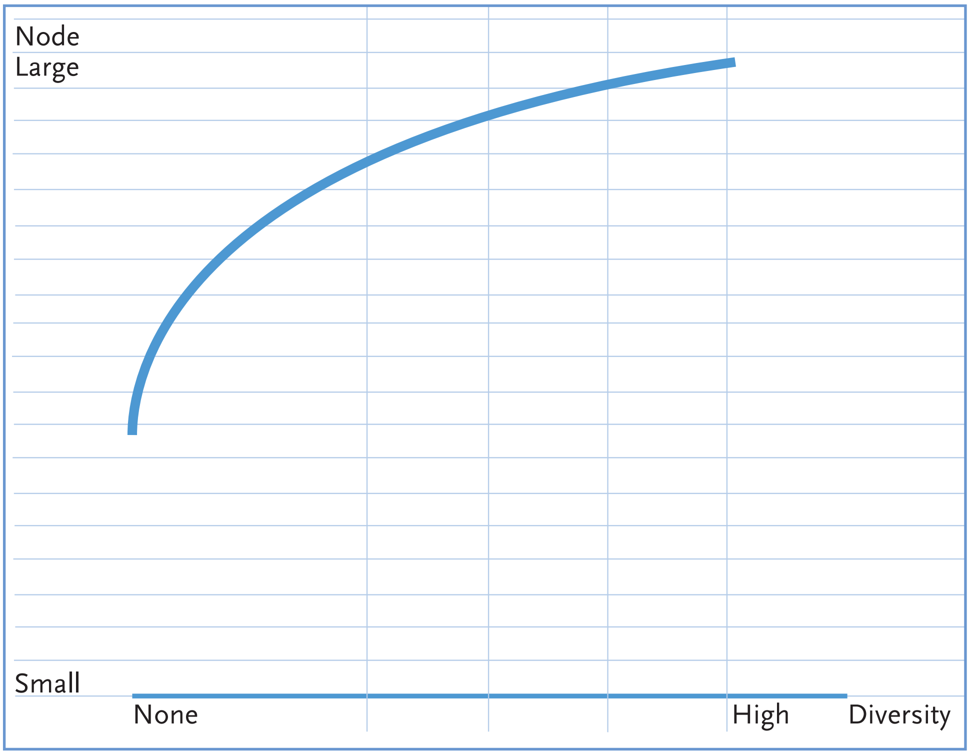
Diversity and resilience may already be declining due to reductions in the number of networks and exchanges and that with fewer major sites there may be more dispersal of signals – rendering them more vulnerable to local outages. Diversity declines the closer one gets to the end user of the system and that the absolute level of diversity may not be well comprehended.

The location of elements of the infrastructure such as shared conduits and drains may also be an issue in this regard. The following graph and table provide an insight to the impact of diversity by failure node.

Services Affected and Impact affected			Number of customers	Fixed Failure Node	Scope for Diversity
Telephone	**Internet**	**Private**			
Congestion	Congestion	Partial	millions	Oceanic Cable	Automatic High
Congestion	Congestion	Partial	millions	Satellite Link	Automatic High
Congestion	Congestion	Partial	millions	International Exchange	Automatic High
Congestion	Congestion	Partial	millions	Trunk Transmission	Automatic High
Congestion	Congestion	Partial	400k	Trunk Exchange	Automatic High
Total	Total	Partial	40k	Large Exchange	Automatic Medium
Total	Total	Partial	10k	Medium Exchange	Manual Low
Total	Total	Total	2k	Small Exchange	None
Total	Total	Total	600	Street Cabinet	None
Total	Total	Total	100	Access Cables	None
Total	Total	Total	1	Single Feed	None

Key to impact consequences:

Congestion	Reduced availability, degraded quality of service, slow internet response times
Partial	Loss of private services some of which will be mitigated by contractual diversity
Total	Complete loss of all services



Illustrative Graph of Scope for Diversity by Failure Node

Globalisation

The panel briefly considered the resilience of the whole world infrastructure. Little specific was recorded, but it was noted that whilst global networks create the capacity for dynamic re-routing of telecommunications this may well not deliver benefits at the local level.

It is certainly the case that this aspect needs to be more fully understood and the benefits, risks, opportunities and drawbacks of the global architecture must be addressed.

The Nation and the Suppliers

With an essentially privately owned ICT infrastructure the panel recognised that the resilience of the system is predominantly driven by the commercial imperative to maintain service – only an operating system generates revenue.

To achieve a level of infrastructure resilience which goes beyond the commercial service level agreements imparts a cost to the provider which will not be recoverable from the consumer. The question of 'who pays for non-commercial resilience' then becomes prime. It will be necessary to provide hard, quantified evidence of the commercial implications of climate change in order to engage corporate boards and gain their buy in to the solution.

The commercial model also tends towards a reactive rather than proactive stance – providers wait for a problem or challenge to emerge before addressing it. However, many organisations and consumers are increasingly aware of the need for contingency planning to meet exceptional events.

Trends in the next 100 years

It was recognised that this aspect cannot be dealt with as an exact science, however, a number of themes were considered likely.

There is likely to be increasing use of wireless transmission, coupled to the replacement of copper wire with fibre optic cables where physical infrastructure is required. This may facilitate smaller cells and a more decentralised system. Overall though the system is likely to become more complex and more comprehensively networked – and become increasingly hard to diagnose and repair in the event of local failure – although dynamic rerouting may compensate for this at some level.

Physical resources such as rare earth metals, which are essential components in much ICT equipment, are expected become increasingly scarce, which may constrain the development and deployment of solutions.

If there is a trend towards increased homeworking then the dependency on ICT will shift from corporate systems to domestic systems and local supply. Whilst potentially having high resilience (no single points of failure at a network level), continuous individual connectivity will be a prime concern. Homeworking may also increase load on local infrastructure (exchanges, distribution boxes, wireless cells) which may need to have increased capacity and resilience – and may even need systems of prioritisation for corporate over personal data and voice traffic.

Adaptation options to meet issues and challenges

Nothing in the range of climate conditions anticipated in UKCP09 falls outside the range of conditions already existing in other countries around the world, where existing equipment is known to function normally. From a technical perspective both network and end-user devices can be expected to cope with expected changes although it may be necessary to adopt some learning from those other locations in relation to network resilience. It is also notable that the 'refresh' rate of end-user devices and network elements is faster than the rate of climate change. It is reasonable to expect that from this perspective the ICT systems should remain functional and adapt at the rate necessary.

However, looking more broadly at the ICT 'system' a number of questions arose. The first was concerned with the role of the regulator. The panel questioned whether the regulator should be allowed to move beyond the current economic role to consider other aspects of the industry, in particular whether there should be some encouragement for the regulators of different elements of the infrastructure to co-operate/collaborate on questions of resilience. The panel also raised the question of how to encourage investment by the suppliers in network infrastructure artefacts that are purely focused on improving resilience.

It was asked whether the system resilience was properly understood and how diversity in the system was being measured and managed – particularly where there is shared infrastructure (masts and conduits). It was recognised that reliance on the ICT networks for 60 60 24 7 cover is increasing (eftpos, business critical on-line applications and so on) and the sustainability of the system against this requirement was questioned.

The panel also looked at the supply chain and recognised that whilst large volume users and critical infrastructure users can be expected to have robust multi-supplier arrangements in place, this is unlikely to apply to SMEs or individuals – who form the greater part of the total economy.

Further information and reporting is required of the reliability of systems, the need for prioritisation and changes in the human interaction with the systems – how and when they are used and for what purpose. In particular, the gap between rainfall forecasts and the prediction of impact on specific elements of infrastructure and systems should be investigated. ICT operators would benefit from an early warning system to highlight the potential of live, catastrophic weather events. No suggestion was made as to how this might be done – or who might do it.

Barriers to implementing adaptation options

The principal barriers identified to delivering adaptation are commercial and legislative although there are technical aspects.

Dealing first with the technical, the question was raised as to the challenge of small antennae and the cumulative impact of additional points. This led to consideration of the planning challenges arising if more, smaller cells are to be constructed – these challenges also extending to the cost/value proposition for the host organisations. This is especially an issue in relation to multi-use as business rates are calculated on aspects of diversity issues.

The question was also raised as to the calculation of 'public value' and the possible need for regulatory change in this regard. A particular concern in this area is the potential frequency of adverse events and the national impact thereof. Whilst it is entirely possible to build a completely robust 'gold-plated' network, the cost to value ratio of such a system is hard to compute – and would probably be impossible to justify commercially.

Interdependencies

ICT has strong interdependency with the other sectors being considered in this programme (energy, water, transport). The issues raised were diverse.

The emergent trend towards 'cloud computing' – a technology which supports homeworking, tele-commuting and all forms of 'work at a distance' increases data traffic volumes and relies on the continued operation of the ICT networks while, potentially, reducing reliance on the transport sector. The net effect on carbon emissions of this change has not been quantified within this work.

In addition, the proportion of economic value (contribution to GDP?) which is reliant on the ICT networks is increasing continually rendering the sector more important over time – and with as yet not fully quantified effects on population distribution and energy or water consumption in the home.

There are challenges around broadcast spectrum availability and potentially a need to use higher frequencies – which carries new technical challenges.

Opportunities arising from climate change

The ICT networks provide a great opportunity for the provision of information in relation to climate change. It can provide networks of sensors and other data points to provide information in respect of weather events (precipitation, sunshine, wind speed, humidity etc), and could integrate and assemble such data in relation to both built and natural environments. This could supplement work already undertaken by OFCom in relation to the reliability of the ICT system itself.

The opportunity also exists to share elements of groundworks with other infrastructure providers. For example, running telecoms conduits inside water pipes could have significant benefits in terms of groundworks costs and may enable increased resilience of the water pipe itself (through cost sharing) – but would have the downside of rendering both elements at risk to the same event (such as ground heave or penetration by digging equipment).

The changing climate in the UK may make it a more attractive (and lower risk) location for operations and business currently operating in other, increasingly vulnerable, locations.

