



Resilience of UK Infrastructure



National infrastructure, such as transport, energy, water supplies and communications, is essential to the UK. Investment is needed to protect it from existing natural hazards and any effects of future climate change. This briefing outlines efforts to improve the resilience of infrastructure to these risks. Vulnerability due to the interdependence of different infrastructure components, where failure of one may lead to failure of others, is also discussed.

Background

The government defines the UK's national infrastructure (NI) as "facilities, systems, sites and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the UK depends".¹ It identifies nine areas as NI: energy, transport, water, communications, food, health care, emergency services, financial services and government itself. This POSTnote considers some of the issues surrounding the resilience of the first four, which provide the core infrastructure on which the remaining five depend. Issues include:

- **Short-term hazards:** flooding during the summer of 2007 (see Box 1) cost an estimated £3.2 billion. The subsequent report, *The Pitt Review: Learning Lessons from the 2007 Floods*,² has set out the need to address resilience to current hazards.
- **Long-term climate change:** climate change may increasingly affect NI. The Climate Change Act 2008 requires the government to report on climate change risk and prepare adaptation strategies.
- **Interdependence:** the national infrastructure is a highly interconnected network both within and between sectors. Failure in one area can spread unexpectedly to others.

The need to meet greenhouse gas emissions targets, such as the 80% emission reduction by 2050, to replace ageing infrastructure and respond to population rise and changing patterns of demand are also key motives for investment.

Overview

- Recent events have exposed weaknesses in the resilience of national infrastructure to some natural hazards, such as flooding.
- The UK has begun to address this vulnerability through the Critical Infrastructure Resilience Programme.
- New and existing infrastructure must be prepared for effects of long-term climate change, such as higher temperatures.
- Population increase over the next 20 years, especially in the South East of England, will place extra pressure on UK infrastructure.
- Better knowledge about the risks of infrastructure failure and the impact of interdependence between components is necessary to improve overall resilience.
- Some have suggested a new authority to oversee the future of UK infrastructure.

Box 1. The Summer Floods of 2007

The vulnerability of national infrastructure was dramatically highlighted during the summer of 2007, when widespread flooding led to power failures and loss of water supplies throughout Gloucestershire, Worcestershire and East Yorkshire. However, it was recognition of narrowly avoided disasters that made clear the need for a more systematic approach to resilience planning.

Key Areas of Damage

- Flooding of the Mythe water treatment works in Gloucestershire led to the loss of water supplies to 350,000 people for up to 17 days.
- Heavy rainfall resulted in bank-slipping incidents and flooding on the rail network causing delays in the service and subsequent delay in the supply of fuel.
- Motorway closures affected large parts of the road network. Repair costs of local and trunk roads were estimated at £40-60 million.
- Damage to electricity distribution assets cut off 40,000 people in Gloucestershire for 24 hours. In Yorkshire and Humberside 9000 customers were placed on rota disconnection (rolling blackouts) for several days.

Near-misses

- Walham substation in Gloucestershire came close to failure. This would have meant the loss of power to 500,000 people in Gloucestershire and South Wales.
- A near breach of the Ulley Reservoir dam threatened other infrastructure assets including the M1 motorway, a major electricity substation and a gas network connection for Sheffield.

Source: *The Pitt Review, Chapter 14*

Governance

Following recommendations from The Pitt Review, a *Natural Hazards Team (NHT)* was set up in the Civil Contingencies Secretariat at the Cabinet Office. Its role is to establish a cross-sector resilience programme between the government, regulators and industry, to address the short-term (0-5 years) vulnerability of NI to natural hazards.

The NHT seeks to encourage better practice and to foster cooperation between operators. To this end, it has established a *Critical Infrastructure Resilience Programme (CIRP)*; where *Critical National Infrastructure (CNI)* is defined as those assets whose loss would lead to “severe economic or social consequences”.¹ However, in the private sector, which accounts for the majority of national infrastructure, investment in resilience remains the responsibility of individual companies and market regulators.

The Department for Environment, Food and Rural Affairs (Defra) leads a cross-departmental project examining how to increase the resilience of NI to future climate impacts (see ‘Long-Term Climate Change’ below). Nevertheless, several bodies, such as the Council for Science and Technology, have expressed concern that no single authority for national infrastructure exists³ (see p4).

Short-Term Resilience to Natural Hazards

As part of the CIRP, government departments which deal with aspects of national infrastructure are working with the NHT to develop *Sector Resilience Plans (SRPs)*. The first version of these plans identified the present level of resilience of CNI to flooding. The SRPs form part of a longer consultation leading to a *National Resilience Plan for Critical Infrastructure* due in 2011. This will seek to address all current risks identified by the Cabinet Office’s *National Risk Register*, such as storms and heat-waves.

