

# **The Economics of Climate Resilience Buildings and Infrastructure Theme: Strategic Road and Rail CA0401**

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# The Economics of Climate Resilience

## Buildings and Infrastructure Theme:

### Strategic Road and Rail

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## Context of this report

The Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to develop evidence to inform the National Adaptation Programme and the adaptation plans of the DAs. The report should be read in the context of other programmes of work on adaptation being taken forward separately.

## The scope of the ECR

The ECR follows the publication of the UK Climate Change Risk Assessment (CCRA) in January 2012 and differs in scope from work envisaged prior to that date. While its original aim was to consider individual climate change risk metrics from the CCRA and specific adaptation options, this evolved as the project was considered across government departments. The current ECR therefore focuses on broader policy questions, with each report covering multiple climate risks and CCRA risk metrics. In this context, the economic assessment is broader than a quantitative assessment of costs and benefits – it concerns identifying and assessing market failures and other barriers to effective adaptation action, seeking to understand drivers of behaviour which hinder or promote the adoption of adaptation actions. The framework for assessing the costs and benefits of adaptation actions is considered in a separate phase of the ECR.

## Questions addressed

The questions addressed by the ECR were chosen following cross-government engagement by Defra. They ask whether there is a case for further intervention to deliver effective adaptation given the current context – i.e. the current adaptive capacity of those involved and the policy framework. Criteria for the choice of questions by policy officials include: the current and projected degree of the climate change risk; priorities for additional evidence gathering beyond that already being considered in other work-streams, and the data and evidence currently available. Questions were deliberately broad to allow the wider context to be considered, rather than just individual climate metrics. However, this approach prevents a detailed evaluation of individual risks or localised issues being made. Detailed assessments of climate thresholds and the limits of specific adaptation options have also not been possible.

## Analysis undertaken

The analysis has sought to build on existing assessments of current and projected climate change risks (such as the CCRA). The context in which sectors operate has been assessed, including the current adaptive capacity of relevant actors and the policy framework in which those actors function. Categories of actions currently being taken to adapt to climate change have been explored, including those which build adaptive capacity where it is currently low, and those which limit the adverse impacts or maximise opportunities, allowing identification of barriers to effective adaptation. The case for intervention is then presented.

The degree to which an adaptation action is likely to be cost-effective requires more detailed assessment, reflecting the particular context in which adaptation is being considered.

This report is underpinned by stakeholder engagement, comprising a series of semi-structured interviews with sector experts and a range of other stakeholders. This has enabled the experiences of those who undertake adaptation actions on the ground to be better understood. We are grateful to all those who have given their time.

# 1 Executive Summary

The UK's transport network is already experiencing various impacts of climate change, including extreme weather events. Relevant climate change risks include flooding, heat effects on the rail network (e.g. rail buckling), bridge scour and landslides. Although subject to uncertainty (see Annex 3), these risks are projected to increase.

In response to these climate change risks, government policy officials identified a need for additional evidence in relation to adaptation on strategic road and rail. In particular, they set the following question to be addressed in this report:

**“Given projected climate change, what is the case for further intervention in relation to adaptation on strategic road and rail<sup>1</sup> in the UK?”**

Particular focus was requested on:

- Road and rail delays caused by flooding and heat;
- Impacts of flooding and heat on strategic road and rail infrastructure; and,
- The potential impacts of landslides in Scotland and Wales.

The analysis draws on an extensive published evidence-base, expert guidance and stakeholder consultation. Around 20 semi-structured interviews were conducted with transport authorities and agencies, policy officials, academics, researchers and transport sector experts. In addition, two focus groups were held to test emerging findings.

## How prepared is the sector to respond?

The degree of on-going investments in the maintenance and renewal of infrastructure and the high level of specialist skill within relevant organisations indicate that the **adaptive capacity of the sector is relatively high**.

**Action is already being taken on strategic road and rail routes to adapt to climate change, and further action is expected in the near-term (to 2020).** Action will be driven by the need for Network Rail to meet its licence conditions, and the responsibility of the strategic highways operators to ensure a safe and reliable transport system.

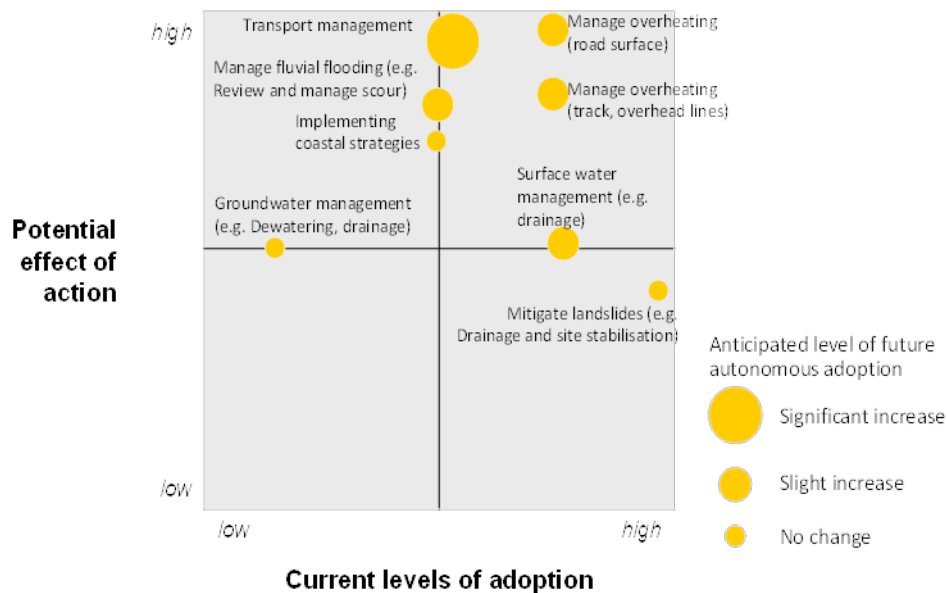
**Figure 1** summarises the assessment of the extent to which adaptation actions are already being taken by relevant transport authorities related to strategic road and rail, their relative effectiveness and the degree to which actions are likely to

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<sup>1</sup> Key strategic routes are defined as those managed and operated by central government departments and their agencies, rather than local authorities.

increase to 2020. Each yellow marker reflects a category of adaptation actions, identified on the basis of evidence from the literature, experts and wider stakeholders. Those in the top-right of **Figure 1** are both effective and widespread.

**Figure 1.** Summary of current and anticipated adaptation actions on UK strategic road and rail routes



*Note: Barriers to action are indicated when actions are not in the top right of the figure. Actions which are effective but not widespread appear in the top left of the figure. It should be noted that an assessment of costs and benefits would be required to determine whether the wider application of such actions is appropriate.*

Although significant action is being taken, there are particular barriers in terms of adaptive capacity and effectiveness.

### Barriers to effective adaptation

**Interdependencies and external costs or benefits:** In many of the categories of adaptation actions, there are strong interdependencies and cross-sectoral linkages that act both to support and impede adaptation actions. Examples identified include:

- **Intra-sector interdependency:** transport is a network and as such there are several interdependencies (i) with other links of the same road classification; (ii) with other road traffic networks (i.e. local roads); and, (iii) across transport modes.

## Executive Summary

- **Inter-sector interdependency:** the reliance of the strategic road and rail sectors on other sectors, such as information and communications technology (ICT) and the power sector (for example, for managing traffic flow, railway signalling and, in the case of electric trains, current for traction) means that the strategic road and rail sectors are vulnerable to a failure in related sectors. This is likely to become increasingly important as real time information and smart technologies are further embedded within strategic transport functions. This could be an increasingly important issue as the provision of real-time information and smart technologies are embedded within the functions of strategic transport.
- **Information and uncertainty:** Decision-making in the strategic road and rail sector is affected by uncertainties over the extent of climate change and its potential impacts, likely future technological developments and non-climate related drivers, such as socio-economic development and travel demand. Barriers identified particularly relate to:
  - Uncertainty over the impacts of climate change given the long asset lifetimes being considered; and,
  - The relative lack of ex-post analysis of the costs and benefits of adaptation actions, with which to guide decision-makers. Although efforts are underway to develop this, evidence currently remains limited.

## Recommended interventions

### Build adaptive capacity by:

- **Undertaking case study research in areas at risk of flooding or landslides to understand better the nature of interdependencies** within and across sectors. Case studies should include areas where single, or a limited number of, links are relied upon for access or to connect locations. Such case studies should be used to inform the development of cross-sectoral adaptation roadmaps at the appropriate geographical (or other) scale for strategic road and rail. Case studies could focus on the effects of flooding or landslides on major and minor roads and the cross-sectoral interactions between strategic road and rail and other policy areas such as business, land-use planning and other infrastructure providers
- **Undertaking a series ex-post evaluations of adaptation actions that improve the climate resilience of strategic road and rail.** This information should be collated into a common and accessible format to share with transport agencies and enhance best practice. For example, on the supply-side, this should include the impacts of improved drainage on travel reliability and delays, and the costs and benefits of bridge scour action. On the demand-side, it should include the effectiveness of demand management and traffic flow management during times of floods.

- **Developing further the evidence-base on the risk of bridge scour** for strategic motorway and, importantly, non-motorway routes.
- **Incorporate a requirement within the Department for Transport's transport appraisal guidance (WebTAG) for appraisal scenarios to reflect different probabilities of disruption** which may result from a range of projected extreme weather events, where appropriate. This would ensure that the associated costs are reflected in the 'do minimum' option, against which the relative costs and benefits of the intervention can be assessed.

### *Barrier*

Public ownership, management and operation of strategic routes will enhance further adoption of effective adaptation action, as licensing requirements set by the Office of rail Regulation (ORR) and safety and reliability targets set by the DfT and Highway Agency (HA) will incentivise change. However, it is important to ensure that full account is taken of climate change adaptation in decision-making processes and appraisal.

### *Recommended intervention*

**Maximise opportunities from renewal programmes to enhance resilience in an iterative way.** Given the level of investment in maintenance and renewal programmes on key strategic infrastructure, it is important that programmes build sufficient infrastructural resilience as new information emerges on the climate risk. For example, by considering alternative climate change emissions scenarios – including severe weather events - when planning the work.

### *Barrier*

The effectiveness of adaptation actions such as traffic management and demand management rests on the assumption that travellers will behave 'rationally' and respond to pricing, information or policy signals. However, it is likely that some travellers will be unwilling to change their behaviour owing to habits, personal travel preferences or a lack of willingness to accept official information.

### *Recommended intervention*

**Maximise opportunities from traffic and travel demand management as an adaptation action.** Undertake research to:

- Explore the use of traffic and travel management on non-motorway routes to manage flood-related delays; and,
- Better understand traveller behaviour in response to traffic and demand management initiatives.

### *Barrier*

The number of organisations involved in adaptation decision-making both within and between strategic and non-strategic networks may hamper the co-ordination of adaptation actions

### *Recommended intervention*

<b>Develop adaptation roadmaps collaboratively</b> involving local and national networks, and appropriate stakeholders across sectors.
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## 2 Strategic road and rail theme

### 2.1 The focus of this analysis

Government policy officials set the following question to be the focus of this report:

**“Given projected climate change and expected adaptation, what is the scope for further intervention in relation to adaptation on strategic road and rail routes in the UK?”**

Analysis was required to focus on strategic routes only, exploring:

- Road and rail delays caused by flooding and heat;
- Impacts of flooding and heat on strategic road and rail infrastructure; and,
- The potential impacts of landslides in Scotland and Wales.

The scope of the work therefore excludes local transport networks, though these are important to consider as part of the resilience of the transport system as a whole.

Strategic routes are here defined as those interurban networks operated by the UK government, Devolved Administrations and their Agencies. For rail, we refer to rail infrastructure operators (not train operating companies).

#### 2.1.1 Approach

The analysis was undertaken over a period of two months and draws on a wide published evidence-base and evidence from stakeholder engagement.