The panel recognised the opportunity to raise awareness of interdependency at Corporate Board level and to promote inter-disciplinary thinking at lower levels in organisations – particularly focusing on raising awareness amongst younger engineers.

It was also thought important to track the impact of social changes on the networks and to understand how distribution of demand is shifting.

In parallel – and recognising again the absolute reliance on electricity for the continued functioning of the ICT networks, the panel recognised the need to focus on the 'energy per bit' measure as a device for driving up performance.

Appendix 1 Summary of Interdependencies

	Telephone exchanges		Telephone poles		Satellite earth		Mobile base stations		Data centres stations		Satellites-comms		Satellites-gps		Buried cables comms		Ducts		Terrestrial microwave comms		Submarine comms		Private infrastructure		Core network	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Road access	H	L	H		H	L	H	L	H	L	H	L	L	L	L	L	H	L	H	L	H	L	H	L	H	
Electricity	H	L			H	U	H	H	H	M	H	U							H	L	H	U	H	L	H	
Road/off road access	L	L	H	L	L		L	L	L	L	L	L			L	L	L	L	H	L						
Fuel - Diesel/gas	U	L	L	L	U	L	L	U	H	L	U	U			L	L	L	L	U	U	M	M	M	L	U	U
Launch Facility	L	L	L	L	L	L	L	L	L	L	H	L	H	L											H	L
Duct ownership	H	L															H	L			H	L	M		H	L
Cable ownership	H	L	H	L											H	L					H		M			
Supply chain	H		H		H		H		H		H		H		L		L		H		H		H		H	
Rare metals	H		L		H		H		H		H		H		L		L		H		H		H		H	
Configuration management	H		L		M		H		H		M		M		M		M		M		H		H		H	
Trained workforce	H		M		H		H		H		H		H		L		L		M		H		H		H	
Physical access	H		H		H		H		H		H		H		H		H		H		H		H		H	
Line of sight							M				M		M						M							
Data traffic management	H		L		L		H		H		H		L						M		H		M		H	
Bridges/road wayleave	H		M				H		H						H		H						H		H	

Appendix 2 Climate change potentially impacting ICT infrastructure

ICT INFRASTRUCTURE AFFECTED	High temp		Low temp		Water table rise		Sea level rise		Storm surge		Prolonged rainfall		Flood		Drought		Snow		Extreme wind		Electric storm		Frost		Fog		Soil shrinkage	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Telephone exchanges	L	L	L	L	H	U	L	L	L	L	L	L	H	U	L	L	L	L	L	L	H	L	L	L	L	L	L	L
Telephone poles	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	M	H	M	H	L	M	M	L	L	L	L
Satellite earth stations	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	M	H	M	M	L	L	L	L	L	L	L
Mobile base stations	M	L	L	L	U	L	L	L	L	L	L	L	L	L	L	L	M	M	M	L	M	L	L	L	L	L	L	L
Data centres	M	M	L	L	H	U	U	U	U	U	U	U	H	U	L	L	L	L	L	L	M	L	L	L	L	L	L	L
Satellite-comms	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Satellite-gps	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	U	L	L	L	L	L	L	L
Buried cables	L	L	L	L	U	U	L	L	L	L	L	L	U	U	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Ducts	L	L	L	L	U	U	L	L	L	L	L	L	U	U	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Terrestrial RF comms	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	L	M	L	U	U	L	L	L	L	L	L
Submarine comms	L	L	L	L	L	L	U	U	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Private infrastructure	U	L	L	L	U	U	U	L	L	L	L	L	M	L	L	L	L	L	L	U	U	L	L	L	L	L	L	L
Core network	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

D – equates to damage, Low, Medium, High
P – equates to probability, Low, Medium, High
U – equate to unknown

6.4 Water sector report

ENGINEERING, INFRASTRUCTURE & CLIMATE CHANGE ADAPTATION STUDY

Report of the Water Sector Workshop July 2010

Summary

This report outlines the discussion and findings from a workshop on the adaptation of the UK's energy infrastructure to the projected changes in climate (set out in UKCP09). The workshop was one of a series on infrastructure sectors arranged by *Engineering the Future*, an alliance of engineering institutions, the Royal Academy of Engineering, Engineering UK, the Engineering Council and the Institute of Physics. The workshop was led by the Institution of Civil Engineers.

The UK's water infrastructure is very varied. It comprises water used or managed for societal benefit, including lakes, reservoirs, rivers and other waterways, aquifers, and estuary and coastal waters, and all assets built and operated to effect society's use of water.

Climate change presents a long-term problem to which both new and existing infrastructure must adapt. Additionally, there are two other major trends that it must adapt to:

- demographic changes (especially population growth); and
- additional environmental quality regulations (such as the Water Framework Directive and the new Bathing Water Directive).

Impacts and operational challenges arising from climate change

The workshop was informed by three scenarios from the 2009 UK Climate Projections (UKCP09), and by consideration of their impacts in the 2020s, 2050s, and 2080s. This allowed the sensitivity of water infrastructure to be examined.

It is anticipated that seasonal and extreme waves will increase in parts of the UK, and the sea's salinity will fall while temperature increases. Rainfall will increase in some areas, decrease in others, and occurrences of heavy downpours are expected to increase. Prior work by the government suggests that water infrastructure is, in general:

- not vulnerable to predicted changes in wind;
- slightly vulnerable to changes in storms;
- quite vulnerable to changes in temperature, and;
- very vulnerable to changes in precipitation.

Impacts as a result of climate change include increased incidences of both flood and drought, water pollution and the need for more water storage.

Adaptation options to meet issues and challenges

The conditions created by climate change are similar to those currently found elsewhere in the world. The technology, skills and knowledge to adapt to these changes are often transferable.

Furthermore, adaptation to climate change may not always need large-scale structural developments. In many cases, an interdisciplinary systems perspective – in which engineers work alongside economists and social scientists – may provide more cost-effective solutions. This may require a rethinking of engineering education content and training, however, both at university level and – importantly – in continuing professional development.

As well as educating engineers, there is a need to engage with policy makers, regulators and the public; engineers as well as other professionals should have a major role in this engagement.

Demand may be reduced through economic incentives such as pricing, as well as educating users to change their behaviour, although the very low cost of water (as low as £300 per year per household) mitigates against any price elasticity. Statute through water efficiency byelaws would be much more effective. More water-efficient domestic fittings and appliances should be required by regulation. Smart meters and "intelligent pipework" could also be used to support both economic and behavioural incentives and, at time of extreme shortage, may be used restrict access to limited water resources as well as reduce leakage.

Engineers have frequently used assumptions based on (for example) extrapolation from historic data – but the changes to climate are likely result in non-linear or step-change consequences (both at input and consequence stages), with wider variation and less certainty. The profession thus needs to cope with greater uncertainty, for which the appropriate response may be more probabilistic, imaginative and less deterministic.

Barriers to implementing adaptation options

Climate change adaptations face a variety of barriers to implementation. The key issues are both technological and behavioural, requiring engineering and socio-economic analysis and solutions. Finance is likely to be a central issue: upgrading infrastructure to meet revised standards, particularly in urban environments, is likely to be costly.

Regulation of the water industry can be a barrier to as well as a driver for change. Particular ways of working can become fixed within an industry's operating processes to meet regulations, making flexibility and change difficult. The regulatory environment is further complicated by having responsibilities split across several different government departments (e.g. Defra, DECC, BIS) and regulatory authorities (e.g. EA, DWI, Ofwat).

Society needs to decide what it is willing to pay to meet its expectations, or decide that lower standards (for instance, an interruption to delivery) may be acceptable at a lower price. This will require a programme of sustained and extensive education and engagement with the public and policy makers.

Interdependencies

The following inward dependencies were identified:

- energy: water infrastructure is dependent on electricity to power its facilities, particularly pumping and water treatment, and its information and communications technology (ICT) systems;
- ICT: water infrastructure is dependent on ICT to control geographically distributed assets, run its centralised IT systems and for communication;
- transport: the infrastructure is dependent on road and rail transport for personnel and supplies.

There is an internal dependency on the water infrastructure, in that much of the infrastructure is susceptible to flooding, particularly for treatment works and waste water removal.

Water has significant impacts on other infrastructure:

- energy is dependent on water for cooling power generating and oil and gas processing plant; energy transmission infrastructure and plant is highly susceptible to flood damage;
- ICT cables are susceptible to flood damage;
- transport systems are also susceptible to flood damage.

Taking a wider view, any system or process dependent on human intervention is reliant on water for hygiene and drinking.

Opportunities arising from climate change

There are considerable opportunities to be gained from adaptation of water infrastructure to climate change.

Examples of opportunities include the possible expansion of the use of water as a renewable energy resource, particularly within a localised, distributed infrastructure for water storage. Similarly, "energy from waste" schemes could form part of a distributed waste treatment system. It may be possible to expand the development of conventional hydro, wave and tidal energy production as a result of climate change.

In addition to the UK learning from other countries, there is the opportunity to export the UK's learning and expertise as it develops, helping other nations adapt to their climate change issues.

Unsolved problems

The workshop suggested a number of radical ideas that need to be evaluated and piloted. Further work by an expert group is needed. However, the status quo (or more of the same) will not be effective.

Adaptation requires engineering and social solutions. It seems likely that distributed and local systems will become more important for resilience, and that conservation and demand management will also be required.

The great Victorian engineers complemented outstanding engineering vision with a full understanding of the market for their "solutions"; the social and behavioural drivers therefore ultimately supported their asset development models.

Introduction

Background

This paper is a report of the Water Infrastructure Adaptation to Climate Change Workshop held at the Institution of Civil Engineers on 12th July 2010. The workshop was chaired by David Nickols.

The workshop was organised around five key questions and was introduced by a discussion paper:

1. What are the issues/technical and operational impacts from climate change (focusing on medium and long-term impacts)?
2. What are the potential adaptation options to address these issues/impacts?
3. What are the potential barriers to implementing these options?
4. What interdependencies does the sector have with other sectors and will climate change exacerbate these?
5. What are the opportunities from adapting our infrastructure?