The level and type of protection needed for an infrastructure component depends on the risks involved: that is, an assessment of the consequences of losing a component combined with the probability of such loss. Furthermore, improving resilience can be approached in a number of ways, for example, by:

- **reducing risk** - relocating key sites away from hazards;
- **mitigating risk** - investing in protection and defences;
- **preparing for consequences** - contingency planning to ensure alternative supplies, reserve capacity, or the rapid restoration of services.

Risk assessment helps to provide for the effective targeting of resources by making economic cases for the most appropriate actions. A key part of the SRPs has been to identify the most crucial components of NI and try to establish the consequences of their loss to other assets.

The first iteration of the Sector Resilience Plans was completed in March 2010 and focused on vulnerability of components to flooding. The plans set an initial resilience standard for CNI assets at 0.5% annual flooding probability, meaning protection to a level that has a 1 in 200 chance of being equalled or exceeded each year¹ (see Box 2).

Box 2. The March 2010 Sector Resilience Plans

The first cycle of the Sector Resilience Plans focused on the present level of protection of national infrastructure from flooding. Some of the findings for each sector are listed below.

- **Water:** the water sector is particularly vulnerable to flooding due to the position of assets close to lakes and rivers. The CIRP mapping exercise identified a total of 63 sites at a risk exceeding the 1 in 200 year standard. During the most recent price review in 2009, the water regulator Ofwat allowed water companies to charge an additional £400 million to customer bills for investment in resilience.
- **Energy:** the electricity transmission and distribution companies in Great Britain have plans and cost options to provide a target level of protection of a 0.1% annual flooding probability (1 in 1000yr) for critical assets. A similar exercise is being conducted for gas infrastructure. In the price review for the period 2010-2014, Ofgem, the energy regulator, permitted electricity companies to collect an extra £112 million from customers for flooding resilience.
- **Transport:** a large range of transport options (road, rail, aviation and shipping) provides alternatives should a given subsector fail. Sector operators have thus decided to accept some interruption of service, rather than providing extra protection, as the most cost effective approach to flood management. The Highways Agency undertakes risk assessments monthly of key hazards on major trunk roads and motorways. Network Rail operates a similar policy. The majority of the rail network is built to withstand a 1% annual flooding probability.
- **Communications:** the 2007 floods had a limited impact on this sector but options for 14 sites found to be at risk during the CIRP mapping exercise are being discussed. Flooding can prevent engineering work on components, such as mobile phone masts, and assets may be vulnerable when they depend on other sectors (see Box 4). The Digital Economy Act 2010 assigned a duty to the communications regulator Ofcom to report on resilience.

Because risks change over time it is necessary to re-evaluate risk and to modify resilience strategies continually. However, there are no fixed plans for the form of any transition between the short-term work started by the NHT and the long-term implications of climate change.

Long-Term Climate Change

The Defra-led cross-government *Adapting to Climate Change (ACC)* programme has identified infrastructure adaptation as a priority. In April 2009, the ACC started a cross-departmental project *Adapting Infrastructure to Climate Change* to examine how to increase the resilience of NI to future climate impacts. It is due to report its findings and recommendations for increasing long-term climate resilience in March 2011.

The most recent set of UK Climate Change projections for the coming century, UKCP09, predict hotter and drier summers, warmer and wetter winters and more frequent extreme weather such as heat waves, storms, floods and droughts. In addition, sea-level rise (see forthcoming POSTnote) is expected to increase the frequency of flooding in tidal areas. While flooding is a hazard for all sectors, other changes pose specific problems.

Energy, Transport and Communications Sectors

After flooding, extreme heat events and gradually rising temperatures represent some of the most serious threats to infrastructure. In the energy and transport sectors, higher temperatures can reduce the capacity of electricity

transmission (though this is likely to be less important than increases in demand), lead to melting road surfaces and buckling of rail track. Likewise, storms can damage transmission lines, bridges, ports and other coastal assets. The Department for Transport is researching topics such as the degradation of railway and road embankments due to changing precipitation patterns and higher temperatures. Similar issues threaten communications: assets such as telephone exchanges must be kept cool, while communication masts require protection from storms. Operators will need to prepare by upgrading or retrofitting their assets to deal with future conditions.

Nevertheless, much of the infrastructure technology needed for hot or stormy climates already exists in other countries and expertise will be transferable. Operators argue that robust standards can be introduced in advance of climate change impacts. However, there are concerns about the cost effectiveness of adaptation measures and a range of climate change projections means that it can be difficult for operators to know which standards to adopt (see page 4).