##### *Stakeholder engagement*

Stakeholder engagement has been an important source of evidence for this analysis. Around 20 semi-structured interviews were held with stakeholders alongside guidance and input from expert advisors and two focus groups to test emerging findings. Stakeholders are listed in Annex 1 and include:

- Those who implement adaptation measures themselves (for example, the HA, Transport for London, Network Rail and Eurotunnel);
- Government policy officials (for example, in Transport Scotland, the UK Department for Transport, the Welsh Government and the Department for Regional Development, Northern Ireland); and,

- Academics, researchers and others who support the transport sector (for example, the University of Birmingham, the Transport Research Laboratory and the Knowledge Transfer Network).

We are grateful to our expert advisor, Robin Hickman of the Bartlett School of Planning, University College London, for his advice and input, and to Tom Worsley, Visiting Fellow at the Institute for Transport Studies, Leeds University, for reviewing the work.

## Analysis

The framework for analysis to address the question involves a series of steps.

- Understand the scale of the challenge: this involves exploring the evidence on the current scale of risks posed by climate change (including extreme weather events) and understanding the potential magnitude of impacts these give rise to.
- Understand the context in which adaptation is considered: this includes identifying the relevant actors and their adaptive capacity as well as identifying relevant policies that are likely to facilitate or hinder effective adaptation.
- Identify and assess adaptation actions currently being implemented by some in the sector, considering their adoption and relative effectiveness. These actions include building adaptive capacity and implementing action to limit damage or make the most of an opportunity. Barriers are then identified in terms of where uptake or effectiveness (or both) is constrained. Barriers are explored in the following categories:
  - Market failures: the degree to which there are market failures relating to pricing signals; externalities<sup>2</sup>; public goods; and where information may not be timely, accurate, relevant or is incomplete;
  - Policy: the framework of regulation and policy incentives;
  - Governance: institutional decision-making processes; and,
  - Behavioural: for example, short-sightedness and willingness to act.

The case for intervention to address those barriers is then explored through the consideration of adaptive management and illustration of ‘what-if?’ scenario

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<sup>2</sup> Where there are costs or benefits imposed on others that are not accounted for in individual decision making.

analysis to demonstrate the potential effectiveness of actions if barriers are overcome.

Within the time and scope of this report, it has not been possible to model quantitatively the wide range of impacts of projected climate change on the strategic road and rail sector under a full range of projected future climate scenarios. Instead, analysis focuses on the outputs of the CCRA, the impacts of recent major climate events and illustrative ‘what if?’ scenarios.

### 2.1.2 Structure of the report

The report is structured as follows:

- Section 3 presents the scale of the challenge posed to the sector by projected climate change;
- Section 4 describes the context for adaptation, i.e. key characteristics of strategic road and rail supply and demand, adaptive capacity of key actors relevant for strategic road and rail, and the role of policy in adaptation;
- Section 5 explores the range of actions that are already being taken or are expected in the near-term along with the key enablers and barriers to taking effective adaptation action;
- Section 6 presents the case for intervention including illustrative adaptation roadmaps, consistent with the concept of adaptive management. ‘What if?’ scenarios are shown to illustrate the potential effectiveness of particular actions.



## 3 Scale of the challenge

### Key messages

- Rainfall, floods and heat – including changes in average climate conditions and extreme events – are likely to pose the greatest climate threats to the transport network to the 2050s. Floods are highly variable in nature but are projected to become more frequent. Temperatures are likely to rise, increasing the risk of rail buckling and infrastructure damage. Heavy rain following dry spells could prompt more landslides.
- Flood related damage to strategic roads is unlikely to be extensive owing to significant on-going maintenance and renewal programmes, and high design specifications. However, the intensity of use of these routes – often carrying more than 25,000 vehicles per day – means that disruption costs from flooding could be particularly high.
- The risk of scour is likely to increase in future, but the impact on road and rail networks is uncertain.
- The effects of heat on strategic roads are likely to be small to the 2050s due to the already high design specifications for road surfaces, though could lead to increased rail buckling and speed restrictions on the rail network.
- The number of roads affected by landslides is unlikely to change substantially in the future but the frequency and/or impact of such events could increase. Economic costs of landslides could be large for local communities where they have limited alternative routes available so could be cut off. Present and future landslide risk in Wales is currently being studied.

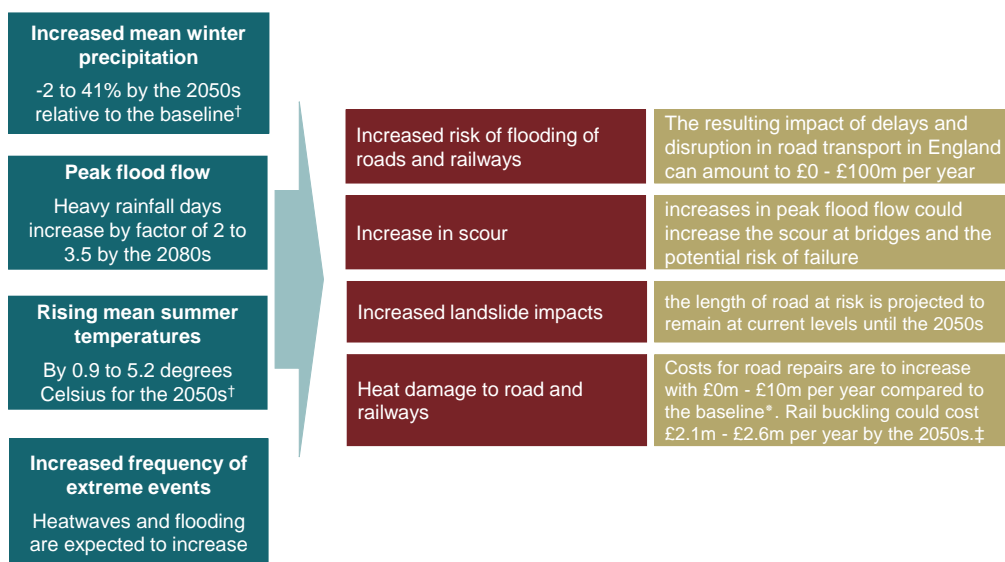
### 3.1 Introduction

The key climate risks facing the sector are shown in **Figure 2**. These risks are described and their severity is assessed in the following sections. Particular focus is given to:

- Flooding;
- Scour;
- Rising temperatures; and

- Landslides in Scotland and Wales<sup>3</sup>. Potential climate impacts for the UK and the modelling process are discussed in more detail in Annexes 3 and 4.

**Figure 2.** Climate threats to strategic transport routes



Source: UKCP09; Murphy *et al.*, 2009; Solomon *et al.*, 2007; CCRA: Thornes *et al.*, 2012. Baseline is 1961-1990.

<sup>†</sup> Ranges with lower bound values for the p10 low emissions scenario and upper bound values for the p90 high emissions scenario<sup>4</sup>.

\* Costs for road repairs for England. It is estimated that these costs are less than £ 1million for Northern Ireland, while figures for Scotland and Wales are not available.

‡ Costs for rail repairs and delays in England, Scotland and Wales, under the p50 low to high emissions scenarios.

## 3.2 Flooding on strategic roads

This section begins by outlining the current level of risk of flooding indicated by recent past events. It then describes projected changes to the severity and frequency of rainfall events and increases in sea levels.

### 3.2.1 Current level of flood risk to strategic roads

Not all categories of flood risk are well understood. In particular, there is less knowledge of potential risks from future groundwater flooding, while river and

<sup>3</sup> England is not in the scope of the question for this report.

<sup>4</sup> Where possible, the ranges for climate projections cited cover the UKCP09 low emissions scenario, 10% probability (10th percentile), meaning that the value is very likely to be exceeded, to a high emissions scenario 90% probability (90th percentile), meaning that the value is very likely not to be exceeded.

## Scale of the challenge

tidal flooding are better understood. Consequently, the following sections do not consider all flooding types for road and rail.

Around 9% of main roads (motorways and A-roads) (CCRA: Ramsbottom *et al.*, 2012 and DfT, 2011a<sup>5</sup>) and 15% of railways (CCRA: Ramsbottom *et al.*, 2012; DfT, 2011d and Scottish Government, 2010<sup>6</sup>) in England and Wales are currently at risk of flooding from rivers or the sea, with an annual probability of 1.3% or 1 in 75 year return period<sup>7</sup>.

Delays to strategic transport routes – whether caused by flooding or other factors – are dependent on a wide range of factors. Important to recognise are:

- **Impacts on the wider network must be considered:** because transport is a complex system, impacts in one part can affect others (across areas, modes etc.). If a transport interchange is affected then there could be cascade effects on the rest of the network.
- **Variations in scale and scope of event:** past events vary in their characteristics (location, duration, proportion of network affected, travellers affected etc.). Averages would therefore hide locally specific conditions that would be important to understand in determining the case for policy intervention.
- **Volume and composition of travellers affected:** if business travellers or freight are delayed the reduction in productivity due to loss of time would have a greater economic cost than if leisure travellers are delayed.
- **Availability of substitute options for travellers and their responsiveness:** The impacts are likely to be more significant where the number of available alternatives for travellers is limited, such as in rural or remote areas, or where there is reliance on only one route to connect particular locations. When travellers do have options, they often relate to making adjustments to their journey of travel, mode (road, rail etc.), route, and indeed whether to make the journey at all (assuming they have pre-warning).

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<sup>5</sup> DfT (2011a) provides the length of motorways and A-roads in England and Wales in 2011 (39,609 km), while Ramsbottom *et al.* (2012) provide the length of motorways and A-roads at risk of fluvial and tidal flooding (3,382km).

<sup>6</sup> DfT (2011d) provides the length of railway in Great Britain in 2011 (15,777km) and the Scottish Government provides the length of railway in Scotland in 2010 (latest figure available, 2,759 km), while the CCRA provides the length at risk (2,000 km).

<sup>7</sup> Note that the methods of calculation of total route length by DfT and the length at risk by the CCRA are different (the CCRA calculation is approximate). These percentages are therefore only indicative and are not intended to give precise estimates.

- **Frequency of event:** higher levels of frequency imply greater levels of delay. However, travellers may learn or become accustomed to other alternatives should events become more frequent, mitigating some of the impacts. This means that impacts in the long term where events are more regular could be different to short term behavioural responses.
- **Delays must be considered alongside other factors:** if travellers are re-routed, not only may this add to the distance and time taken to get to a particular destination but it is also likely to lead to additional costs. Such costs are likely to be incurred by leisure travellers (including commuters, those on trips for recreation or shopping) and business travellers (for example, if there are delays to meetings, appointments or deliveries). The sum of all of these impacts are welfare costs.

Given this complexity, and the time available for this analysis, current estimates and projections of national road delay caused by flooding have not been developed. Rather, a pragmatic approach has been used to illustrate the potential scale of effects, drawing on existing data from past real events and available studies of potential future impacts. The well-established method of placing an economic valuation on road delays is to measure the additional time taken to make a particular trip (relative to what would otherwise have happened absent the climate change event) and estimating the monetary value by applying an appropriate 'value of time', and associated operating costs (e.g. fuel used).

### *Economic costs of floods*

**The economic costs of floods on transport routes can be substantial.** For example:

- The total costs of road travel interruption and damage during the summer 2007 floods in England were estimated to be around £191 million in 2007 prices – half of which was associated with infrastructure repair and half was due to delays (Environment Agency, 2010). The impacts were calculated by modelling the type and magnitude of traffic flows that would have been diverted at 'nodes' on the road network that were blocked by the flooding. The effects were concentrated - 16 local authorities accounted for 86% (£75 million) of the total road damage costs (£85 million) to all Local Government Authorities.
- Local roads were most adversely affected by the floods – the HA reported extra costs of only £33,000. In part, this is because the HA's road network is generally relatively recently built and designed to cope with some adverse weather conditions – maintenance expenditure is aimed at ensuring the asset does not deteriorate, despite heavy utilisation (motorways typically carry over

### *Scale of the challenge*



25,000 vehicles on a daily basis). Annual expenditure on maintenance by highways authorities is substantial: 29% of the Highways Agency resource and capital expenditure in 2010-11 was accounted for by maintenance (Highways Agency, 2011b). In 2011-12, the annual maintenance and renewals budget was £417 million (resource) and £416 million (capital). This covers replacing and maintaining surfaces, bridges and other structures. It also includes the associated upkeep of fencing, drainage, lighting, signage and managing winter conditions. Not only does such expenditure aim to mitigate deterioration but it also offers an opportunity to enhance resilience to climate change on an incremental basis.