The workshop commenced with a brainstorming session around the primary concerns and issues before considering options and choices in response to assumed consequences of climate change.

Water Infrastructure Definition

For the purposes of the workshop, UK water infrastructure comprises water in the environment that is used or managed for societal benefit, including lakes, reservoirs, rivers and other waterways, aquifers, and estuary and coastal waters, and all assets built and operated to effect society's use of water.

UK water infrastructure includes:

- land drainage systems;
- pluvial drainage and surface water management systems;
- fluvial and coastal flood management and protection systems;
- inland waterway, port and harbour water assets;
- all infrastructure owned and operated by the regulated water industry;
- agriculture, food production and food processing;
- private reservoirs and other water assets.

The impacts of climate change present a long-term problem and both our new and existing infrastructure will need to adapt:

- existing water infrastructure in the UK has been engineered and built for our past or current climate and may not be resilient to climate change;
- new water infrastructure, often having a life-time of 40-100 years (or more), needs to be resilient to long-term climate change.

Workshop discussion on water infrastructure definition

The infrastructure involved with water serves several different functions with a prime focus on public health, reflecting the water cycle, and includes natural and man-made waterways, and flood and coast protection as well as the infrastructure required for the storage and delivery of water to domestic, agricultural, industrial and other commercial consumers and the removal, treatment and recycling of waste water.

The nature of the infrastructure is therefore very varied, depending on its function. The adaptation in response to climate change is a product of the effect of climate change on the current infrastructure rather than the infrastructure per se. In addition, much of the infrastructure has other functions, such as environmental and recreational.

Potable water and sewerage and sewage treatment assets are essential for the continued health of the population, one of the drivers which led to the development in the 19th century of much of the infrastructure still in use today. This is assumed to meet an ongoing need for the security of society which will continue in the foreseeable future.

In addition, management of water courses, the abstraction of water from the environment, and the return of waste water to the environment, present major environmental responsibilities which need to be met in part through the industry's infrastructure. Flooding (river and paved surface) can be especially unpleasant when combined with sewer-derived flows.

Whilst the plumbing within buildings might be seen as outside the scope of water infrastructure, some of the engineering adaptations (e.g. conservation) to climate change necessarily involve customer-side interventions which are deemed in scope.

Issues other than climate change that need to be considered

In addition to climate change, there are two other major trends that water infrastructure must adapt to: demographic changes, especially population growth, and additional environmental quality regulations, such as the Water Framework Directive and the new Bathing Water Directive.

Population growth

The UK population of 61.8 million in 2008 is forecast to grow to 69 million in the 2020s, 79 million in the 2050s, and 85-90 million in the 2080s[7]. Without reductions in demand from today's average of 150 l/d/person, water demands will rise significantly. Water demands are also increasing due to the increase in single-person households.

Additional environmental quality regulations

Additional regulations such as those resulting from the Water Framework Directive and the new Bathing Water Directive can be expected to lead to several impacts on the UK's water infrastructure:

- restrictions on some water abstraction licenses from rivers and aquifers;
- a need for higher levels of wastewater treatment or reduced discharges;
- a need to increase dry weather flows in some rivers by increasing reservoir discharges.

In the longer term there may be additional requirements due to further implementation of the Water Framework Directive, Drinking Water Directive and Urban Waste Water Directive.

Adaptation measures in the Water Industry also need to be implemented in compliance with the requirements of the Climate Change Act 2008, which requires reductions in carbon emissions from 1990 levels (26% by 2020, and 80% by 2050)[8]. However, due to investments made to comply with environmental quality regulations, the UK's regulated water industry has already increased its emissions dramatically compared to 1990 levels and will further increase its emissions over the 5-year AMP5 regulatory period (2010-2015).

Workshop discussion on these other issues

Whilst the climate is changing, the water sector will simultaneously face impacts from changing demographics. The population is forecast to grow substantially in the 21st century while simultaneously the number of occupants in each house is forecast to reduce, so the water infrastructure will also need to meet these challenges. Demand is therefore likely to increase whilst supply decreases, and there may be an increased separation from the geographic location of demand from areas of supply. Alternatively, greater local recycling could/should reduce the centralised level of supply from remote sources.

Issues and operational challenges arising from climate change

Climate changes that may affect water infrastructure

Climate change was considered for the 2020s[9], the 2050s, and the 2080s. The workshop discussions were informed by three scenarios from the 2009 UK Climate Projections (UKCP09)[10], allowing the sensitivity of water infrastructure to be examined:

- Scenario A: Low emissions/10% probability
- Scenario B: Medium emissions/50% probability
- Scenario C: High emissions/90% probability.

Outputs from UKCP09 (UK-wide unless noted otherwise)

Parameter	Scenario A	Scenario B	Scenario C
Winter mean temperature	+0.2 to +2.0°C	+1.1 to +3.0°C	+1.7 to +5.7°C
Summer mean temperature	+0.5 to +1.4°C	+1.2 to +3.9°C	+2.1 to +8.1°C
Summer daily max. temp. (South East)	+2.2°C	+3.7°C	+6.7°C
No. of very hot days (>28°C) (London)		13 times more	
Annual mean precipitation (South West)	+1%	+0%	+1%
Winter mean precipitation	-5 to +6%	+4 to +23%	+8 to +73%
Summer mean precipitation	-29 to -46%	-9 to -28%	+22 to -2%
No. of days with heavy rain (>25mm)		<3.5 times more	
Mean sea level	+4.3 to +30.5cm	+5.7 to +36.3cm	+7.5 to +43.3cm

Note: The ranges shown reflect regional variations and variations from the 2020s to the 2080s

Individual projections are available for the 16 UK administrative regions.

Future projected trends in storm surge height are small everywhere around the UK, and in many places can be accounted for by natural variability. Consequently, changes in extreme sea level by 2100 will likely be dominated by increases in local mean sea level.

Seasonal mean and extreme waves are generally projected to increase to the South West of the UK, reduce to the north of the UK and experience little change in the southern North Sea. Changes in the annual maxima are typically in the range –1.5 to +1 m.

The shelf seas around the UK are projected to be 1.5 to 4°C warmer and ~0.2 practical salinity units fresher (lower salinity) by the end of the 21st century. The strength and period of summer stratification is projected to increase in the future.

Likely climate change impacts on water infrastructure

Prior work by the government suggests that water infrastructure is in general not vulnerable to predicted changes in wind, slightly vulnerable to changes in storms, quite vulnerable to changes in temperature and very vulnerable to changes in precipitation. Suggested impacts include:

- increased number of flooding incidents (pluvial – sewer and urban – and fluvial as well as water infrastructure facilities themselves) and combined sewer overflows caused by a greater frequency and intensity of rainfall;
- changes in raw water quality variations due to changes in precipitation;
- increased water pollution incidents due to increased pluvial flooding;
- failure of or damage to flood defence structures along estuaries and coastal areas due to increased sea levels, especially when high tides and storm surges combine;
- saline intrusion of coastal aquifers and into coastal area sewers due to sea level increase;
- increased number of droughts especially during the summer months due to higher temperatures and reduced rainfall;
- need for increased water storage due to shorter, higher intensity precipitation events;
- higher mean water temperatures affecting biological treatment processes and water quality in surface waters (e.g. rivers, lakes/reservoirs) and coastal waters, and drinking water quality in water distribution networks;
- reduced summer river flows and aquifer recharge restricting abstractions and wastewater discharges to rivers;
- increased sewer network sedimentation due to lower flows during dry summer periods;
- increased evaporation due to higher temperatures, reducing available yields in lakes/reservoirs and rivers;

- moisture reduction in soils due to drier and hotter summers (causing damage to buried pipe networks, foundation problems at treatment works and other facilities [especially dams], and subsidence and damage to flood defence structures and embankments);
- changes in diurnal demand patterns (and potentially increased peak demands) due to higher summer temperatures;
- increased water demands for irrigation in hotter, drier summers;
- land drainage system modifications to cater for higher river flood levels and sea levels.

Work has been performed for the water industry on climate change impacts by UKWIR (see bibliography).

Impacts and operational challenges

It is anticipated that water infrastructure and its use will be materially affected by climate change.

UK climate projections (UKCP09) predict increased summer temperatures, which are expected to increase evaporation from the soil, rivers and reservoirs. Precipitation is expected to change both in volume (with some areas showing increased and others decreased rainfall) and in the pattern of rainfall (with an increase in very heavy rainfall events and extended, possibly across years, periods of drought expected). There are expected to be rises in sea-level.

These changes may be expected to lead to seasonally reduced supplies from reservoirs and further reduced summer river flows, whilst higher temperatures may lead to higher demand from consumers. Pumped storage schemes such as Carsington Water offer an early environmentally neutral response to variable precipitation by widening the use of winter flow capture before loss to the sea.

Increased periods of very heavy rainfall are likely to stress drainage systems, leading to both an increased likelihood and an increased severity of flooding. Flood events similar to those experienced in England in 2007 are expected with increased frequency. Exceptionally heavy rainfall may see an increase in flash-floods such as effected Keswick and Cockermouth in 2009. Flooding damages the water supply system and waste removal and treatment facilities.

Extended dry periods may lead to the drying of river and canal banks which, coupled with more frequent and violent flood events, could cause changing patterns of erosion and deposition. These in turn may affect the water flow which could be a significant impact on navigable waterways.

Rising sea-level could similarly effect coastal erosion and deposition, which could threaten some habitation as well as affect maritime navigation.

Increased wind, fog and rain impact on water-borne transport. Wind and fog can particularly affect maritime transport, whilst low or high rainfall can impair inland waterways which face specific risks from sudden increases in flow or reduced flow.