Water Sector

Though extreme weather, such as periods of heavy rain, will place extra demands on drainage and add to the risk of flooding, changing precipitation patterns are the greatest hazard to the water sector from climate change. Effects will differ throughout the country: drier summers and wetter winters will leave some regions with more water while others are faced with periods of drought.⁴ Replenishment of ground water is predicted to reduce by 5-15% and coupled with more intermittent rain this will result in lower average river flow; in summer by up to 50-80%⁵ in some areas. Reduced availability of water will also increase the concentration of pollutants,⁴ damaging the environment and raising the cost of treatment (see POSTnote 320).

New sea-water desalination plants and more water storage may be necessary to maintain supply during periods of drought. However, a combined approach is needed to deal with water scarcity: to consider demand as well as supply options. More metering could be employed to help to reduce water use. In England and Wales only 37% of customers have a water meter, while on average, households reduce their water consumption by 10% after one is fitted.

Demographic Change

The threats to NI associated with climate change are likely to be exacerbated by concurrent demographic change as greater demand reduces spare capacity. The UK population is projected to reach 71.6 million by 2033, an increase of 16.6% from 2008; much of this will occur in London (19.8% increase) and the South East of England (20.1% increase).

The impact of population growth on water infrastructure is a particular concern; the South East of England is already one of the most heavily pressured areas in the UK with current demand causing 'unacceptable damage' to the local environment during periods of low water flow. Important

decisions must be made about land use in future adaptation strategies, particularly concerning the desirability of accommodating a growing population in the South East as opposed to encouraging development in other regions.⁵ An ageing population and altering lifestyles will also affect demands on the NI, particularly the transport sector, as people choose to retire or live away from urban areas. Infrastructure built now must be prepared for such changes.

Interdependence

The highly connected nature of NI is a major concern for sector operators trying to improve its resilience. The two main forms of interdependence, *Cascade Failure* and *Single Point of Failure*, are discussed below.

Infrastructure components often exhibit a chain of dependencies. For example, water companies rely on energy companies for their power supplies and both sectors need communications to coordinate the functioning of their assets. Failure of one component in such a chain will thus propagate to dependents, a process dubbed *Cascade Failure*. Since neither the extent nor complexity of chains of dependence is well known, cascade failure may represent a significant threat to infrastructure³ (see Box 3).

When a number of components are dependent on a single asset, or type of asset, this becomes a *Single Point of Failure (SPF)*. In this sense *Regional Convergence*, where multiple infrastructure components are located in the same area, is a form of SPF, and constitutes a risk to resilience by magnifying the impact of localised disasters (see Box 3).

Discussion about how best to address interdependence is in its early stages, but some methods may include:

- **Reducing coupling:** gaining a better understanding of interdependencies, and if possible eliminating them, makes it easier to manage consequences of asset failure.
- **Improving diversity:** where dependence on supply from other assets is unavoidable, ensuring the availability of a range of sources can remove single points of failure.

Box 3. Examples of Interdependence

Cascade Failure

- The Cumbrian Floods in 2009 destroyed a bridge carrying 312 fibre optic circuits serving 40,000 people, including police and local businesses. Disruption to the transport sector due to the collapsed bridge was compounded by the loss of communications.
- Had the Ulley Reservoir dam failed in 2007 and flooded the nearby electricity substation and M1 motorway this would have been a case of cascade failure (see 'Near-misses' in Box 1).

Single Point of Failure (SPF)

- Many infrastructure components rely on precise time signals to synchronise with other assets. Dependence on signals from Global Positioning System (GPS) satellites is now a widespread SPF.
- In April 2010, a faulty anti-virus update, supplied by the McAfee software company, crashed thousands of computers running an identical version of the Microsoft Operating System.
- A recent case study of Humberside has identified three major coal fired power stations and renewable energy assets, 17% of the UK's generating capacity, co-located in a region vulnerable to flooding.⁴

Barriers to Improving Resilience Investment and Planning

Planning for future capacity, to replace retiring assets and to meet other goals (such as CO₂ reduction targets), has a central role in long-term resilience. In particular, climate change and the changing energy mix (see Box 4) may alter how energy infrastructure is used, with greater overall consumption of electricity and higher summer demand.

Box 4. Future Energy Infrastructure

The UK Low Carbon Transition Plan (July 2009) outlines plans for 40% of UK electricity to come from low-carbon sources by 2020: 30% supplied by renewable energy and 10% from sources such as nuclear power and fossil fuelled power stations equipped with carbon capture and storage (CCS) technology (see POSTnote 335). According to the plan, meeting these targets will require a five-fold increase of renewable energy on current levels, demonstration CCS plants and replacement of existing nuclear power stations, all but one of which are due to close by 2023. In addition, investment in electricity transmission to serve new assets is needed. To connect proposed wind power generation in mid-Wales, for example, the National Grid hopes to build a new substation and a 400kV grid transmission line by October 2015. Offshore wind and tidal power will also require new connections (see forthcoming POSTnote).