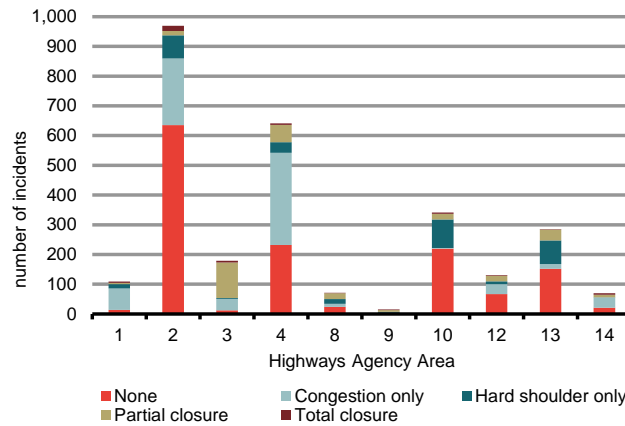
- Although the repair costs on strategic roads in 2007 are estimated to be relatively low, the disruption costs are disproportionately high on strategic highway routes owing the intense usage and the fact that stretches of some of the UK's main corridors were closed: M1, M4, M5, M18, M40, and M50 with part of the M1 closed for 40 hours (the Highways Agency estimated the M1 closure alone cost some £2.3 million). Overall, as noted above, disruption costs were estimated to be around £98 million (in the range £22 million - £174 million) (Environment Agency, 2010).

Flood-related costs of disruption can be substantial and would be experienced on top of the other drivers of delays (congestion) on UK roads. Delays more widely cost the UK. For example, the Eddington Transport Study estimated that GDP costs of congestion in 2005 were £7-8 billion (Eddington, 2006); the Freight Transport Association estimated a cost of road congestion greater than £20 billion per year (unknown price base); and Tweddle *et al.*, 2003 estimated a £15.2 billion annual cost for 1996 Great Britain traffic, updated to £24 billion for 2005 traffic (1998 prices).

Not only are there costs of delays to travellers, but there are likely to be wider implications of delays, for example if other activities which rely on particular journeys being made (such as meetings, appointments, or deliveries) are disrupted. Managing and minimising the impacts of floods on travel is therefore an important priority in high flood-risk areas.

The variation in the severity of floods on the road network is significant. **Figure 3** illustrates the range of impacts that can occur due to flooding on the Highways Agency road network. It is clear from this figure that flooding impacts can vary significantly across England and even within local areas.

**Figure 3.** Impacts of flooding on the Highways Agency road network since 2006



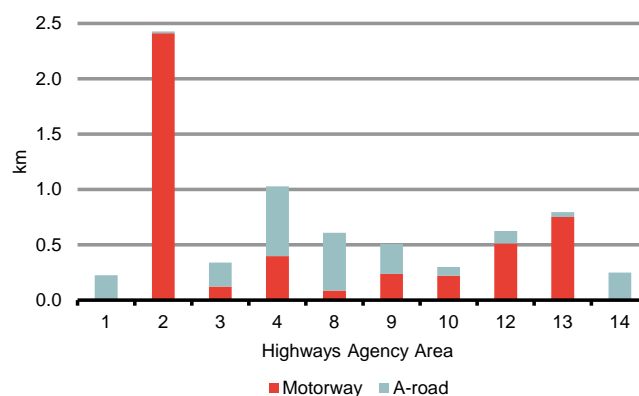
Source: Data provided by the Highways Agency (see Annex 2 for area locations. Regions with the highest number of incidents are Area 2 (South West); Area 4 (South East); Area 10 (North West); and, Area 13 (North West)

Note: The category "none" refers to the classification in the Highways Agency flood severity index that there is 'no impact on traffic' of the reported flood.

While the majority of floods are shown to have no effect or result in congestion only, as opposed to closure, it is the more severe events that are likely to cause the larger impacts to the roads affected and the wider network.

**Figure 4** illustrates that the extent of flooding can vary significantly across road types and regions. While the average length of road typically affected by a flood is low, more severe floods can affect significant stretches of highway. For example, one flood in 2010 caused flooding on 50 km of the M4. It should also be noted that the length of time for which roads are affected is typically less than one day, but can last for several days in some cases.

**Figure 4.** Average length of Highways Agency road affected by each flooding incident since 2006



Source: Data provided by the Highways Agency

### 3.2.2 Projected climate change risks to strategic roads: changing rainfall patterns and sea level rise

Projected increases in rainfall intensity and rainfall duration are likely to increase the already considerable risks from surface water flooding. In the p50 medium emissions scenario, mean winter precipitation in the 2050s is projected to increase by 9–17% (depending on location) relative to the 1961-1990 baseline<sup>8</sup> (Murphy *et al.*, 2009). The spread in projections is wide: from -2% for the lower bound of the UK Climate Projections (UKCP09) low emissions scenario in Scotland East to +41% for the upper bound high emissions scenario in South West England.

Heavy rain days (>25 mm) are likely to be more frequent over most of the lowland UK. For example, central estimates show an increase by a factor of 2 - 3.5 in winter and 1 - 2 in summer by the 2080s (UKCP09, under the medium emissions scenario). There is a wide range of projections around this central estimate so this is indicative only. Heavy rainfall increases the risk of flooding since soil saturation and filling of stream and river channels would be more common (CCRA: McColl and Angelini, 2012).

Flooding events could also result from sea level rise. As the earth's crust is moving upward in the northern parts of the UK, sea level rise is projected to differ across the regions. The north is projected to be less affected compared to the south (Lowe *et al.*, 2009). According to the central estimates of relative sea

<sup>8</sup> Central estimate of the medium emissions scenario. There is uncertainty around this figure.

level changes with respect to 1990, sea level will rise by between 18 cm in the low emissions scenario and 26 cm in the high scenario in London by 2050, and between 11 and 18 cm in Edinburgh (Lowe et al., 2009).

**Figure 5** illustrates how these changes could affect strategic roads in the UK. The length of motorway in England and Wales at significant risk of fluvial and tidal flooding<sup>9</sup> is projected to increase by 46% by the 2050s (CCRA: Ramsbottom *et al.*, 2012) under the p50 medium emissions scenario<sup>10</sup>. Projections range from 10% in the low emissions (p10) scenario to 79% in the high emissions (p90) scenario.

For A-roads in England and Wales, the projected increase is 30% in the medium emissions p50 scenario (4-48% range for the low p10 to high p90 scenarios), and for rail 28% (6-45% range)<sup>11</sup>.

While fluvial flooding currently accounts for the majority of the risk, the proportional increase in risk is projected to be approximately equal for the two flooding types. Importantly, there are likely to be regional variations. The most significant effects are projected to be in the South West of England and Wales.<sup>12</sup>

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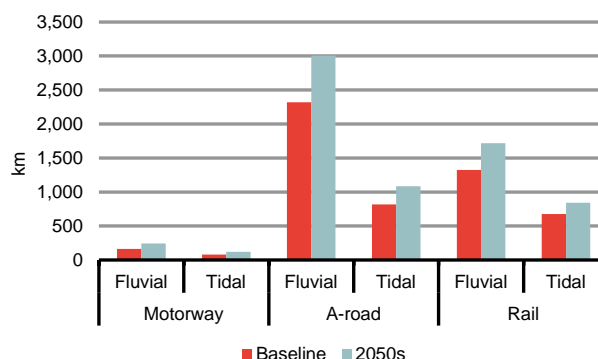
<sup>9</sup> Significant risk is defined as an annual probability of flooding of 1.3%.

<sup>10</sup> These increases are measured against a baseline of 1961 to 1990 for fluvial flooding and 2008 for tidal flooding.

<sup>11</sup> Percentage increases calculated by ECR team based on data in CCRA: Ramsbottom *et al.*, (2012).

<sup>12</sup> Note that the estimates are based on simplistic assumptions of the length of route in a given land area so these could be substantial underestimates.

**Figure 5.** Length of route in England and Wales at significant risk of flooding under the p50 medium emissions scenario<sup>13</sup>



Source: CCRA: Ramsbottom *et al.*, (2012)

These estimates are subject to uncertainty<sup>14</sup> because they are based on averages i.e. typical route length per area (not accounting for the geography or topography). Routes that run side-by-side would therefore not be accounted for specifically, nor the extent to which those routes are used. In addition, some roads and rail routes are built on embankments, so may not flood even if they are in a flood zone.

For comparison, analysis of the flood risk to the Highways Agency road network (Highways Consultancy and Research Group, 2011) found that the national length of road at an annual risk of fluvial and pluvial<sup>15</sup> flooding of at least 10% could increase from 211 km to 246 km by the 2050s (under both a p50 and p90 medium emissions scenario)<sup>16</sup>.

Transport Scotland is currently developing its understanding of the potential impacts of flooding on the road network in Scotland - projections of flood delays for Scotland are therefore not assessed here. Similarly, the Welsh Government is at an early stage in understanding possible impacts. Stakeholder interviews have indicated that flooding is a significant risk in Northern Ireland, particularly in coastal areas and cities. However, no projections have been developed of this risk at the time of writing.

<sup>13</sup> The baseline period is 1961-90 for fluvial flooding and 2008 for tidal flooding. Results are presented for the UKCP09 p50 medium emissions scenario.

<sup>14</sup> Please see Annex 3 for a full discussion of the causes of uncertainty around climate change projections.

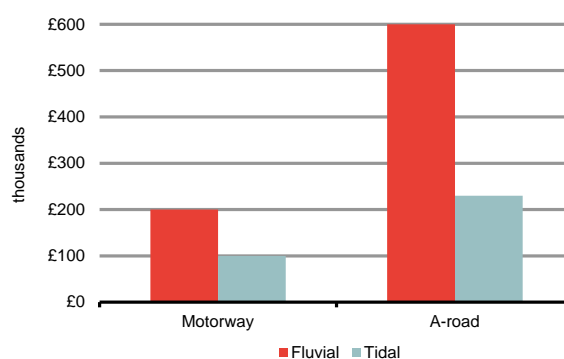
<sup>15</sup> Fluvial flooding is associated with rivers and streams, while pluvial flooding is directly related to rainfall.

<sup>16</sup> While the total length at risk is equal under both scenarios, under the p90 scenario a greater length of road would be at a higher annual risk of flooding. See Annex 4 for a detailed discussion.

In terms of what these projections mean for delay costs, the CCRA estimated that precipitation-related floods in England could cost between £1 million and £10 million per year by the 2050s under the p50 medium emissions scenario (CCRA: Thornes *et al.*, 2012), and £10-100 million per year under the medium and high p90 scenarios in 2010 prices.<sup>17</sup>

Ramsbottom *et al.*, (2012) also estimated the future costs of disruption on motorway and A roads in England and Wales due to fluvial and tidal flooding. Roads with an annual probability of 1.3% of flooding were considered. **Figure 6** summarises the total disruption costs for the p50 medium emissions scenario.<sup>18</sup> These costs are within the range indicated by Thornes *et al.*, (2012). The costs in different climate scenarios vary according to the variation in the percentages of route at risk. It should be noted that the analysis used a per km cost figure to quantify the impacts of delays, which does not fully take into account the varying scale of risk due to congestion and alternative transport modes. Obviously, there is uncertainty around these estimates; they should be considered illustrative only.

**Figure 6.** Annual disruption cost in the 2050s for motorways and A-roads in England and Wales for the p50 medium emissions scenario



Source: CCRA: Ramsbottom *et al.*, (2012)

The impacts associated with flooding will also depend on traffic levels and many other factors. If flooding occurs in those areas which are projected to become increasingly congested (see **Figure 33** in Annex 4) this would lead to a relatively greater economic cost than in less busy areas.

<sup>17</sup> The CCRA reports present all costs in 2010 prices.

<sup>18</sup> A figure of £200,000 per day per km was used to cost motorway disruption. A figure of £77,000 per km per day was used for A-road disruption. These figures were estimated as part of the TE2100 project (TE, 2100).

### *Limitations of the analysis*

It has not been possible to model projected flood-related delays on the strategic road network to the 2050s within the timeframe of this 2-month report. Network or area modelling would be required to produce plausible estimates because the impact of a flood would affect more than the flooded route alone – it would impact on surrounding routes as traffic re-routes, but also on other modes of transport as some travellers shift modes. It is however clear that the costs associated with flood-related delays are expected to increase in the future as the risk of flooding rises and both the volume of traffic and the value of time of travellers, and hence the cost per delay, increase.