Adaptation options to meet issues and challenges

Many conditions created by climate change are similar to those currently found elsewhere in the world. Hence the technology, skills and knowledge to adapt to these changes are transferable with some already readily available. For instance, Australia has been pioneering "water-sensitive cities", Singapore has experience in the re-use and recycling of water, USA has been developing an urban environment for climate change adaptation, the Netherlands has extensive experience in building on land at risk from flooding, and Mediterranean countries such as Greece have experience in managing fluctuating, seasonal water supplies.

However, this is likely to require a changed view from engineers: the adaptations to climate change may not always need large-scale structural developments but instead in many cases require an interdisciplinary systems perspective in which engineers work alongside economists and social scientists, recognising the importance of these disciplines.

Technology does have a great deal to offer, for example with respect to water conservation (in industry, agriculture and the home) and with respect to robust system operation. Multiple solutions are needed. Note that much of our current infrastructure is based on engineering solutions designed for the 19th century, when conditions were different and believed to be stable. The situation facing England in the 21st century is significantly different, and needs a different outlook to find solutions to the issues faced. Future engineering approaches must benefit from high quality, imaginative and rigorous cross-discipline, cross-functional working.

This may require a rethinking of engineering education content and training, both at university level and importantly in continuing professional development. Traditionally, engineers have frequently based their analyses on assumptions of stationarity (for example extrapolating from historic data); the changes to climate are likely result in non-linear or step-change consequences (both at input and consequence stages), with wider variation and less certainty. The adaptations to climate change will therefore need to cope with uncertainty and the engineering response more probabilistic, imaginative and less deterministic.

A different approach to data may also be needed. Lack of data hinders traditional analysis of the problem. Scenario-based approaches, focussing data collection on those areas most at risk, developing projects on the basis of uncertainty rather than certainty, collecting data as the project progresses or incorporating data collection into the design and build phases using a "best robustness" scenario should make projects more flexible to cope with the real unfolding challenges.

As well as educating engineers, there is a need to engage with policy makers, regulators and the public; engineers as well as other professionals should have a major role in this engagement. The public may have expectations regarding the service they receive which will either not be met or will only be able to be met with significantly increased costs. Contributing to a public debate on the nature of services which can be delivered through the infrastructure available, together with government and regulators, should be a central role for wider conceptually-based engineers now and in the future. For instance, some communities may be subject to an increased risk of flooding, and it might not be economical to offer them sufficient flood protection. Deciding who pays to protect communities, and what proportion of scarce available finance should be directed towards them, are issues for society to resolve.

The role of the insurance industry in managing risk will also be central to the debate.

Consumer cultural changes are also required to support a future move from centralised water systems towards centralised systems combined with distributed storage and treatment systems that would result in lower carbon and water footprint infrastructure. It is anticipated that within 20 years (if drinking water quality regulations continue to become more stringent), final treatment polishing of drinking water will likely be at the point of consumption rather than in large treatment works as our pipe networks will be unable to maintain the quality of water required[11]. Local recycling will be used widely for non potable uses. This would enable more economic treatment by treating water to a level fit for its purpose, rather than treating all water until it is potable. Moves to distributed storage could lead to local management of the water cycle and further decentralisation, with the centralised network functioning as a partial supply (if economic, possibly as a "back-up" supply). A parallel is developing in domestic energy provision as network delivery there can be up to 300% more inefficient.

There is an extensive water infrastructure currently in use, a large proportion of it the legacy of earlier generations, including large reservoirs and the urban sewer systems. Whilst these large assets were built for one purpose and are essentially "forever" assets, there may be other functions which they could also serve. For instance, further adapting the sewer systems to store water to alleviate pollution or flooding might be a more effective use of the infrastructure. A creative approach to using the existing infrastructure could yield multiple benefits for society. Note that storing "clean" water in such sewers will be volumetrically immaterial as well as a treatment challenge too far.

Collection and storage systems at a local, community or consumer (agricultural, industrial or residential) level would reduce dependence on water transport systems and make available water directly at the site of consumption. Similarly, greater use of water recycling systems at different scales would improve the effectiveness of water usage, meeting perhaps 20-30% (or even much more) of usage, and reduce reliance on infrastructure.

Developing distributed systems may also enable different benefits at different times or under different conditions. For instance, distributed water storage could be used for hydro power generation, to manage river flows, for agricultural irrigation, for habitat protection and development and for recreation purposes. Realising such multiple benefits may increase the economic value of such schemes and make it more likely to overcome local resistance.

The use of centralised dual water supply to consumers, with one highly treated "potable" water source and another lower grade, is often seen as rational and intellectually attractive as it saves the cost and energy of treating water to a higher standard than needed for its intended use. While such dual supplies can be economic in new developments of sufficient scale, they are economically irrational in developed-world urban areas with existing infrastructure.

The increased seasonal and regional variability in rainfall may also require developing new supplies, through, for instance, new reservoir deployment (e.g. Carsington), additional reservoirs or desalination schemes. The use of localised, quality-matched water supply to consumers would also make available more water resources.

As well as providing for new supplies, adaptation should involve improved demand management. It has been suggested that opportunities exist to reduce water abstracted from the general (remoter) environment by 50-60%. The use of low-flow appliances could reduce domestic demand, and more effective use of water in agricultural and industrial processes would also reduce stresses on the water infrastructure.

Publication of all water use, including the embedded water that consumers use in the products they buy (in the same way that the calculation of an individual's carbon footprint includes all sources of carbon, direct and indirect), should be considered, although it is unlikely to be a significant lever in influence consumers' behaviour.

Demand may be reduced through economic incentives such as pricing, as well as educating users to change their behaviour, although the very low cost of water (as low as £300 per year per household) mitigates against any price elasticity. Statute through water efficiency byelaws would be much more effective. More water-efficient domestic fittings and appliances should be required by regulation[12], Smart meters and "intelligent pipework" could also be used to support both economic and behavioural incentives and, at time of extreme shortage, may be used to restrict access to limited water resources as well as reduce leakage.

Such changes to the water management system would need concurrent changes in consumer expectations as well as regulatory and business processes. This would require extensive engagement with the public. To support this would require strengthening of and changes to government policies.

Much could also be achieved by revising design standards and regulations. For instance, strengthening planning processes to prevent building in areas at high risk of flooding, such as flood plains, would reduce the impact of the increased likelihood of floods. Alternatively, and more pragmatically, incorporating adaptations to make new buildings and their associated infrastructure more resilient to flooding could achieve the same goal.

Adherence to regulations and standards implies a presumption of a particular way of doing things, with designers, engineers and business models locked into one way of working. Adaptation to climate change should also benefit from a fundamental review of the ways in which water infrastructure is conceived and used.

Work has been done on adaptation issues for water infrastructure associated with inland navigation and seaports by members of the European WFD Navigation Task Group (see Appendix).

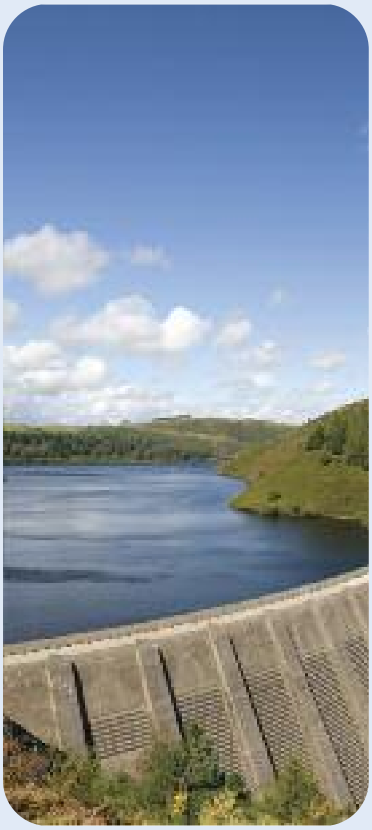
Summary of adaptation options

General

- The range of climate change impacts on the UK will fall within the range of climate experienced elsewhere in the world, so technological solutions and behaviours already exist elsewhere and do not need to be "invented" from scratch.

Potable water

- Conservation/demand reduction is the quickest adaptation (and least cost) and is best achieved by regulation/statute; behavioural change is extremely difficult to achieve without regulation, especially as practical financial incentives are too small to be effective.



- Reservoir design should combine flood alleviation and river regulation functions where practical; retrospective re-engineering and water transfers should be evaluated.
- Future drinking water quality standards will likely need "in property" final polishing treatment. This local treatment can form part of a new distributed supply and treatment model, complemented by local re-use and rainwater collection leading to central supply volume reductions.
- Local re-use/rainwater collection can provide dual supply at very local scale (household or small development only; it is uneconomic at larger scale).
- Local area storage will be needed.

Used water

- Retrospectively in existing areas, and in all new developments, increase the degree of foul/surface water separation – preferably by keeping surface water out of piped networks.
- Separation (and reduced potable usage) will beneficially increase treated sewage quality by increasing sewage strength; in-sewer tanks may need modification.

Flood management

- Increase the use of sustainable urban drainage systems (SUDS), etc. for drainage and make many urban and suburban paved surfaces porous to attenuate flows and reduced used water volumes.
- Increase use of "sacrificial" flood areas along rivers and in built-up areas.
- Enhance flood protection (or relocate if more economic) for water and sewage treatment works and for potable water storage tanks and distribution systems (especially pumping).
- Protect transport (strategic roads, railways, etc.) and key utility supply/generation and distribution systems from flooding.

Barriers to implementing adaptation options

Workshop discussion of barriers

The adaptations to climate change identified face a variety of barriers to implementation.

Finance is likely to be a central issue: upgrading infrastructure to meet revised standards, particularly in the urban environment, is likely to be costly especially where non-potable needs were also unnecessarily met. The economics is further complicated by allocation of the benefits and the costs to different communities and to future generations, though this is less of a problem with distributed storage and treatment facilities more closely situated to users.

There may be particular financial issues with any moves to more distributed (local) water systems. In the past, finance has generally been available for large scale capital expenditure projects but less so for ongoing maintenance. With distributed systems, the upfront capital cost is likely to be less, but there may be higher ongoing maintenance costs. Reconciling this to the current regulated economic model may be difficult – the economic model would need to be revised.