In March 2010, *Infrastructure UK*, which advises on the planning and delivery of infrastructure investment at HM Treasury, published a report identifying a lack of finance for large, “complex projects in the low-carbon sector”.⁶ Private companies are often unwilling to invest in unproven or complex projects such as carbon capture and storage (CCS) or offshore wind farms. To address this, the government has supported the establishment of a Green Investment Bank, likely to be funded by a mix of public and private money.

There is also an acknowledged need for a planning framework that can deliver assets quickly. The Planning Act 2008 established the Infrastructure Planning Commission to speed up the planning process, but this has since been abolished. The government has proposed streamlining public inquiries to reduce unnecessary delays.

Short-Term Thinking

Business models which aim to boost short-term efficiency, such as those which eliminate spare capacity, may conflict with investment in resilience to the detriment of long-term performance.³ In principle, regulation can help to discourage such approaches. For example, in its 2009-2014 review Ofwat, the water regulator, promoted long-term planning by asking water companies to set their five year business plans within a 25 year context. However, the Institution of Civil Engineers has criticised the present system of regulation, arguing that it focuses too much on consumer price rather than “increasing resilience and funding reserve capacity”.⁷ They propose that government expand regulators’ remit to ensure improvement of resilience is incentivised directly.⁷

Uncertainties about the expense of adaptation and the potential cost of taking no action are also a barrier to investment for infrastructure operators trying to target limited

resources. As part of the ongoing *Climate Change Risk Assessment (CCRA)*, provided for in the Climate Change Act 2008, Defra has begun an *Adaptation Economic Analysis*, due in 2012. This will assess both the total costs of adaptation and those areas where action will have the most benefits. The CCRA will be reviewed every five years.

Interdependence and Governance

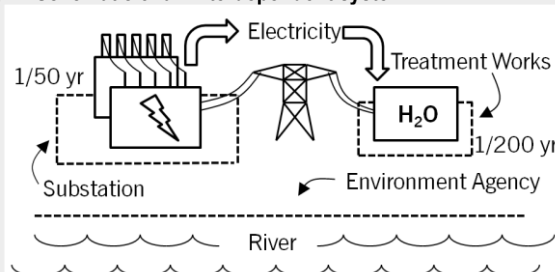
Insufficient knowledge about the level of coupling between assets can undermine other attempts to improve resilience. In 2004, for example, more than 130,000 telephone lines were blocked in the North West due to a fire in a communications tunnel; spare capacity was situated next to the main cables and, as a consequence, also damaged.

Furthermore, lack of communication between different operators can make it difficult to identify interdependence, to establish responsibility for resilience and to target resources efficiently. The Council for Science and Technology has recommended that a body be established to provide clear leadership, to coordinate systems-based approaches (see Box 5), to mediate responsibilities, and to oversee both the short and long-term planning of national infrastructure.³

Box 5. The Need for Systems Based Approaches

The following hypothetical scenario illustrates some of the challenges posed by interdependency. Figure 1 depicts a water treatment works sourcing its electricity from a neighbouring substation. Resilience to flooding by a local river, indicated by dashed lines, is different for each of the two assets: the substation is protected to a 1/50yr event and the treatment works to 1/200yr.

Fig. 1: Schematic of an interdependent system



However, in this situation the higher resilience of the treatment works is redundant, since it will still be rendered inoperable by cascading failure from a 1/50 yr event flooding the substation. Indeed, identical levels of protection may seem appropriate. But there is another operator in this system: the Environment Agency is responsible for the maintenance of the river; it could raise an embankment to protect both the substation and the treatment works simultaneously. The most effective resilience planning may only be developed by reviewing the system as a whole.

Endnotes

- 1 Cabinet Office, *Sector Resilience Plans for Critical National Infrastructure 2010*, (March 2010)
- 2 Cabinet Office, *The Pitt Review: Learning Lessons from the 2007 Floods*, (June 2008)
- 3 Council for Science and Technology, *A National Infrastructure for the 21st Century*, (June 2009)
- 4 URS report for Defra, *Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change*, (January 2010)
- 5 Government Office for Science Foresight Project Report, *Land Use Futures: Making the Most of Land in the 21st Century*, (February 2010)
- 6 HM Treasury, *Strategy for National Infrastructure*, (March 2010)
- 7 Institution of Civil Engineers, *The State of the Nation: Defending Critical Infrastructure*, (June 2009)