Much of the existing evidence considers fluvial and tidal flooding, with less known about surface water flooding. Any changes in the frequency or severity of this type of flooding would increase costs further.

### **3.2.3 Rail delays due to flooding**

The majority of the rail network is built to withstand a 1% annual flooding probability (Cabinet Office, 2010). Notwithstanding this, the impacts on services and passengers caused by floods can be significant.

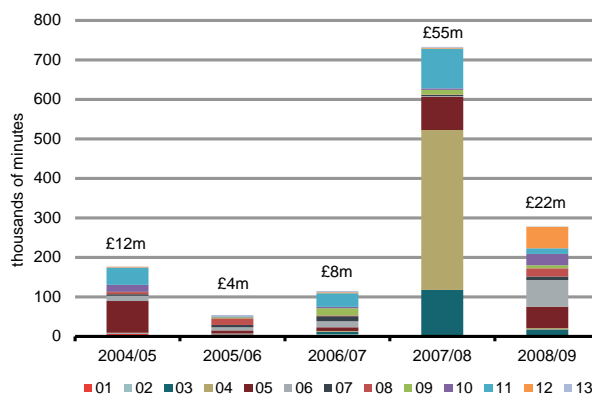
#### *Current level of risk*

Network Rail collects detailed information on the delays caused by flooding. This information demonstrates that there can be large variations in the frequency and severity of flooding across months and years, as shown in **Figure 7**. Applying a valuation figure of £73.47 per minute of delay for each train<sup>19</sup> (National Audit Office, 2008) and accounting for inflation, rail delays cost passengers between £4 million in 2005/06 and £55 million in 2007/08 (in 2006/07 prices). The estimated annual cost for each year (delay minutes to the service multiplied by the value of time) is displayed above each bar in the chart. Network Rail also incurs a cost in the event of flood delays because it must compensate train operators when delays occur due to issues with the rail network (although this cost is a transfer between entities rather than a loss, unlike the costs for passengers).

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<sup>19</sup> This was estimated using data from Network Rail and the Office of Rail Regulation to determine the average number of passengers per train and data from the Department for Transport to produce an average train containing 14 business travellers, 95 commuters and 73 other passengers. Values of time for each respective journey traveller were used (National Audit Office, 2008).

**Figure 7.** Rail delay minutes caused by flooding on the GB rail network per 4 week period (period 01 begins on April 1<sup>st</sup>), with indicative annual cost displayed above each bar.



Source: Based Network Rail delay data (note 1-13 refer to the 4 week periods of the year. These figures reflect delays and not cancellations. They refer to the delay minutes to the rail service.)

The 2007 floods are notable on the chart. The types of incidents that flooding causes and the length of associated delay vary significantly across incidents and by 4-week period.

**Table 1** shows a comparison of the reported flood related delay minutes for passenger trains and compares this with total passenger delays on Network Rail routes (caused by Network Rail, i.e. excluding weather events etc.)<sup>20</sup>, for context. This shows that relative to overall delays, the impacts of flooding at the aggregate level are relatively low. However, it should be noted that on an individual line, passengers may be acutely affected by flood related delays (e.g. in getting to work etc.).

<sup>20</sup> Note that this is lower than the figures estimated by the National Audit Office because they exclude events that are not in the control of Network Rail.



**Table 1.** Comparative rail delays (minutes of delay to passenger services)

	Delays from the floods	Annual delays reported (Network Rail)*
<b>2004-05</b>	176,400	9.3 million
<b>2005-06</b>	53,800	8.4 million
<b>2006-07</b>	114,600	8.4 million
<b>2007-08</b>	732,800	7.7 million
<b>2008-09</b>	278,000	7.2 million

Source: Annual delays from Network Rail Annual Return, 2009 (Network Rail, 2009); Flood delays: Network Rail.

\* delay minutes caused by Network Rail

### Projections

Ramsbottom *et al.*, (2012) calculated that disruption costs for rail flooding events with a 1.3% annual probability could reach £540,000 per year by the 2050s for river flooding and £210,000 per year for tidal flooding under the p50 medium emissions scenario for England and Wales.<sup>21</sup> These estimates suggest that the delay costs of flooding on the rail network may be relatively low in future (particularly when compared to the costs of flood-related delays on strategic roads, discussed above). However, as with the analysis of flooding delays on roads, there can be significant variation in the impacts across localities and time periods and many factors are not accounted for in these estimates (network effects and population growth, in particular). Variation in the costs across climate scenarios reflects the variation in the percentage of route at risk, discussed above.

Tomorrow's Railway and Climate Change Adaptation (TRaCCA, 2011) developed projections of the risk of flooding of the rail network in Great Britain. The analysis suggests that there could be a 10% to 40% increase in the number of extreme rainfall events by the 2040s (RSSB, 2011). The TRaCCA project also projected the number of days when surface water flooding is likely on the rail network with increases of between 0% and 30% by the 2040s. However, the authors stress that different versions of their model generated a wide range of results, including decreases in the number of these events.

<sup>21</sup> A figure of £115,000 per day per km was used to cost rail disruption in the CCRA. This was sourced from the TE2100 project (TE2100, 2009).

### *Limitations of the analysis*

While no new rail network modelling was possible within the timeframe of this project, it is clear that flood-related rail delay costs are projected to increase.

As in the previous section, there is little evidence for the impacts of changes on surface water flooding. Clearly, any such changes would increase the costs of flooding on the rail network further than described in this section.

## **3.3 Scour**

Another possible effect of river flooding on road and rail networks is scour. While no quantitative projections of changes in the incidence of scour are available, river flood flows in England and Wales (the cause of scour) are projected to increase by between 0 and 40% by the 2050s, relative to 1961-1990 baseline (CCRA: Thornes *et al.*, 2012). This estimate cannot be taken as an accurate indication of how the frequency of scour could change in future – it is subject to substantial uncertainty. The incidence of scour depends on a range of factors, such as the characteristics of a particular site and specific river flows.

Most motorway structures have been constructed in the past 50 years and have deep foundations for structural reasons; as a result scour may not affect the trunk road network to a significant extent.

### *Limitations of the analysis*

While the potential effects of scour in the future are largely unknown, it is clear that the rail network is particularly vulnerable to scour due to the age of many railway bridges. This could require investments to be made to reinforce vulnerable bridges and carry out site assessments.

## **3.4 Rising temperatures**

### **3.4.1 The impacts of rising temperatures on strategic roads**

Higher temperatures may contribute to higher rates of heat damage to road surfaces. This manifests itself in two ways: firstly, the physical damage and deformation of roads due to the impact of high road surface temperatures. Secondly, the road surface must be sufficiently cool before repair work can commence.

Repair costs of overheating on the trunk road network in England could be less than £1 million per year by the 2050s (based on expert judgement) (CCRA: Thornes *et al.*, 2012) for all p50 climate scenarios. The costs are relatively low due to the fact that temperature rises are likely to fall within the current range incorporated into trunk road design standards. The repair costs could amount to

### **Scale of the challenge**

£1-10 million per year in the low to high emissions p90 scenarios. No estimates are available for Scotland or Wales.

The CCRA analysis used a repair cost which was based on current expenditure by Leicestershire County Council. Stakeholder interviews and the literature (see Thornes *et al.*, 2012) indicate that many Highways Agency roads are designed to a higher standard than local roads, and so the repair cost estimated above may be lower.

It should be noted that this analysis did not include the delays that may be incurred as a result of repair work, and did not estimate repair costs for Scotland or Wales. Heat waves, which are also not accounted for, would be likely to pose an additional risk and, if they exceed design standards, could potentially imply additional costs. These extremes are more likely to affect the South of England than other regions. Interviews with stakeholders indicated that overheating is not a major issue for the road network in Scotland.

### 3.4.2 The impacts of rising temperatures on the rail network

There are multiple potential impacts on the rail network and its users due to heat. Broadly, these are:

- rail buckling;
- speed restrictions;
- track work delays; and,
- the sag of overhead equipment..

#### Rail buckling

As summer air temperatures are projected to rise, so are rail temperatures. This is likely to result in more rail buckling<sup>22</sup> in future.

#### Current level of risk

Estimates of the costs of heat impacts on the rail network vary. The 1995 hot summer led to estimated passenger delay costs of £1 million and a similar cost for repair (Thornes, 1997), whilst the 2003 hot summer led to estimated passenger delay costs of £2.2 million as well as maintenance costs of a further £1.3 million (Metroeconomica *et al.*, 2006). The latter costs were also discussed in the CCRA which noted that in that year, there were 137 rail buckling incidents in

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<sup>22</sup> This is defined as a track misalignment serious enough to cause derailment.

England, Scotland and Wales. These incidents led to a cost of about £2.5 million for repairs and delays.

Between 1995 and 2009 there were on average about 50 rail buckling incidents per year in the UK, at a cost of nearly £1 million per year (CCRA: Thornes *et al.*, 2012).

### *Projected level of risk*

The costs of rail buckling will depend on a number of factors, such as air and track temperature, track condition and congestion levels. Rail buckling events could rise to over 120 per year in the 2050s. This is a rise of almost 150%. For England, Scotland and Wales, this could result in repair and delay costs of £2.3 million per year by the 2050s (CCRA: Thornes *et al.*, 2012) under a p50 medium emissions scenario (with a range of £2.1-2.6 million between the low and high p50 scenarios). Note that the projected costs do not reflect the rising value of time to the 2050s (values of time are projected to rise by some 57% in the 2050s than in 2012<sup>23</sup> (DfT, 2012)). Finally, the analysis does not take into account future increases in demand, which could increase the economic costs of rail buckling incidents.

Costs of rail buckling have also been estimated by Dobney *et al.*, (2009). This work suggests that, using a medium-high emissions scenario (using UKCIP02)<sup>24</sup>, the additional 30-year cost by the 2050s above baseline (1961-1990) of buckles and rail-related delays could be £10.3 million (baseline £3.3 million) and £9.2 million (baseline £3.3. million) respectively by the 2050s<sup>25</sup>.

The South of England is likely to continue to be the most affected region. This is important as many busy commuter routes are into and out of this region.

**Table 2** presents a summary of delay and repair costs across a range of studies.

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<sup>23</sup> This is because the value of time is assumed to be related to rising income per capita.

<sup>24</sup> This assumes for the total duration of this time slice the cumulative carbon emissions for each scenario are 1862 GtC

<sup>25</sup> Costs have been estimated using £50 per delay minute.

## Scale of the challenge

**Table 2.** Comparative costs of heat-related rail delay and repair in England, Scotland and Wales

Event	Estimated costs	Categories of cost included	Source
<b>1995 hot summer</b>	£1m	Repair	Thornes (1997)
	£1m	Delay	
<b>2003 hot summer</b>	£2.5m	Repair to rail and delays	CCRA: Thornes et al (2012)
<b>2003 hot summer</b>	£1.3m	Repair	Metroeconomica (2006)
	£2.2m	Delays	
<b>Current rail buckling</b>	£1m per year	Repair to rail	CCRA: Thornes et al., (2012)
<b>2050s p50 medium projection (p50 low and high)</b>	£2.3m (£2.2-2.6m)	Repair to rail and delays in England, Scotland and Wales	CCRA: Thornes et al., (2012)
<b>2050s projection (low to high emission scenarios)</b>	£3.3 - 18.9m (low) and £3.5 - 20.5m (high)*	Delays	Dobney et al., (2009)
<b>For context</b>			
<b>Total annual track maintenance expenditure (2010/11)</b>	£423m	Track maintenance for Great Britain	ORR (2011)

\*This is based on the cost per delay minute of £73.47 and represents the mean plus trend variation.

### Speed restrictions

The TRaCCA project carried out by Network Rail and the Met Office (RSSB, 2012) has developed projections of other effects of heat on the rail network in Great Britain. For South West England, the number of days when speed restrictions are imposed could increase by a factor of between 2.5 and 7 by the 2040s (RSSB, 2011). For Great Britain as a whole, the frequency of speed restrictions<sup>26</sup> associated with track buckle risk and high temperatures are

<sup>26</sup> 30mph and 60mph speed restrictions.

projected to increase. The North and West of the country are projected to see the greatest proportional increases in these impacts, but the majority are likely to occur in the South. Speed restrictions imposed because of hot weather are relatively uncommon. For example there has been an average of 16 days of speed restrictions in the South West across 30 summers between 1971 and 2000.