Regulation of the water industry can be a barrier to as well as a driver for change. Particular ways of working can become fixed within an industry's operating processes to meet regulations, making flexibility and change difficult.

It was noted at the workshop that the way the UK approaches its international and national regulations and obligations is, generally, through rigid, strict and transparent application; this is not always believed to be the case for some other EU member countries. An alternate view suggested that regulations are a manifestation of societal expectations. Society needs to decide what it is willing to pay to meet those expectations, or decide that lower standards (for instance, an interruption to delivery) may be acceptable at a lower price[13]. This will require a programme of sustained and extensive engagement with the public and policy makers.

The regulatory environment is further complicated by having responsibilities split across several different government departments (e.g. Defra, DECC, BIS) and regulatory authorities (e.g. EA, DWI, Ofwat). Navigating the different authorities can greatly increase the regulatory complexity. Simplifying or "joining up" the regulatory environment may ease the development of adaptation strategies, allowing for a greater sharing of data across institutions and bodies and improved, co-ordinated activity.

The regulatory regime itself would need to adapt. Regulation evolved during a period of apparently stable conditions to maintain society's health and security. As a result of climate change, conditions are likely to be changing significantly and rapidly in the foreseeable future, and the regulatory regime will not be "fit for purpose". To meet these changing conditions, a more flexible and responsive regulatory regime will be required.

Some regulations can have perverse consequences. For instance, current regulations focus on efficiency of energy use in water treatment by measuring the amount of CO_2 emissions per megalitre of water treated, in order to reduce the amount of CO_2 released. This incentivises water companies to maximise through-put, rather than reducing the level of water used by consumers.

Similarly, Defra has an aspiration to reduce the amount of domestic consumption from 150 litres per person per day to 130 litres. It was felt that by taking a more rigorous approach, far larger reductions could be accomplished: Defra was taking the current usage as its starting point, instead of analysing what could be the ultimate possible reduction, even before any local recycling.

Current regulations promote operating efficiency, which drives the industry towards centralisation, possibly at the cost of infrastructure resilience, flexibility and sustainability. A move to distributed water systems could lead to decreased efficiency but increased resilience and sustainability.

Existing planning processes were also felt to be potential barriers. It was felt that by allowing central government to overrule local decisions, particularly regarding developments in flood plains, and by incentivising local planning authorities on reducing the number of referrals to central government, the planning process is sometimes skewed in favour of projects proceeding in areas subject to high risk of flooding.

With an increased likelihood and increased severity of flooding, as well as increased sea-levels, there needs to be a debate about the role of flood and coastal defences. These may be improved to protect areas subject to potential flooding or storm damage, but they become increasingly expensive to maintain in order to protect the population, to the extent that the defences may not in the future be viable. The costs of defences are not necessarily borne by the communities they protect. There may need to be a public debate into the equity (short and long term) of this policy.

Changing engineering education, training and continuing education in order to meet the adaptation needs also represents a potential barrier - one which may be difficult to overcome quickly.

Summary of barriers to adaptation options

The key issues are both technological and behavioural (or, expressed differently, they require engineering and socio-economic analysis and solutions). Statutory drivers ("sticks") such as byelaw changes/regulation are more effective with consumers than "carrots", especially as the price of water is so low. For privatised regulated utility companies, financial incentives are essential to cause change – innovation and change must create profit.

The "sunk costs" should be recognised and major existing assets valued/utilised (cited as £3,000 per person in the UK vs. £30/person in developing countries). The UK is not starting with a blank sheet of paper.

Potable water

- Conservation/demand reduction is the quickest adaptation (and least cost) and is best achieved by regulation/statute; behavioural change is extremely difficult to achieve without regulation, especially as practical financial incentives are too small to be effective.
- Reservoir design should combine flood alleviation and river regulation functions where practical; retrospective re-engineering and water transfers should be evaluated.
- Future drinking water quality standards will likely need "in property" final polishing treatment.[14] This local treatment can form part of a new distributed supply and treatment model, complemented by local re-use and rainwater collection leading to central supply volume reductions.
- Local re-use/rainwater collection can provide dual supply at very local scale (household or small development only; it is uneconomic at larger scale).
- Local area storage will be needed.

Used water

- Retrospectively in existing areas, and in all new developments, increase the degree of foul/surface water separation – preferably by keeping surface water out of piped networks.
- Separation (and reduced potable usage) will beneficially increase treated sewage quality by increasing sewage strength; in-sewer tanks may need modification.

Flood management

- Increase the use of SUDS (etc.) for drainage and make many urban and suburban paved surfaces porous to attenuate flows and reduced used water volumes.
- Increase use of 'sacrificial' flood areas along rivers and in built-up areas.
- Enhance flood protection (or relocate if more economic) for water and sewage treatment works and for potable water storage tanks and distribution systems (especially pumping).
- Protect transport (strategic roads, railways, etc.) and key utility supply/generation and distribution systems from flooding.

Interdependencies

Energy

- Electricity supply to treatment works, pumping stations and other infrastructure assets.
- Gas supply to some treatment works and pumping stations.
- Renewable energy generated by water utilities.
- Water supplies to power generation plants (for cooling and process use).

ICT

- Communications networks for voice, video and data transmission and for control systems for geographically distributed assets.

Transport

- Deliveries to treatment works and pumping stations (fuel, chemicals, other).
- Transport of operating and maintenance personnel.
- Transport offsite of wastes (e.g. sewage sludge, hazardous chemicals).
- Transport of water quality compliance samples.

There is an internal dependency on the water infrastructure, in that much of the infrastructure is susceptible to flooding, particularly for treatment works and waste water removal.

Water has significant impacts on other infrastructure:

- energy is dependent on water for cooling power generating and oil and gas processing plant; energy transmission infrastructure and plant is highly susceptible to flood damage;
- ICT cables are susceptible to flood damage;
- transport systems are also susceptible to flood damage.

In addition, any system or process dependent on human intervention is reliant on water for hygiene and drinking: without accessible water, such processes will stop.

Similarly, food production and processing is highly dependent on water.

Opportunities arising from climate change

There are considerable opportunities to be gained from adaptation of water infrastructure to climate change.

It may be possible to expand the use of water as a renewable energy resource, particularly within a localised, distributed infrastructure for water storage. Similarly, "energy from waste" schemes could form part of a distributed waste treatment system. It might also be possible to expand the development of conventional hydro, wave and tidal energy production as a result of climate change. Materiality and resilience will always be the key constraints in these areas.

Significant opportunities could arise from recreational and tourist use of water systems as a result of climate change and adaptation. The development of wetlands could bring benefits for environmental diversity.

Using adaptation solutions with multiple benefits, especially for local communities, would make it easier for the solution to be supported by the community.

Since the conditions the UK is likely to experience as a result of climate change is similar to those currently experienced elsewhere, there is a great opportunity to learn from the steps taken to copes with these conditions in other countries.

Additionally, there is the opportunity to export the UK's learning and expertise as it develops, helping other nations adapt to the issues they face through climate change.

Unsolved problems

This workshop suggested a number of radical ideas that need to be evaluated and piloted. Further work by an expert group is needed. We need to trial and test ideas like those discussed at this workshop to determine which should be implemented widely. However, the status quo (or more of the same) will not be effective.[15]

Adaptation requires:

- More technology/engineering and understanding social acceptance of key external drivers — be they persuasion by education or regulation (new fittings, usage regimes etc.)
- More reliability of water resources against the growing challenges by use of more recharge options such as Carsington-style pumped storing and later river release to maximise reliable yield along with ground water recharge (with an adequate focus on treatment before recharge).
- Recognition that conservation followed by recycling is the next ("virtual") water resource development.
- Development of more local solutions to support and partially replace the current centrally-supplied and networked provisions.
- Understanding that flooding, river and urban, is increasingly beyond "total" control and that development restrictions and dealing with increasing frequency and severity of events is inevitable (because otherwise cost increases would be too high). For example, bunded or stilted or periodically

sacrificial ground floors must become acceptable with a "chooser pays "principle (i.e. when a drier choice was available but was not chosen).

- Addressing the issue that an inexorable rise in quality standards for water (potable and discharge) is an "arms race" that we can only lose, because carbon footprints at the exponential ends of treatment exacerbate the climate challenges we are trying to meet. These quality standards also diminish our already fragile immune systems (caused by reduced microbiological challenges along with damage from the micro-pollutants and wider consequences of modern living).
- Addressing coastal erosion/flooding and navigation issues with a blend of engineering, technological and social behavioural components.

When we look at the great Victorian engineers, they complemented their outstanding engineering vision with financial skills, with each of these fundamentally as part of a full understanding of the market for their "solutions"; the social and behavioural drivers therefore ultimately supported their asset development models.

Fundamental Resource efficiency, and even technical delivery, will require a growing focus on distributed systems, as well as ongoing centralised network delivery.

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Appendix

Inland navigation, sea ports and maritime navigation adaptation report

This paper was prepared and endorsed in June 2009 by members of the European WFD Navigation Task Group[16] as an input to the WFD Common Implementation Strategy drafting group preparing the Guidance document No. 24 River Basin Management in a Changing Climate.