### *Track work delays*

The number of days when track work is prevented due to overheating is projected to increase across Great Britain by a factor of between 1.5 and 3.5 by the 2040s, with most incidents concentrated in the South East of England (RSSB, 2012). However, the number of track work-days in the baseline period is not particularly high, at 345 days across 30 summers between 1971 and 2000 in Scotland, for example.

### *Sag of overhead equipment*

The sag of overhead equipment was projected to increase by a factor of between 1.5 and 7 by the 2040s. However, the frequency is expected to remain rare (RSSB, 2012) due to the high temperature threshold at which sag occurs (33 degrees). Across the 30 summers between 1971 and 2000 in central England, temperatures exceeded this threshold for 1.4 days.

### *Other influences*

Heat-related rail costs would be expected to rise in the future owing to both projected increases in rail travel (e.g. Rail forecasts suggest annual average growth in passenger kilometres across different routes typically between 2% and 3% to 2034 (Network Rail, 2011)) and the rising value of time as income rises. Both the highest temperatures and rail demand are projected to be greatest in the South East of England.

## **3.5 Landslides in Scotland and Wales**

Landslide hazard is very much associated with mountainous regions. The risk of landslides is likely to be smaller in England than other regions of the UK in future and the associated impacts more limited. This report therefore focuses on Scotland and Wales – the question set for this report excludes England. Thornes *et al.*, (CCRA, 2012) estimated that landslide risk in England would remain broadly similar to today under low to high p50 emissions scenarios.

Thornes *et al.*, (2012) projected that between 50 km and 200 km of trunk roads in Scotland could be at risk of landslides by the 2050s across the p50 low, medium and high emissions scenarios. The length of road at risk could range from 50-200 km under a p10 low emissions scenario to 200-330 km under a p90 high

### **Scale of the challenge**

emissions scenario. The present and future level of landslide risk on roads in Wales is currently being developed (at the time of writing), so this would benefit from more detailed study and data collection over time.

However, although indicative, the length of road at risk does not tell the whole story. In many areas, a landslide could result in the closing of the only route into a village or town. Even the closure of a short length of road could have significant economic impacts. In addition, a road closure as a result of a landslide could have knock-on effects on surrounding roads in terms of displaced traffic or much longer diversion routes being imposed in rural areas.

The impacts of landslides can be substantial, especially when they close roads for long periods. For example, the A85, which carries up to 5,600 vehicles per day, was closed for 4 days in 2004 (Scottish Executive, 2005). The roads at risk are generally in the North and West of Scotland, where levels of precipitation tend to be highest.

No analysis has been carried out by the time of writing on the future risk of landslides on the rail network in the UK. Given the localised nature of each event, it is difficult to model national changes in risk. There are also many complexities involved in the modelling process. These issues precluded the development of projections for the risk of landslides on the rail network for this report. As transport authorities increase their evidence base, this analysis will become possible.

## **Conclusion**

While landslide risk is unlikely to change extensively in future, the costs could be significant for local communities where they are remote and have few, if any, alternative means of travel or access/entry to the area – they could be cut off so action to mitigate this risk would be needed. This assessment is qualified by the limited evidence currently available, particularly for Wales.





## 4 Context for adaptation

### Key messages

- Planning policy and design standards are both important in the context of climate change adaptation. They can significantly affect the resilience of the physical infrastructure and are constantly reviewed and updated. They offer a valuable opportunity to ensure climate change adaptation is accounted for.
- Adaptive capacity of the sector (strategic road and rail) overall is considered to be high.

### 4.1 Introduction

This section focuses on the context for adaptation in terms of the key characteristics of strategic road and rail, the adaptive capacity of relevant (non-government) actors and the policy framework in which they operate.

Whether adaptation action is likely to be taken to address climate threats effectively requires two key factors to be considered:

- **Adaptive capacity (see below):** Adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies, so as to reduce the likelihood and magnitude of harmful outcomes resulting from climate change (Brooks and Adger, 2005).
- **Adaptation actions (see Section 5):** There is a suite of actions that could form part of an effective adaptation strategy. The choice of actions will depend on the capacity of both the organisation and the sector in which it operates, and the climate change risks under consideration – these factors should be considered systematically together with non-climate risks.

Government policy is briefly outlined before exploring adaptive capacity in this Section. The adaptation actions currently being taken, and those likely to be taken in the near-term, are discussed in Section 5.

### 4.2 Key characteristics of strategic road and rail

#### 4.2.1 Infrastructure assets

There is an extensive network of strategic road and rail routes across the UK. Currently, 3,500 km of motorway cross Great Britain, and 46,000 km of A-roads (DfT, 2011a). Northern Ireland has an additional 115km of motorway and 2,300 km of A-roads (DRDNI, 2012a). The length of motorway in Great Britain more than tripled from 1970 to 1994, but increased by less than 10% between

1994 and 2010, while the length of A-roads has increased by 2% since 1970 (DfT, 2011b). This indicates the high level of connectedness that has already been achieved.

There are 16,000 km of rail track in Great Britain (DfT, 2011d), and 340 km of track in Northern Ireland (DRDNI, 2012b). The length of rail in Great Britain has decreased by almost 17% since 1970, although there has been very little change in the last two decades (DfT, 2011d). The length of rail in Northern Ireland has not changed at all in the last 6 years (DRDNI, 2012b). With major infrastructure located across the country, transport will be exposed to some degree of climate change effects.

**The length of local roads far exceeds that of strategic roads in the UK.** There are 344,000 km of local roads in Great Britain (DfT, 2011a) and an additional 22,900 km in Northern Ireland (DRDNI, 2012a). These figures illustrate the importance of local roads as part of the transport system.

**Strategic roads and rail cannot be considered in isolation from local networks because they are intrinsically interconnected and both complement *and* can act as a substitute for each another.** Events and demand on one can significantly affect the other. For example, through re-routing following a disturbance to strategic flows, traffic could divert via local networks and increase congestion.

#### 4.2.2 Infrastructure maintenance and renewal

**Strategic (and local) road maintenance expenditure has been increasing.** Road maintenance costs were £1.3 billion in 2009-10 in England (DfT, 2011c), a doubling since 1996 (at constant prices). Total maintenance and construction costs in Northern Ireland in 2010-11 were £491 million (DRDNI, 2012a). This is an increase of more than 50% since 2006 (and may include expenditure on local roads). Maintenance offers opportunities for adaptation actions and upgrades to be implemented incrementally as part of the natural cycle.

**Rail renewal rates have been high but have fallen recently.** Between 3% and 8% of the rail network in Great Britain is renewed each year (Network Rail, 2011). There has been a decrease in track renewal in the last two years. This is due to the elimination of the backlog of renewals inherited by Network Rail from its predecessor, and increased efficiency.

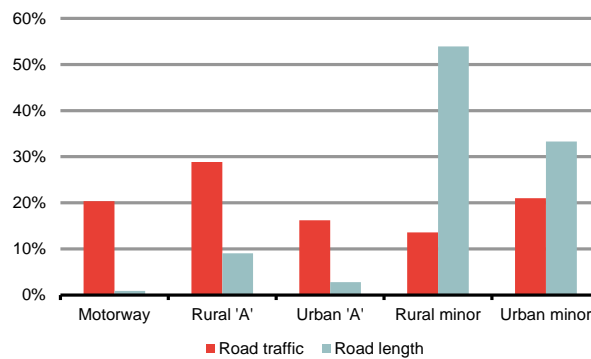
#### 4.2.3 Travel demand on strategic road and rail routes

**Transport infrastructure is used intensively for long periods of the day:** In Great Britain in 2010, 98 billion kilometres were travelled on motorways, and 136 billion kilometres on A-roads (DfT, 2011g). In Northern Ireland in 2009, 1.5 billion kilometres were travelled on motorways and 9.3 billion kilometres on A-roads (DRDNI, pers. comm., 2012). Between 2010 and 2011, 509 million

kilometres of journeys were timetabled on the national rail network (DfT, 2011d). Such intensive use implies any disruption could potentially affect significant numbers of travellers (depending on time of day and location).

**The private car is the most dominant mode of transport** and around 90% of all travel is on roads. The majority (65%) of traffic is on strategic routes in Great Britain, highlighting the importance of strategic routes for economic activities, as illustrated in **Figure 8**.

**Figure 8.** Road length and traffic by road type in Great Britain



Source: DfT (2011a)

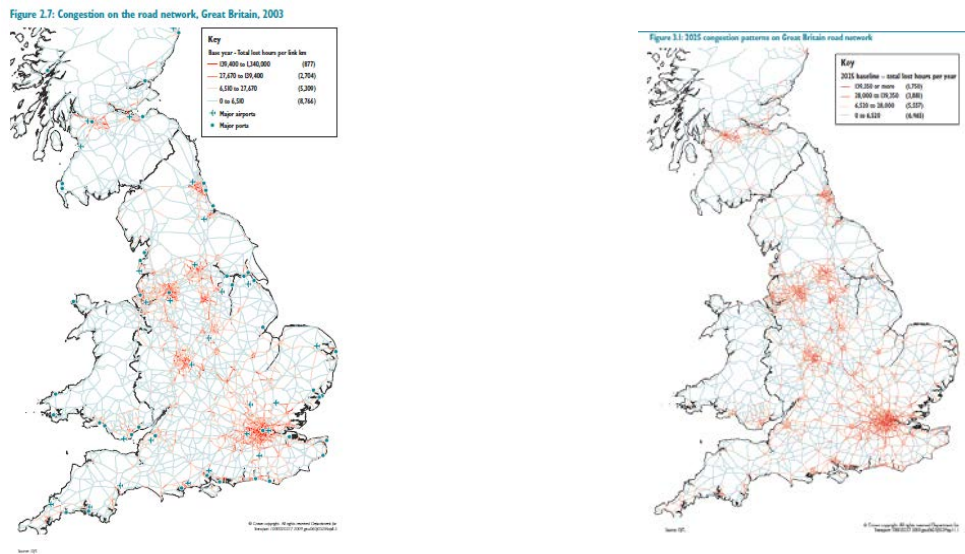
**A wide range of factors will drive travel behaviours** including future policy, relative prices, technology developments (which could reduce the need to travel or change the way we travel), cultural norms, socio-economic factors and urban design. The UK population is projected to increase by 17% between 2010 and 2035 (ONS, 2011), incomes are expected to rise and the pace of technological development is rapidly increasing. Published projections of travel demand typically reflect 'business as usual' assumptions only and not necessarily a change in travel behaviours or cultural norms.

Between 2010 and 2035, total traffic in England is forecast to grow by 44% (DfT, 2012). Stronger growth is projected on rail routes (Network Rail forecasts suggest annual average growth in passenger kilometres across different routes typically between 2% and 3% to 2034 (Network Rail, 2011)).

#### 4.2.4 Performance of the strategic network

**Overcrowding and congestion are important issues for some routes.** In autumn 2010, trains in London and the South East of England carried an average of 3% of passengers in excess of capacity during the morning and evening peak travelling hours (ORR, 2011). Congestion on the roads is currently concentrated in London and other urban centres, as shown in **Figure 9**.

**Figure 9. Recent (2003) and projected (2025) road congestion**



Source: Eddington (2006)

Congestion (time lost per km relative to free flow conditions) occurs more notably in large urban centres. The distribution of locations where congestion occurs is not projected to alter significantly in the future. However, congestion is projected to increase by 30% between 2003 and 2025 (Eddington, 2006)<sup>27</sup>.

If traffic volumes increase in future, as described in the previous section, overcrowding and congestion could increase significantly on both the railway and strategic road networks.

The next section discusses the policy framework in which travel activity and investment activities take place.

### 4.3 Role of the policy framework in adaptation

The Department for Transport is responsible for transport policy in England (including capacity i.e. road length and width), with significant amounts of policy and all infrastructure management devolved to country level. The strategic road network in England is funded by the Department for Transport (DfT) via the Highways Agency which manages and maintains the network. In Scotland, the trunk roads are operated by Transport Scotland, an agency of the Scottish

<sup>27</sup> On monitored roads in Scotland, an average delay of 49 seconds delay was experienced per vehicle kilometre in 2010 (Transport Scotland, 2011).

Government. Trunk roads in Northern Ireland are controlled by the Department for Regional Development, and in Wales the responsible body is the Transport Department in the Welsh Government. These agencies are responsible for managing the strategic road network so they are strongly incentivised to maintain high-flow conditions on the network.

Rail infrastructure in Great Britain is provided by Network Rail which is regulated by the Office of Rail Regulation (ORR)<sup>28</sup>. It operates under license awarded by the Secretary of State for Transport<sup>29</sup>. Network Rail receives substantial grants from DfT and Transport Scotland as well as additional funding from local authorities and others for specific infrastructure projects (plus revenue from train operators who pay to use the track). Rail in Northern Ireland is operated by Translink. Public provision of such infrastructure means that it is subject to the financial budgeting of Government.

Adaptation actions would therefore be largely under the influence of government, Network Rail and the rail regulator.

### 4.3.1 Devolved Administrations

#### *Scotland*

Scotland's Climate Change Adaptation Framework - Transport Sector Action Plan (Scottish Government, 2009) outlines the consequences of climate change for Scotland and discusses integrating adaptation into public policy and regulation. The work of adapting the transport sector to climate change has already started through the Scottish Road Network Climate Change Study (Scottish Government, 2005) and the Scottish Road Network Landslides Study (Scottish Executive, 2005), but this adaptation work needs to continue to ensure that procurement of transport infrastructure and services takes account of adaptation.

The Adaptation Framework also identifies the key challenges for Scotland's transport infrastructure, for example, that road and railway lines at greatest risk of flooding or damage should be identified and mapped.

#### *Wales*

Legislative powers related to highways and transport are devolved to the Welsh Government. Under the 1980 Highways Act, the Welsh Government shares responsibility for the Welsh railways network franchise with the Secretary of State for Transport. The Transport (Wales) Act 2006 requires the Welsh Government to publish a strategy outlining the Government's policies to ensure

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<sup>28</sup> The regulator ORR is needed because the railways infrastructure system is a natural monopoly.

<sup>29</sup> [http://www.rail-reg.gov.uk/upload/pdf/netwrk\\_licence.pdf](http://www.rail-reg.gov.uk/upload/pdf/netwrk_licence.pdf)

safe, efficient and sustainable transport policies in Wales, which inevitably enhances adaptation.

Under the Wales Transport Strategy (Welsh Assembly Government, 2008), the Welsh Government is working with rail and road partners to link the climate change adaptation plan with existing and planned transport infrastructure.

### *Northern Ireland*

Preparing for a changing climate in Northern Ireland emphasises the need to improve and monitor infrastructure and emergency planning to account for the effects of climate change. Ensuring a Sustainable Transport Future - A New Approach to Regional Transportation outlines how the Department will develop regional transportation beyond 2015, setting out a number of objectives covering the economy, society and the environment.

#### **4.3.2 UK infrastructure policies**

There are several specific policies that provide important context in relation to adapting to climate change.

### *Planning Act 2008*

The Planning Act 2008 introduced an Independent Infrastructure Planning Commission to review nationally significant infrastructure projects. Section 87 of the Planning Act 2008 states that when the commission reviews nationally significant infrastructure projects, the authority must have regard to any guidance issued by ministers before projects can be approved (Department for Communities and Local Government (DCLG), 2008). This guidance comes in the form of National Policy Statements that require consideration of climate change adaptation in all planning applications.

The National Networks National Policy Statement (NPS) will determine planning policy for strategic road networks, rail networks and freight interchanges over a certain size (CCRA: Thornes *et al.*, 2012). The statement requires that adaptation measures and any critical safety elements of the proposed infrastructure are assessed against the more extreme climate change scenarios. The National Networks NPS should facilitate the development of climate resilient infrastructure, but it is not yet finalised.

Guidance such as the Strategic Rail Freight Interchange Guidance (DfT, 2011j) has been produced to help the Infrastructure Planning Commission with its decision making. The guidance outlines how the infrastructure sector needs to support the development of low carbon technologies and options that improve adaptation and encourage the transfer of freight cargo from road to rail (DfT, 2011j).

## **Context for adaptation**

The National Planning Policy Framework (NPPF) outlines the government's prescriptions for the planning system. Combined, the NPPF and the NPS will require applications for significant road and rail infrastructure to account for the government's policies around mitigation and adaptation<sup>30</sup>.

### *Climate Change Act 2008*

The Climate Change Act 2008 introduced a new power for the UK Secretary of State for the Environment to direct “reporting authorities” (companies with functions of a public nature such as water and energy utilities) to prepare reports on how they are assessing and acting on the risks and opportunities from a changing climate<sup>31</sup>. Network Rail and the Highways Agency submitted reports on the predicted impacts of climate change on the functions of the rail network and a list of proposals on the policies for adapting to climate change.

In combination with the National Networks NPS, the Adaptation Reporting Power, which requires that all companies assess the risks to their current and future assets in relation to climate change will oblige road and rail infrastructure project assessments to incorporate considerations of climate change. Thus, the Adaptation Reporting Power should help deliver infrastructure that is capable of being operated effectively within changing climates.

## 4.3.3 Rail Policy and Strategy

### *Network Licencing*

Network Rail is the owner and operator of most of the rail infrastructure in Great Britain. It operates under a Network Licence from the Department of Transport that sets out the conditions under which it must operate. The purpose of the licence is to secure the efficient operation and maintenance, renewal and replacement, and improvement and development of the rail network. This condition also includes specific obligations surrounding asset management, replacement and maintenance standards.

Network Rail is subject to the regulation of the ORR. As a monopoly, ORR reviews the access charges Network Rail imposes on train operators for the use of the track. Such reviews establish the revenues and associated financial framework required for Network Rail to operate, maintain and renew its infrastructure. This periodic review is normally carried out once every five years. The next review will be completed in 2013. The outcome of the review is a determination by ORR of the access charges paid by the train operators, of the

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<sup>30</sup> <http://infrastructure.independent.gov.uk/legislation-and-advice/national-policy-statements/>

<sup>31</sup> <http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/>



direct government funding and of outputs for a 5-year Control Period. The next Control Period starts on 1<sup>st</sup> April 2014.

With climate change projected to lead to an increase in extreme weather events along with changes in average mean temperatures, the maintenance, replacement and operations of the network will all be affected. Consequently, Network Rail will have to account for these changes if the network is to meet its licence requirements (Network Rail, 2011).

### *Rail Design Standards*

Network Rail is aware of the potential impacts of climate change on the network and is carrying out research through the Rail Safety and Standards Board (RSSB) in areas, such as drainage and track resilience, that may be impacted by climate change (DfT, 2010). The majority of the rail network was built with drainage systems that were designed to cope with rainfall and flooding levels experienced in the 19<sup>th</sup> and 20<sup>th</sup> centuries. Projected changes in climate could therefore exceed capacity of drainage system in some cases.

Under the Department for Transport's Departmental Adaptation Plan (2011h), planned research to underpin policy development through bodies such as the RSSB has been highlighted. This research looks to quantify the impacts of climate change and identify and stimulate adaptation measures that can help build the future resilience of the network. Further discussion on the implementation of measures is included in Section 5.

### *Strategic Road Design Standards*

Guidance on the impacts of climate change on highway drainage systems was included in the latest iteration of the Design Manual for Roads and Bridges (DMRB) (Highways Agency, 2012). DMRB was introduced in 1992 (and updated regularly) in England and Wales, and subsequently in Scotland and Northern Ireland. It provides a comprehensive manual which accommodates all current standards, advice notes and other published documents relating to the design, assessment and operation of trunk roads (including motorways)<sup>32</sup>. Further discussion on the implementation of the standards is included in Section 5.

The HA is also developing a series of adaptation plans, each covering an individual aspect of the HA's responsibilities and assets. Structure, pavements, drainage systems are, among others, all given their own adaptation framework.

The HA has reviewed the design codes that it uses for infrastructure and has deemed them sufficient.

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<sup>32</sup> <http://www.dft.gov.uk/ha/standards/>



#### 4.3.4 Importance of Interdependencies

Road and rail networks are heavily interconnected, with failures on one part of the network likely to lead to temporary shifts or impacts on other. This ‘cascade effect’, if large enough, could result in capacity failure on parallel networks (URS, 2010). Within government engagement in this issue is increasing; for example, the Department for Transport recently produced an internal paper to highlight sector interdependencies so that they are accounted for within the Department’s adaptation and contingency planning (DfT, 2010). These issues will be discussed further in Section 4.

#### 4.3.5 Overview of role of government in adaptation

Government therefore ensures climate change adaptation is accounted for in the provision of new strategic road and rail infrastructure through the planning system and design standards. For existing infrastructure, adaptation is reflected through licence agreements, design standards and maintenance schedules.

What is not clear is the extent to which climate change adaptation is considered alongside other, potentially conflicting, policies that are not directly concerned with maintaining and renewing the existing infrastructure or additions to it.

Furthermore, the policy landscape may be affected further by the recent announcement to review privatising road infrastructure.

##### *Road infrastructure and financing*

In his speech on March 19<sup>th</sup> 2012 at the Institute of Civil Engineering, the Prime Minister David Cameron said:

*“We need to look urgently at the options for getting large-scale private investment into the national roads network; from sovereign wealth funds, from pension funds, from other investors. That is why I’ve asked the Department for Transport and the Treasury to carry out a feasibility study of new ownership and financing models for the national roads system and to report progress to me in the autumn. Let me be clear: this is not about mass tolling and, as I’ve said, we’re not tolling existing roads; it’s about getting more out of the money that motorists already pay”.*

The outcome of this feasibility study could affect the provision and management of UK road infrastructure.

### 4.4 Adaptive capacity

For the purposes of the ECR, adaptive capacity, or the ability to adapt, is analysed using a simplified framework informed by the Performance Acceleration

through Capacity Building (PACT)<sup>33</sup> model (Ballard *et al.*, 2011) and the “weakest link” hypothesis<sup>34</sup> (Yohe and Tol, 2002; Tol and Yohe, 2006). Both PACT and the weakest link models introduce the idea of discrete levels of an attribute and allow identification of where an actor is now and where they would like to be, while illustrating the areas that need most development to get to the desired end point (Lonsdale *et al.*, 2010).

This project defined adaptive capacity using the CCRA definition:

### Adaptive capacity

“The ability of a system/organisation to design or implement effective adaptation strategies to:

- Adjust to information about potential climate change (including climate variability and extremes);
- Moderate potential damages; and,
- Take advantage of opportunities, or cope with the consequences”

Source: Ballard *et al.*, 2011 (CCRA – modified IPCC definition to support project focus on management of future risks)

Adaptive capacity refers to both the structural capacity within the overall sector, and also the capacity of different actors in the transport sector. The assessment of these factors allows exploration of the ability of actors to implement effective climate change adaptation measures.

In assessing the ability of the strategic road and rail sectors to adapt to projected impacts of climate change, this project considers two factors: the **structure** of the sectors in general terms (i.e. the role and size of different organisations involved), and the **organisations** in the sectors - the function of key players who make critical decisions and their performance (i.e. gross margins, outputs and benefits delivered). An analysis of these two factors will describe the ability of the

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<sup>33</sup> This model was chosen as it was used in the CCRA, which this project follows, and because in a UKCIP review of adaptation tools it was ranked as the most robust (Lonsdale *et al.*, 2010). The PACT model identifies six clear stages of development when organisations take on the challenge of climate change. These are called response levels (RLs) rather than stages as each level is consolidated before moving to the next. RLs 2 and 3 are characteristic of ‘within regime’ change, RL4 is characteristic of ‘niche experimentation’ (or ‘breakthrough projects’) and RL5 is conceptualised as regime transformation. RL6 would be conceptualised at the landscape level. In this report, the RLs were used very simplistically as a comprehensive assessment of the adaptive capacity of the sector using PACT could not be undertaken. It is recommended that this be undertaken in further work.