1. Potential **implications of climate change** for inland navigation, sea ports and maritime navigation

Climate change characteristic	Potential implications for inland navigation	Climate change characteristic	Potential implications for seaports and maritime navigation
Increased (e.g. winter) precipitation	Increased frequency of: Strong Stream or out-of-channel events; reduced freeboard; reduced operating headroom or clearance all with potential to interrupt navigation. Increased risk to structural integrity of navigation/logistics assets and infrastructure (e.g. due to seepage, overtopping or erosion); reduced capacity (sluices, culverts, etc.)	Sea level rise	Reduced capacity of infrastructure. Increased risk of overtopping or flooding; operational issues (e.g. vessel relative to quay); bridge clearance; increased risk of pollution/ emissions in flooded areas. Changes in salinity and extent of brackish zone potentially affecting port infrastructure.
Reduced (e.g. summer) precipitation	Increased frequency of low flow events and hence carrying capacity; increased risk of groundings*; increased frequency of water resource shortages; risk to integrity of certain navigation assets and infrastructure	Increased storminess; wave heights; storm surges; tidal prism. Increased precipitation	Coastal erosion; flooding. Disruption, damage to port infrastructure, increased downtime (vessels at berth; port; supporting transport infrastructure). Increased risk of accidents. Increased run-off with consequences for sedimentation.
Change in sediment regime	Potential changes in erosion and deposition; sediment accumulation; changes in concentrations of contaminants	Change in sediment regime	Changes in suspended sediment level; erosion; deposition/accumulation; changes in concentrations of contaminants
Increased air temperature	Drying out of banks (increased potential for fissuring, settlement, erosion, undercutting); changes in characteristic vegetation types	Increased water temperature	Survivability of non-indigenous species, implications of/for ballast water management; port industry discharges
Increased air/water temperature	Increased growth of bank-side and aquatic vegetation; increased risk of algal blooms (associated health risks; loss of amenity value for recreational users)	Increased air temperature	Heatwaves causing disruption or damage (e.g. to terrestrial transport infrastructure)

* particularly on rivers without River Information Systems and on recreational water bodies

2. Potential **climate change adaptation measures** (suitability typically dependent on both climate change scenario and site specific characteristics)

Inland navigation consequence	**Potential adaptation measures** (some may already be in place)	**Maritime navigation consequence**	**Potential adaptation measures** (some may already be in place)
Safety issues of increased frequency of Strong Stream conditions, low flow events, etc.	Long term data collation and management. Ensuring effective communication of warnings to users*; awareness raising; behavioural change where necessary. Provision of additional temporary moorings; safe havens, etc. Vessel design options (where practicable)	Infrastructure capacity, vulnerability	Assess risks; survey assets; collate data; create long term database to inform decision making.
Implications of more frequent extreme conditions for integrity of physical infrastructure	Adaptive management: modify survey frequency, flexibility in maintenance operations and management regimes; 'climate-proof' ongoing operations and new development projects	Infrastructure capacity, vulnerability	Reduce exposure; increase freeboard; raise protecting structures (flood defences, breakwaters); protect infrastructure or assets against wave or wind energy, erosion, extreme heat
Water flow, quantity implications of reduced seasonal precipitation	Integrated, multi-disciplinary water storage, supply and use assessment and implementation; (additional) water conservation measures in waterway operation and maintenance (e.g. locks, sluices)	Change in sediment regime	Changes in suspended sediment level; erosion; deposition/accumulation; changes in concentrations of contaminants
Changes in erosion, siltation	Reduce sediment run-off; soft engineering bank protection. Reduce vessel-induced waves/currents (e.g. practicability of speed limits, modifications to vessel design)	Changes in sedimentation	Increased dredging requirements; modify dredging methods or disposal options
Sediment accumulation	Increased dredging requirements	Risk of incidents or accidents	Contingency planning; effective communication of warnings.
Increased plant growth; change in species types	Increased frequency of cutting, clearance activities; role of vegetation in structural integrity; alien species management	Establishment or migration of alien species	Modify or improve ballast water management or anti-fouling systems
Increased recreational demand	Multi-functional infrastructure planning and management combining water use functions; 'climate-proof' new developments.	Opportunities for renewable energy supply or generation	Shore-side electricity from renewable source; wind, wave or tidal power
Opportunities for renewable energy generation	Wind turbines; heating and cooling systems; hydropower; lock power		

* on rivers without River Information Systems and on recreational water bodies

6.5 Interdependencies workshop report

Background and Introduction

This document reports the discussion and findings of the Infrastructure Interdependencies: Adaptation at the Systems Level workshop held at the Royal Academy of Engineering on 19th October 2010. The event was chaired by Professor Robert Mair CBE FREng FRS.

The workshop process was organised around the issues raised in a briefing document, based on previous workshops organised around the key sectors of Information and Communications Technology (ICT), energy, water and transport in response to requests by DEFRA.

National infrastructure has been strictly defined by Government, incorporating for example only 5% of the total UK road network. However, national infrastructure relies on local infrastructure to support it. Although the use of utilities has a major impact on that infrastructure the use of utilities by domestic and commercial consumers is not defined as national infrastructure. Discussion of this distinction is included here.

Much of infrastructure is subject to devolved powers in relation to Scotland and Wales, particularly with respect to the environment, whilst DEFRA is responsible for such matters within England. Infrastructure UK, within the Treasury, is the Government body tasked with overseeing national infrastructure and is concerned with provision of infrastructure in a coordinated way between private and public sector, to ensure fitness for purpose. Adaptation of the infrastructure is part of this and Infrastructure UK is currently carrying out a set of projects on protecting the national infrastructure system.

The workshop focused on the impact of, and adaptation to, climate change. Infrastructure may also be subject to other, more sudden changes which could cause damage or reduced performance with implications for national security. Much of the discussion in the workshop may be of relevance to these aspects.

Interdependencies and the infrastructure system

Each of the sectoral workshops identified the key interdependencies affecting their sector. It is apparent that each sector is heavily dependent on the others, and that the degree of interdependence is increasing.

Energy

Energy is critical to all national infrastructure, and is dependent on each of the other sectors. Water is essential for power station cooling systems and the processes in the oil and gas production industries, as well as for the health and hygiene of staff working in energy installations. Additionally, some energy installations are sensitive to flooding. For example, the Castlemeads and Walham substations in Gloucestershire had to be turned off and emergency protection against flood waters installed during the summer 2007 floods.

The production and transmission of energy is dependent on ICT for communication and control systems. Similarly, the energy sector is dependent on transport for maintaining the supplies of raw materials and enabling staff to access energy facilities.

Water

The treatment and supply of potable water is heavily dependent on the provision of energy; it is estimated that water treatment accounts for up to 4% of UK energy usage. The systems managing water treatment and distribution are dependent on ICT, and those involving flood protection are particularly sensitive to data communications for control systems. The movement of staff and raw materials to manage water treatment and supply are dependent on transport.

ICT

ICT is completely dependent on the availability of energy to adequately function. Transport is necessary to enable engineers to access and fix damaged or malfunctioning installations.

Transport

Transport is similarly dependent on supplies of energy for its operation and on ICT for the management of complex transport systems. Road and rail transport are also particularly sensitive to flooding, as are land-side and sea-side dock facilities for shipping.

Other Factors

Each sector has internal dependencies. The production and distribution of energy requires energy to function. The national transport infrastructure is dependent on local transport infrastructure which feeds into the national infrastructure. The functioning of ICT systems depends on other ICT systems and networks to maintain the infrastructure. If communications fail, it is not possible to alert support services to the failure, making adapting or fixing the network particularly difficult.

In addition, the degree of interdependency is increasing, and is likely to continue to increase as a result of technologies used to mitigate climate change. For instance, the development of smart systems in managing electricity, water and telecommunications will make these systems more interdependent, particularly on the availability of electricity and functioning ICT. This may increase the possibility of cascading failures, as the failure of one system spreads to others and increases the drain on those systems, making them more vulnerable.

Smart grids, smart buildings etc increase the interdependencies on energy and ICT, and also increase potential vulnerability to cyber attacks. Diverse networks can be more resilient. For instance, having access to various mobile and fixed telecommunications service suppliers increases resilience. However, there have been occasions when major BT network problems (like the Manchester cable chamber fire in March 2004) impacted on other providers whose networks had been thought to have been independent and had been used as supposedly resilient backups.

Means for categorising and prioritising interdependencies

Various systems for classifying and prioritising infrastructure interdependencies are possible, with no one system meeting all needs. There is currently no single method of prioritising interdependencies, even within a sector: for instance, road, rail, shipping and air travel have different factors affecting them, with no single overview reflecting transport as a whole. However, to enable adequate debate and to inform policy and investment decisions, it is clear that a common methodology of prioritising interdependencies is necessary.

The following criteria for classification and prioritisation were identified:

- operational dependencies, e.g. coinciding peaks in demand or stress (where the same hazard can affect different sectors – eg, snowfall affecting both power supplies and road transport);
- timescale of impact – immediate and acute impact versus long term gradual changes;
- timescale and cost of implementing resilience measures;
- failures where positive feedback loops can cause cascade failure;
- failures likely to cause simultaneous failures in different sectors;
- number of people affected;
- risk matrix – likelihood against consequence of failure;
- cost/benefits.

Scenario planning may offer an alternative method for prioritising which interdependencies should be addressed. This would allow the resilience of each network to be estimated under a variety of scenarios.

Dependencies on systems outside of the UK

ICT is considered to be highly dependent on, and interdependent with, ICT systems located around the world, through shared and outsourced facilities and the use of overseas networks. Whilst this increases the risk that UK infrastructure may be affected by failures arising elsewhere in the world, it also increases the resilience of the infrastructure by enabling routing through alternate networks around the world.

ICT and other sectors are dependent on overseas markets for commodities for raw materials, such as lithium for fuel cells, and components manufactured overseas. This creates vulnerability to political issues and climate events in other countries which may make such materials inaccessible.

International transport is dependent on shipping and air traffic around the world. A particular sensitivity is air traffic control: air traffic arriving in UK airspace may have had to cross many jurisdictions, each dependent on their own ICT and energy infrastructure. There is currently a move toward European air traffic and maritime control, with EUROCONTROL responsible for air traffic and shipping across Europe.

Energy infrastructure is dependent on supplies of resources from abroad, either through pipelines or through international shipping. In addition much of our Energy infrastructure is dependent on non UK manufactures for the supply of spare parts and specialist labour to execute repairs.

Transport infrastructure may be particularly dependent on overseas markets in the supply chain. For instance, if rail rolling stock capacity is lost for any particular reason, it can take an extensive period for overseas manufacturers to replace parts. Worldwide manufacturing has been at full capacity, limiting options for replacing infrastructure. This is likely to be dependent on the economical cycle.