<sup>34</sup> The weakest link hypothesis enables assessment of the potential contribution of various adaptation options to improving systems’ coping capacities by focusing on the underlying determinants of adaptive capacity. In this report, the determinants were used to assess capacity of an actor rather than an adaptation option. This was used as it provides socioeconomic indicators by which an actor’s adaptive capacity may be categorised. It enables the weakest part of an actor’s capacity to be shown providing an area to focus adaptation responses.

## Context for adaptation

sectors to adapt to climate change and the extent to which the opportunities and risks described in Section 3 are likely to be addressed. It should be noted that adaptive capacity is not only needed to optimise decisions based on climate change adaptation, but for other decisions with long term implications (Ballard *et al*, 2011).

#### 4.4.2 Structural adaptive capacity

Structural adaptive capacity can be used to **identify specific types of decisions where further assessment of climate change implications will be important**. These are related to the construction, maintenance and refurbishment of road and rail infrastructure.

In general, the strategic road and rail sectors have comparatively few structural barriers to adaptation actions. The longer term challenges are already being explored in detail by the Highways Agency, Network Rail and others; this is leading to the development of strategies to increase resilience (Ballard *et al*, 2011).

##### *Sector complexity*

A small number of organisations drive adaptation actions in the rail sector. Network Rail plays a core role in the sector and designs many of its own standards; these are generally adopted with minor modifications by the devolved administrations (Ballard *et al*, 2011). All transport infrastructure sits within a wide transport network so other organisations are also important, either setting mandatory standards or, where adaptation actions are not driven by standards, having the discretion to specify what adaptation should be delivered by the infrastructure provider. These organisations include European Rail Agency (which is responsible for setting the technical Standards for Interoperability), Eurotunnel, Transport for London, Northern Ireland Rail, Transport Scotland, the Department for Transport (DfT), the Technical Strategy Advisory Group (TSAG), the Rail Safety and Standards Board (RSSB) and the Office of Rail Regulation (ORR).

For strategic roads, sector complexity is also low, with the network managed by single organisations in England (Highways Agency) and in the devolved administrations.

While the supply chain for both sectors involves many organisations, Network Rail and the Highways Agency in England control operations directly and have a strong influence over the actions of others.

##### *Interdependencies*

The management of strategic roads and rail involves a range of interconnected sectors and stakeholders. Interdependencies with other sectors include Information and Communication Technologies (e.g. for active traffic management); power (e.g. for electrified rail and, increasingly, vehicle

electrification); other infrastructure-related sectors (e.g. where there is shared infrastructure); service companies (e.g. insurance providers), and those dependent on the strategic transport network (e.g. emergency services).

These interactions can lead to trade-offs between immediate service delivery and building network resilience. Such potential trade-offs highlight the need for organisations active in the transport sectors to work with others in designing resilience.

### *Decision lifetime*

The decision lifetimes for both strategic roads and rail vary from 20 and 35 years (e.g. for base and sub-base layers of pavement) to 40 years (e.g. some track systems), to 60 years (e.g. some drainage, cuttings and embankments) to over 100 years (e.g. tunnels, retaining walls, bridges, and culverts). In practice, some routes experiencing high traffic volumes (and some components) may experience more frequent renewal (HA, 2011a).

### *Activity levels*

While the decision lifetime is long for some structures, for both the road and rail sector decisions are made frequently. By the beginning of the 2050s, rail tracks will typically have been replaced once (and in a few instances more than once) and road surfaces replaced at least twice (HA, 2011a, Network Rail, 2011). Many drains will also have been replaced on that timescale. Given projected levels of investment, there are likely to be natural opportunities for focused adaptation (and opportunities to avoid maladaptation). The extent of replacement and increasing resilience of road and rail networks depends on the extent of central government funding for the renewal and improvement of the assets.

### *Maladaptation*

Maladaptation refers to “Actions or investments that enhance vulnerability to climate change impacts rather than reducing them.”(UKCIP, 2012).

In both strategic road and rail, there are low or moderate levels of maladaptation. There are some examples of drain undersizing, presenting a greater flood risk, although additional costs of replacements are not considered to be excessive by experts in the HA and Network Rail. Future investments could address these risks. Bridges and earthworks have typically been designed with significant tolerance (Ballard *et al*, 2011).

The level of exposure to rail buckling is low, as pre-stressing is part of standard procedures. For roads, pavement design has factored in higher anticipated temperatures (Highways Agency, 2011a).

## **Context for adaptation**

#### 4.4.3 Organisational adaptive capacity

**Table 3** summarises adaptive capacity of actors in the strategic road and rail sector. Unless otherwise specified, the data has been compiled from Ballard *et al* (2011), interviews with stakeholders, experts and review of HA and NR documents and procedures.



**Table 3.** Organisational adaptive capacity

Actor	Resources	Processes	Organisation	Summary
<b>Rail Infrastructure (particularly Network Rail)</b>	<p><b>High:</b> Strong expertise and in-house knowledge.</p> <p>Resources currently allocated for climate change; budgets are dependent on government spending priorities.</p>	<p><b>Medium:</b> Adaptation programmes are becoming embedded in operational decision-making (Ballard <i>et al</i>, 2011).</p> <p>Network Rail procurement typically goes for standard, safe, proven technologies reducing innovation in value chain.</p> <p>A number of strategic challenges have been identified through research projects; these are not yet translated into a strategy for resilience (Ballard <i>et al</i>, 2011).</p>	<p><b>High:</b> Network rail standards and reporting requirements drive senior engagement in climate change (Ballard <i>et al</i>, 2011).</p> <p>Strong industry networks (e.g. RSSB and others).</p>	<b>Medium/High</b>
<b>Highways Agency</b>	<p><b>High:</b> Strong expertise and in-house knowledge.</p> <p>Prioritised and funded programme of activity; funding dependent on government priorities.</p>	<p><b>Medium/High:</b> Processes to understand climate risks and embed into operational systems well established (HA, 2011a).</p> <p>Can take many years to change design standards.</p>	<p><b>High:</b> Strong top management support.</p> <p>Networks for practitioners exist such as UK Road Liaison Group.</p>	<b>High</b>
<b>Local Authorities (non-trunk roads)</b>	<b>Medium:</b> Varies considerably across LAs	<b>Medium:</b> Varies across LAs. Asset management approaches can encourage action.	<b>Low/Medium</b>	<b>Medium</b>

Adaptive capacity of the organisations responsible for strategic transport infrastructure is considered to be high; while not assessed in detail, experts consider the adaptive capacity of local authorities to be variable. There are a number of key implications for the extent of adaptation actions arising from this analysis:

- **Stakeholder responsiveness:** The government sets objectives and the infrastructure owners or managers develop standards they need to set in order to meet those objectives. As such, organisations like Network Rail are incentivised to adapt to climate change risks because the objectives set by the ORR (to meet the broader Government objectives) include a reliability target as part of its licence.

Therefore, Network Rail has a high degree of control over decision-making on railway infrastructure; similarly the Highways Agency sets the direction for strategic roads (Ballard *et al*, 2011). These include, for example, five year output specifications from the DfT, High Level Output Specification validated by the ORR, and multiple standards followed by Network Rail and the Highways Agency. These requirements are then followed by companies in the transport infrastructure supply chains (e.g. engineering firms, equipment manufacturers etc.) as well as in many cases by local authorities.

- **Managing vulnerability:** there are on-going efforts to address short-term (less than 5 years) vulnerability to natural hazards; these are co-ordinated by the Civil Contingencies Secretariat at the Cabinet Office which has established a Critical Infrastructure Resilience Programme (Cabinet Office, 2010).
- **Efficient management:** The Highways Agency and Network Rail have a good understanding of risks; they both have established and well-resourced research programmes. These programmes are firmly embedded within the organisations and there are strong industry-level organisations (e.g. RSSB). This does not always apply to organisations responsible for minor roads where there is variation in effectiveness of management approaches (Ballard *et al*, 2011). Furthermore, there are many incidents that are not related to climate change but that require broadly similar management techniques which are used by the HA and Network Rail
- **Breakthrough projects:** There are several examples of projects in the Highways Agency to understand priority risks and potential responses. In many cases, this tends to translate into specification development at delivery level. In rail, climate change considerations are increasingly factored into assessments of asset resilience; the use of strategic experimentation is more emergent with a number of studies in place. (Ballard *et al*, 2011).



- **Business transformation** (including co-ordination across the sector): an understanding of what “strategic leadership” looks like is developing in highways organisations (Ballard *et al*, 2011); a similar development can be seen in Network Rail. A key issue for the sector is the role of the DfT and central government, who set the priorities which will influence the extent to which the sector can build its resilience.



## 5 Adaptation actions

### 5.1 Introduction

This section provides an overview of some of the categories of actions different actors in the sector are already taking, and would be expected to take in order to maximise opportunities or minimise risks. The categories include actions to build adaptive capacity as well actions that reduce the particular risks of climate change. These categories of actions were informed by literature review and discussions with sector experts. They were then refined and verified in the stakeholder interviews (Annex 1). The interviews were conducted under Chatham House Rule, and so in this report the stakeholders are not referred to individually or by name.

Much of the literature on adaptation to climate change has been at a conceptual or generic level (Adger *et al.*, 2007; Howden *et al.*, 2007;). This has shaped the understanding of what adaptation is, and the importance of the processes and responsibilities regarding adaptation. However, less research exists to quantify the predicted effects of adaptation actions on transport networks.

For the purposes of the ECR, the adaptation actions considered are those that are already being taken, or are expected to be taken. The actions include:

- **Planned adaptation:** this tends to be (but is not exclusively) anticipatory adaptation, undertaken or directly influenced by governments or collectives as a public policy initiative. These actions tend to represent conscious responses to concerns about climate change (Parry *et al.*, 2007).
- **Reactive adaptation:** is taken as a reactive response to climatic stimuli as a matter of course (without direct intervention of a public agency) (Parry *et al.*, 2007).

In some cases, actions could be considered both planned and reactive (for example, a reactive response to a current risk could lead to planned adaptations to limit future exposure). Both planned and reactive adaptations might be 'wrong' or lead to maladaptation, in the long term or for wider society, and may need to be countered with further action, such as building adaptive capacity and by taking specific actions to change and deal with the consequences.

Given the complexity of different engineering (and other) measures, adaptation actions are organised in categories according to key risks. They are intended to cover both strategic road and rail. In each category, measures include future-proofing of designs, retro-fit solutions, developing contingency plans, updating operating procedures, monitoring and research (Highways Agency, 2009).

There is a suite of actions that could form part of an effective adaptation strategy. The choice of actions will depend on the adaptive capacity of the organisation, the sector in which it operates, interdependencies, and the climate change risks under consideration. These factors need to be considered systematically together with all non-climate risks.

The list of actions set out here is not exhaustive, but is intended to illustrate the key types of responses to climate change that actors in the transport sector are taking or will take without government intervention. There are a number of measures not included as the level of understanding of existing implications is low; in particular managing travellers' behavioural response to extreme weather events could be a key part of an effective adaptation strategy.

In a number of cases similar measures are included under different bundles (e.g. pavement design specifications, maintenance schedules, drainage options), to reflect the different risks they are addressing.

Each measure is considered using the same approach: the measure is described, before assessing the current and anticipated level of uptake. The assessment of uptake is based on analysis of the key barriers and enablers and the extent to which they are likely to be significant. Finally an initial view of the potential effect of the measure is discussed. Each of these variables is categorised into high, medium or low (these were validated by a selection of stakeholders and experts).

This report has considered measures individually; naturally each measure could have a co-benefit or interdependency with others. For example, traffic flow management in one area could increase traffic in others, or travel on other modes. Such knock-on impacts should be considered in the decision-making process alongside interdependencies across sectors.

### 5.1.1 Generic adaptation actions

#### *Information systems for infrastructure managers*

Several experts in the sector have mentioned the importance of information systems as an 'enabling' measure; they support the response to multiple risks. Information systems take many forms but common to all is that they involve the use of a central repository of consistent data, often at the geographical level based on a Geographic Information System (GIS) platform.

While there are many systems in place, accountability for particular routes is often devolved to local authorities. Several experts mentioned opportunities for integration and co-ordination to improve the comprehensiveness and effectiveness of systems deployed. Assuming there is agreement among CEOs of relevant organisations, the development of common standards and platforms and sharing of data could occur over the next ten years.