It is the overall resilience of the total infrastructure that primarily matters rather than the resilience of individual types of infrastructure. Expenditure will be optimised when all systems achieve the same level of resilience, since achieving a higher level of resilience on one part of the infrastructure will be negated if it is dependent on another part of the infrastructure with a lower level of resilience.

Issues relating to infrastructure as a whole

A systems approach to infrastructure as whole is needed to capture the interdependencies at the operational level. Treating infrastructure as a holistic system is essential to allow understanding and management of the interactions between the elements of the national infrastructure. It will also recognise the higher order dependencies – education, commerce, healthcare, defence, civil administration – which depend upon and emerge from that basic infrastructure.

Data

There is a perceived need for more data with which to inform decisions at all levels. The lack of available, meaningful, data about the current state of infrastructure assets and the consequent constraint on real knowledge and understanding is seen as a major issue.

Co-ordinating the collection of data from 'self-reporting' infrastructure and sharing models based on UKCP09 projections would reduce the amount of work spent duplicating data collection and analysis.

Whilst the ability to share data and models across sectors may be beneficial, particularly in producing a single view of interdependencies and saving effort duplicating work, there are also risks arising from making more data available and sharing it. Some data on infrastructure is necessarily sensitive and needs to be secure.

The ability to share knowledge may be hindered a lack of cross-system standards for reporting and describing the data.

Contingency planning

The development of effective contingency plans across sectors for national infrastructure is one desired output from the development of system-wide models. Testing the resilience of system models and contingency plans is an iterative process which informs the development of more resilient systems.

Behavioural impact

Whilst technological and engineering solutions may be available to enable adaption to climate change, there are behavioural aspects which have an impact on national infrastructure and sectoral interdependencies. For instance, climate change may affect patterns of travel; if there is, for instance, an increase in home-working, the interdependencies may change.

Consumers' expectations of service delivery may determine consumer behaviour and their subsequent reactions. Managing expectations in the face of changing conditions as a result of climate change, either directly through education or through market processes such as pricing structures, may have a significant impact on resource usage.

Governance and regulation

The structure of governance and regulatory authorities for national infrastructure is fragmented. The Climate Change Act 2008 requires utilities in most but not all sectors to report on the risks arising to their businesses from climate change, including infrastructure. Those sectors without reporting responsibilities, such as ICT, are likely to be able to comply as a result of their business continuity practices.

Since different sectors report to different regulators, each with their own responsibilities and procedures, establishing a unified, cross-sector view is complex. Most regulators have a clear focus on consumer protection, exercised in part through the delivery of regulated prices. This remit focuses on increased efficiency and cost reduction, which may act against the maintenance of resilient networks.

In some cases, regulation may act against organisations sharing information and developing sectoral and cross-sectoral models and contingency plans.

The pressure to deliver higher efficiency has the unintended consequence of reducing the diversity and redundancy in our networks with a consequent reduction in resilience.

Expectations of services levels to be delivered by our infrastructure are continuously rising and these are being built into the way people plan their business and their lives. As a result, any drop off in the level of service will have disproportionate consequences. Any changes in the level of service (eg the likelihood of a power cut) will need to be carefully communicated and managed.

Technical adaptations – case studies

Smart buildings

Although national infrastructure excludes end-consumers by definition, much of the adaptation and mitigation to climate change must involve consumers. By developing 'smart buildings', integrating new and developing technologies, it may be possible to manage consumer behaviour to make more efficient use of resources whilst creating more resilient societies.

For instance, it is possible to design buildings which reduce energy, water consumption and runoff (rainwater which flows off the building and its immediate surroundings), reducing the risk of flooding, thereby increasing the systems' capacity and hence resilience. The utilisation of many such mitigation and adaptation features could represent a considerable opportunity. The UK may also be in a position to export its expertise.

The use of such features in future developments may also be self reinforcing, For instance, the promotion of electric cars in cities may reduce traffic noise, thus reducing the need for sound insulation.

Incorporating living materials into building can also have multiple effects. Growing ivy on external walls provides insulation, manages run off water and absorbs atmospheric CO^2, as would adapting roofs for food production.

It is suggested that retrofitting every building in the UK with such smart features might reduce CO^2 emissions by 80%. However, retrofitting buildings would require considerable investment. The pay-back for this would take several years – possibly longer than the length of occupation. It may be possible to incorporate the costs into, for instance, an 'energy mortgage' which belongs to the building rather than the occupant, allowing the investment to be paid off by successive occupants.

Alternatively, such adaptation may be seen as creating a public good in the form of a more habitable urban environment which may attract public subsidy. The development of such smart buildings may therefore be as much a problem of financial engineering as structural.

Smart grid and intelligent networks

Incorporating appropriate sensors and management systems to automate the management of energy supplies, notably electricity, can enable the development of resilient, 'self-healing' active power flow systems. These require two-way communications, and are thus dependent on available ICT.

Such systems would be better able to cope with incorporating energy production from many small-scale renewable energy plants. Consumers of electricity may also be producers, using, for instance, wind turbines. The transmission grid, which had been designed to deliver electricity from large scale producers to consumers, needs to be able to cope with consumers who are also producers. The continued growth of small scale CHP now being seen even in domestic situations will have a growing impact on the demand profile for both gas and electricity this may result in some smoothing of demand, but the grid may have to cope with more potential inputs.

The use of the smart grid would enable demand management, which may be particularly important if there is growth in, for instance, electric vehicles. Without demand management, the capacity of the network to cope with increased demand to charge electric vehicles might be limited.

The smart grid is planned to be piloted in the Humber smart zone pilot scheme, scheduled to go live in the next two years.

The development of renewable energy resources is driving change in the energy sector. The National Grid will need to transmit energy from areas rich in renewable resources such as Scotland and Wales to areas where much energy is consumed, such as south east England. The unpredictability of some renewable resources such as wind and wave power may increase reliance on storage systems. There may also be a case for the development of a European 'super grid', networking energy supplies across Europe.

The development of smart networks and the necessary sensors is an opportunity for the UK to take a lead in this technology.

Dual water delivery and waste systems

Of water supplied to domestic buildings, only 3% needs to be potable; indeed, 30% of domestic water is used to flush toilets. However, all the water supplied by water companies to UK dwellings has been treated to make it potable, which itself uses up to 4% of UK electricity generation.

The development of dual water supply to domestic consumers, involving supply of both potable and reclaimed (less treated) water would release resources and hence make the water supply more resilient.

There is currently limited dual supply to industrial consumers in the UK. Elsewhere in the world, particularly where there is a high cost of water supply such as the Middle East, dual supply systems have been developed.

General networked dual supply is unlikely to be economical. However, the provision of partial dual supply with waste water used to flush toilets, for instance, would make considerable resource savings.

Options in reducing water supply include:

- waste avoidance, using behaviour change to reduce water consumption;
- dual supply with local reuse and storage of reclaimed water from domestic sources (such as run off from roofs and open spaces and use of "dirty" water from eg washing machines);
- water treatment at delivery;
- industrial and agricultural storage of waste or run off water for their own use, such as irrigation.

However, the use of local storage of waste water may raise public health issues.

Technical adaptations – general issues

Identifying technologies for adaptation already used overseas

The projected climatic conditions are similar to those currently found elsewhere in the world. There may therefore be opportunities to learn from or adopt overseas practices. The ICT sector is global, with the same equipment in use throughout the world. The UK ICT network therefore already benefits from standards adapted to work in more extreme climatic conditions.

As well as Middle East countries adopting dual water supplies, Western Australia has developed conservation mechanisms and implemented consumer behaviour change to reduce water consumption. This was triggered by several years of drought, resulting in water shortages. In Singapore, a combination of waste water reuse (NEWater), efficient collection of runoff even in urban areas and very low levels of leakage means that the island has been able to reduce its dependence on imported supplies.

In the transport sector, the International Union of Railways (UIC) has reviewed railways in different climate zones to enable member organisations to learn from existing conditions.

The Highways Agency in England have adapted standards for warmer climate, in particular the standards for road pavement and water run off. The rainfall in places such as Hong Kong and Singapore, where many UK engineers have worked, is substantially higher than current UK rainfall, and such overseas experience may prove valuable. However, roads will still be subject to rare extreme events such a sudden snowfall, and it is a matter for debate whether it is necessary to adopt systems used in countries which experience such extreme events very frequently.

The energy sector has learnt from experience in the Far East, Mediterranean and Middle Eastern climates. Energy systems can be optimised to work under different conditions, at a cost. In particular, the efficiency of generating systems decreases as temperature increases, being especially sensitive to the temperature of water used for cooling.

Identifying opportunities for dual-use infrastructure

Creating or adapting infrastructure that can have two or more functions may enable systems to increase resilience by switching between functions as necessary.

Examples include:

- Kuala Lumpur's Stormwater Management and Road Tunnel ("SMART tunnel"), which, whilst normally acting as a tunnel for road traffic, can be used to divert floodwater from tropical storms (see box on page 29);
- multiple uses for utility tunnels, such as carrying water and telecommunications cables;
- multiple uses for bridges, carrying telecommunications cables and water pipes;
- road and railway embankments acting as flood defences;
- using building materials with dual purpose, such as using photovoltaic (PV) cells as roofing (eg a major development in Masdar City in Abu Dhabi as well as domestic heating in UK);
- coastal tidal barrages can, in some locations, be used to protect land from storm surges and to generate electricity from tidal energy;
- reservoirs can be used for flood control as well as for water storage;
- anaerobic digestion plants for solid food and human waste at a small or local scale make water treatment easier and can be used for power generation.

Mitigation and adaptation interactions

Many of the adaptation and mitigation strategies discussed have potentially negative systems effects. For instance:

- the smart grid depends on available wireless communications;
- increased use of electric cars may increase demand for electricity which may be hard to sustain;
- increased reliance on broadband technology by domestic and commercial consumers may increase interdependencies;
- renewable energy technologies such as wind and hydro power may be affected by extreme weather.

Other mitigation activities may have beneficial impact on adaptation. For instance, the development of combined heat and power (CHP) for domestic dwellings would reduce the use of energy, and hence increase reserve capacity and resilience, as would the use of ground source heat pumps.

Regulation, policy and society

The interdependencies between infrastructure occur within society, and may be affected by human behaviour. Society is dependent on infrastructure: analyses of New Orleans following Hurricane Katrina showed how quickly behaviour changed in the absence of available electricity and communications.

All businesses are dependent on each of the sectors – ICT, energy, water and transport – to function and hence to provide products and employment.

Design codes and standards

Design codes, standards and building regulations need to be reviewed from the perspective of the projections of climate change to ensure that they remain effective and promote sustainability. Changing standards and regulations can drive the uptake of adaptation and mitigation technologies.

Standards themselves could be more flexible. The process of approval can be slow, lagging the analysis and projections of climate change. Many standards are European or International where the potential lag is even greater.

By adopting new standards, it is possible to change human behaviour. For instance, reduced water consumption and use of local or domestic renewable energy generation could be promoted by changing building and local planning regulations. Similarly, the rate of adapting the large proportion of building stock utilising legacy technologies could be driven by regulation. From some perspectives, existing regulations are not fit for the future with the projected climate change. For instance, it is likely that within 30 years it will be impossible to meet current standards of water quality given climate and demographic projections, and alternative standards or technologies (such as dual supply and treatment at the site of consumption) will be necessary.

Much regulation has been designed to promote competition and protect consumers. For instance, railway companies (Network Rail and the train operating companies) are measured in terms of delays so that costs can be correctly allocated. However, there are no regulations or measurements relating to resilience.

Some regulations skew outcomes. For instance, certain pollution incidents have a strict liability for water companies, even if the incident is not within their control.

Smart power networks require appliances to be fitted with smart power management systems to be fully functioning. Whilst regulations could have included this requirement, they have not done so. Regulations that facilitate the smart use for example of heat pumps or electric cars by identifying the necessary interfaces would accelerate their use in this manner.

Regulations can successfully change behaviour, coupled with education and incentivisation. The Government publishes data on the energy usage of all Government owned buildings. This has led to changing behaviour and a focus on energy consumption.

Adapting regulation for probabilistic scenarios

Climate change projections are necessarily uncertain. While utilities providers ensure their services meet probabilistic standards, domestic customers may not understand as well as commercial customers what levels of service these standards entail.

Some aspects of national infrastructure are easier to understand in terms of probability than others. Data on flooding, for instance, have long been given in a probabilistic form, making their understanding easier through familiarity. However, there can still be misunderstanding, with a failure to appreciate that a one in one hundred years event could still potentially occur in two consecutive years.

The lack of understanding of probabilistic scenarios by politicians and the media could be particularly problematic.

Planning for adaptation at the systems level: decision making processes in government

Infrastructure should not be planned to meet an economic scenario, but should be designed to drive economic development. The economic consequences of a disastrous failure of one or more elements of the national infrastructure would be significant.

Current policy is for planning and other decisions to be made by decentralised and local bodies. This is counter to infrastructure which is by its nature national in importance, and crosses local and regional boundaries. As a result of the large degree of interdependence identified between the four sectors, some degree of strategic large scale view is needed. Central government sets the policy and the environment in which local decisions are made.

A large number of organisations are involved in local planning decisions – decisions which may be taken without regard to the future impacts of climate change. This may make it more difficult to progress large scale infrastructure projects of national importance.

Central government therefore needs to have a co-ordinated, 'joined up' view of infrastructure and its regulation and standards.

Regulators, planners and politicians face short term pressures, not least the political cycle. They need to be convinced of the need for longer term projects.

A greater focus on developing models of complex systems and infrastructure would enable a greater understanding of decision making and its consequences in a probabilistic environment. This may require more data. Such modelling can indicate gaps in the data, allowing for the refinement of models. The Engineering and Physical Sciences Research Council has provided a grant to the University of Newcastle for the study of long term dynamics of infrastructure, leading to the development of tools to analyse the complex systems and interdependencies on a national scale. It is also funding the University of Cambridge to develop tools for monitoring the condition and performance of infrastructure assets, providing data that will be essential for accurate modelling of the system (see page 26 of main report).

Encouraging investment in adaptations

Whilst many adaptations to climate change are already incorporated into the components of infrastructure, large scale adaptation will require investment. In the current economic environment, Government alone is unlikely to be able to fund the necessary investment.

The current models of regulation of privatised industries focus on delivering value for money for consumers, usually through controlled price increases in charges based on the rate of inflation ('RPI-x'). This approach is not well adapted to strategic investments which by their nature will span many quinquennial review periods. Unregulated businesses also have limited interest in funding major long term infrastructure projects unless the economic returns are clearly beneficial. Increasing network capacity to make the system more resilient as an adaptation to climate change risks expressed as probabilistic projections will not necessarily demonstrate a sufficient rate of return to investors.

Developing suitable incentivisation transparency and certainty is therefore central to the success of infrastructure adaptation. This may require a different regulatory model to provide incentives to invest. This may be a financial engineering rather than a physical engineering problem.

Expectation management: what standards of service are reasonable?

Society expects 'always on' utilities, and has come to rely on them, and infrastructure is an important driver of growth in the UK. But the level of our dependence on infrastructure has to be balanced against the costs involved in creating a resilient system.

Unexpected events and the response to them attract a large degree of criticism from politicians, the public and the media. The ability to provide prior warning of extreme events would go some way to ameliorate this. This may require a new system to identify and warn of extreme weather events.

The current delivery of services is based on models of competition, which can lead to technological change but are unlikely to provide the economic incentives for major investment in infrastructure.

The public may not be aware of the infrastructure that is fundamental to the ways in which society is able to work: the infrastructure is largely invisible or part of the environment, and hence is taken for granted.

Infrastructure could be repositioned as a public good in terms of the value which it delivers. It would then be possible to make economic arguments on the costs and benefits of investment.

Alternatively, the public might accept lower reliability and/or service standards in infrastructure as the price for not having to fund the investment.

Timelines: planning a resilient infrastructure for 2060

The rate of climate change is likely to allow a reasonable length of time to implement adaptations to infrastructure. However, the new projects which may be required, the need to adapt plans for existing projects and the finance likely to be necessary, need extensive planning. The Stern Report recommended making changes sooner rather than later, since the benefits will be discounted less and hence be more cost effective. The timescale for meeting mitigation targets is likely, in many cases, to be a much more urgent driver than adaptation.

The most urgent requirement is to start planning for infrastructure adaptation now: with plans in place, implementation could proceed in a measured (and therefore cheaper) way. The development of systems models, strategy, policy and plans for infrastructure is likely to be comparatively cheap and will facilitate debate, allowing more effective decision-making.

6.6 Acknowledgements

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The sector workshop reports (Annexes 6.1 - 6.5) were produced by John Beckford. Many thanks to all participants at these workshops.

References

1 Memorandum submitted by National Grid (FL 80) to the Select Committee on Environment, Food and Rural Affairs. http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvfru/49/8020403.htm

2 "We will create a presumption in favour of sustainable development in the planning system." http://programmeforgovernment.hmg.gov.uk/environment-food-and-rural-affairs/

3 NIMBY: "not in my back yard".

4 A report discussing extremes in the UK's present-day climate is available on the UKCP09 website (http://ukclimateprojections.defra.gov.uk/content/view/16/500/) and one examining the future changes to extremes is in preparation. See http://ukclimateprojections.defra.gov.uk/content/view/739/690/ for more details about extremes in UKCP09.

5 A subsequent extra technical note has been added to the UKCP09 website (http://ukclimateprojections.defra.gov.uk/content/view/1176/500/), examining the behaviour of mean wind speed in the Met Office Hadley Centre's 11-member regional climate model ensemble that was used in UKCP09. A further document, looking at wind gust behaviour, is in preparation.

6 DfT, "Transport Trends 2009 Edition: Section 3 Public Transport" http://www.dft.gov.uk/pgr/statistics/datatablespublications/trends/current/section3pubtran.pdf

7 http://www.statistics.gov.uk/downloads/theme_population/pp2no27.pdf

8 http://www.statistics.gov.uk/downloads/theme_population/pp2no27.pdf

9 The UK Climate Change projections use 30-year periods, designated by the middle decade (i.e. the 2020s refers to the period 2010-2039).

10 http://ukcp09.defra.gov.uk

11 However it should be noted that there is a body of opinion that human protective immunity is being detrimentally reduced by increasing drinking water quality standards (as mentioned in the Third Report of the Group of Experts on Cryptosporidium in Water Supplies, Bouchier 1998, referencing in Appendix 8.12 Frost et al (1997), How Clean Must Our Drinking Water Be: The Importance of Protective Immunity).

12 Example: regulations were introduced requiring new domestic boilers to be condensing. This regulation has been demonstrated to be much more effective in changing behaviour than the economic benefit alone.

13 Although any comparison of present societal expectation with environmental regulation needs to be balanced with the imperative of avoiding environmental degradation – we only have one environment and it needs to be at least maintained and where appropriate enhanced.

14 Future potable standards (down to parts per trillion) are not deliverable through pipes and will need in home quality polishing.

15 The Technology Strategy Board and its associate, the Environmental Sustainability Knowledge Transfer Network, may be able to support this work.

16 The WFD Navigation Task Group is a 'thematic cluster' of European navigation-related organisations which provides the navigation sector's contribution to the WFD Common Implementation Strategy (CIS). The Task Group comprises the following professional bodies, trade associations and other stakeholders concerned with ports, commercial and leisure navigation and dredging: Central Dredging Association; European Barge Union; European Boating Association; European Boating Industry; European Community Shipowners' Associations; European Dredging Association; European Federation of Inland Ports; European Sea Ports Organisation; ICOMIA; PIANC; and Inland Navigation Europe. Central Commission for Navigation on the Rhine, the Danube Commission and the International Sava River Basin Commission are also invited to attend our meetings as observers.

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