## Adaptation actions

It is expected that economies of scale in data collection and their role in facilitating action would incentivise the use of such systems. However, the number and diversity of organisations (e.g. National Grid, British Waterways, Transport Scotland etc.) and data sources involved could be a barrier to co-ordination.

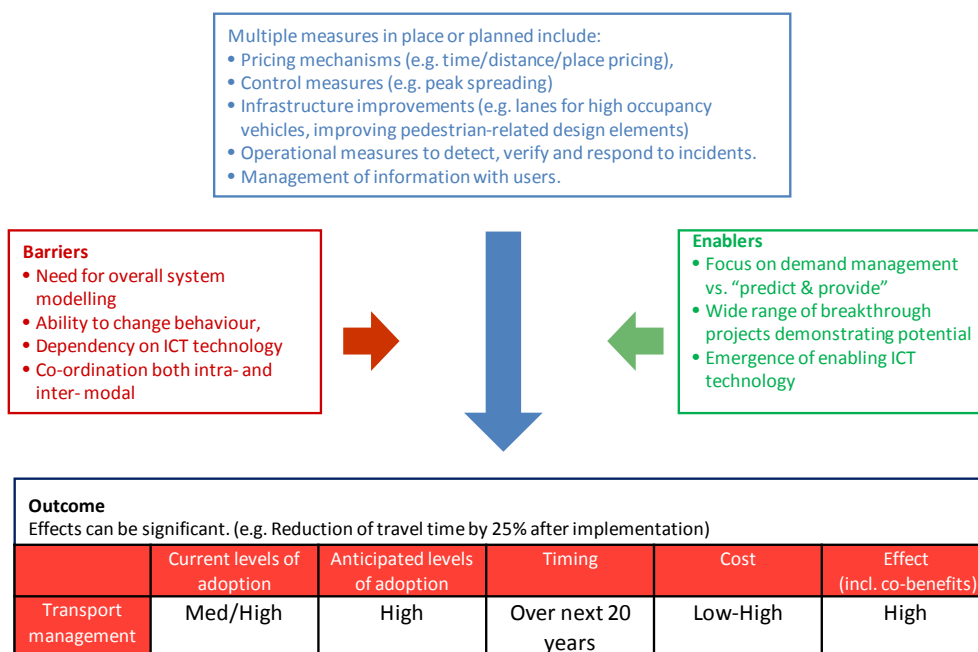
Without consistent recording it is not possible to analyse and compare different events; this measure is important to ensure climate risks can be integrated into asset management plans. This type of measure is often planned adaptation to strengthen the adaptive capacity of the transport system.

### *Travel demand management and traffic flow management*

Travel demand management includes multiple measures intended to manage the projected growth in traffic, and may also help reduce disruptions following an event, and to minimise the risk of some (or secondary) incidents. Examples of these measures include pricing mechanisms (e.g. parking charges and, in central London, time, distance and location pricing), control measures (e.g. speed restrictions, traffic diversion information) and capacity utilisation (e.g. high occupancy lanes (HOV)), hard shoulder running. Some of these are also used as traffic flow measures, along with others, to manage the impacts of incidents. Common to all of these is the high value of information flows between infrastructure operators and travellers. Key issues are summarised in **Figure 10**.

The Highways Agency currently has an extensive network of around 1,500 Traffic Officers who are responsible for clearing incidents on England's motorway network, and reducing the risk of secondary incidents. The current level of adoption of demand management measures (excluding pricing and HOV lanes) is high on the motorways, but it is lower on trunk roads ('A' roads are also managed by the HA) because signage systems and Traffic Officers do not operate there.

**Figure 10.** Travel demand management and traffic flow management



Source: Based on evidence from published sources and stakeholder interviews

Given the high capital costs and environmental implications of adding new capacity to the transport network, demand management is increasingly relied upon to improve the efficiency of travel flows. Hence there is a distinction between traffic demand management (which is usually taken to mean reducing the projected growth in traffic volume often in urban areas) and flow management (which aims to increase the volume and smooth flow of traffic). For example, since the first project on the M42 starting in 2005, the emphasis on active traffic management has increased (Highways Agency, 2007). There is also a wide range of breakthrough projects based on other measures, many of which could be rolled out more widely. In the future, it is likely the use of technology to manage transport demand will become far more prominent (e.g., OST, 2006).

Both academic experts and experts from within HA and Network Rail have identified the importance of understanding traveller response when considering management of incidents and weather events. This can include appreciating the extent to which people do not understand instructions or do not follow instructions as they know better, or decide to take a quicker route which rapidly becomes sub-optimal when there are many users of it. This assessment is critical to understand the case for this adaptation action and to assess the effectiveness of actions implemented. Although such methods are improving and are being developed in some cases, several interviewees identified this as a barrier to effective decision making. Particularly for extreme weather events, such as floods,

## Adaptation actions

which are highly localised and subject to local travel behaviours and transport capacity.

A barrier relevant to both road and rail is the need for overall system modelling which accounts for the interactions of modes, capacity limitations and impacts of different climate change risks (Baker *et al.*, 2009); however it is noted road traffic assignment models such as CONTRAM can provide a good indication of the implications of re-routing (though not of the more delayed responses such as mode shift). There are also a number of barriers identified by several experts affecting specific measures such as the ability to change behaviour, dependency of ICT technology (which could be an issue under extreme weather events if not backed up) and co-ordination across transport operators (including between different modes).

An important factor in managing demand is the channel of information. According to experts, many people would trust informal sources of advice (friends, internet sites, etc.) than official sources. This could be a barrier to the effective provision of official information.

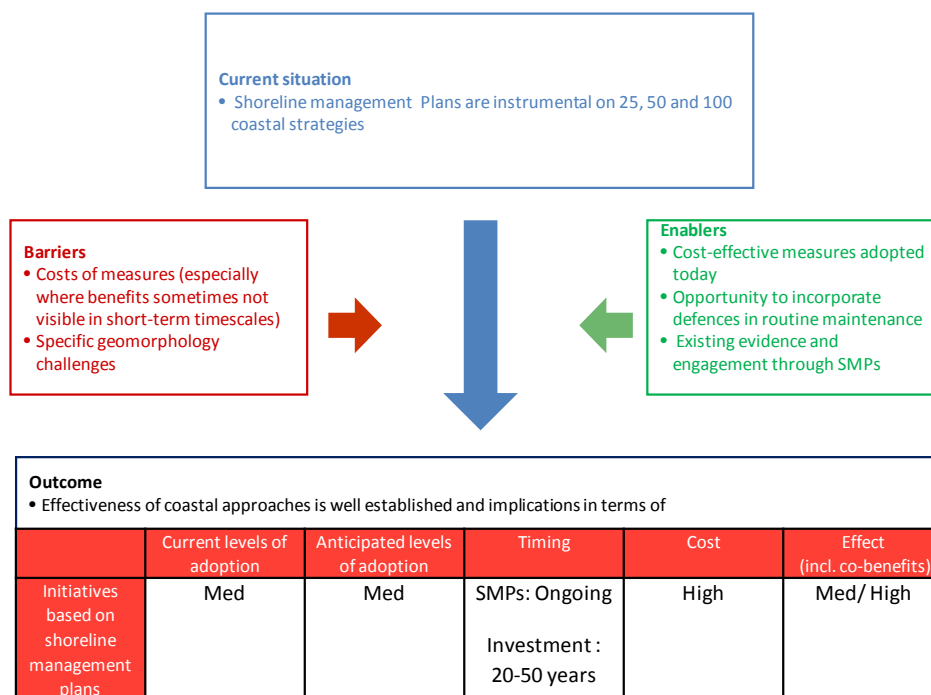
Many studies, both in the UK and internationally, highlight the potential effect of transport demand management. For example, one study assessed the response to road closure over several months; under this situation, 15% of road users change transport mode, 50% changed route; 40 % changed time of travel and route – and only 10% change destination or did not make trip (Department of Transport and Main Roads, 2010).

Several routes such as the M42 already rely on demand management measures; where such measures exist they have the potential to lower the cost associated with a climate change event. For instance, the high level of effectiveness of specific ‘flow management’ measures has been well documented. For example, a review of the M42 managed motorway indicated that journey times reduced by up to 25% and accidents reduced from 5 per month to 1.5 per month (Highways Agency, 2007). More fundamental reductions in the projected growth in travel (traffic demand management) would mean that disruption costs associated with a climate change event would be reduced in the longer term, i.e. there would be fewer vehicles affected by adverse events.

### 5.1.2 Managing Coastal Flooding

Measures involved include developing a strategy for shoreline management (protecting coastal assets) and flood barriers. These measures may be planned or reactive in response to future climate projections and include actions to respond to a specific risk. Key issues are summarised in **Figure 11**.

**Figure 11.** Summary of coastal defence options



Source: Based on evidence from published sources and stakeholder interviews

The process of developing Shoreline Management Plans (SMPs) is well established (EA 2012). The Environment Agency, SEPA and local authorities (especially those in Scotland) have worked to develop 20, 50 and 100 year coastal strategies. These activities are seen by several expert interviewees as an enabler to encourage investment in future defences.

While SMPs will increase understanding, there will be specific challenges based on geomorphology with some parts of the coastline difficult to manage (Policy Research Corporation, 2009). Furthermore there is an ongoing debate as to whether rail lines should form part of the coastal defences in some locations; this would increase total costs to build and maintain than if there was a separate defence (but reducing those incurred by Network Rail).

There are a range of different coastal flooding approaches. The effectiveness depends on the specifics of a given strategy. This can include: “no active intervention”, “hold the line” (maintain existing flood defences where standard of protection would gradually reduce, or sustain present standard of protection as sea levels rise, or improve defences to achieve alignment with relevant standards (FCDPAG3), “Managed realignment of the frontage” or “advance the line” (e.g. Exe Estuary Partnership, 2011). In some cases stakeholders have mentioned examples of maladaptation (e.g. protection of property and exposing transport infrastructure).

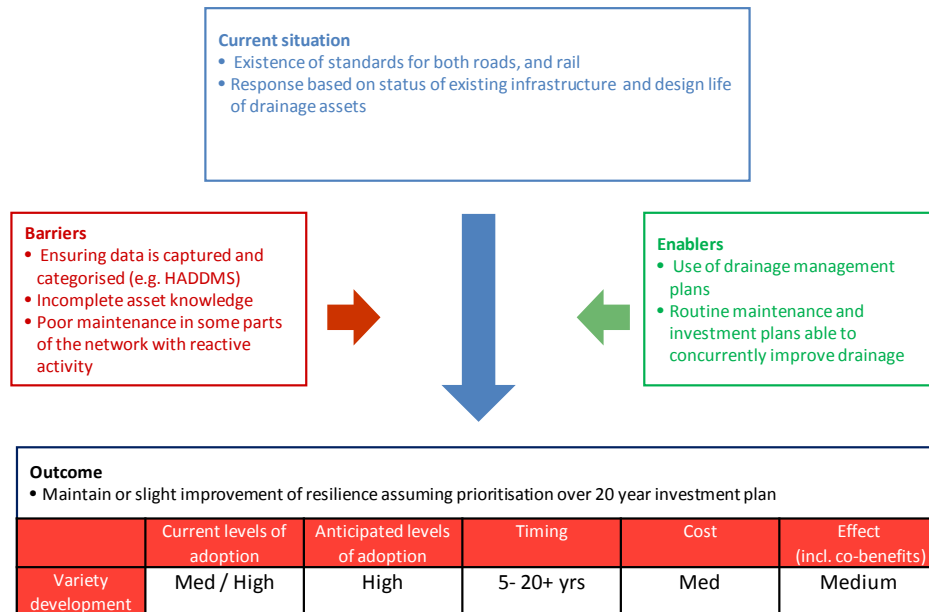
## Adaptation actions



### 5.1.3 Managing surface water flooding

Measures involved include improving drainage capability for roads and rail. For roads, pavement design is also an important factor. These measures may be planned or reactive in response to future climate projections and include actions to respond to a specific risk. Key issues are summarised in **Figure 12**.

**Figure 12.** Summary of options to avoid or manage surface water flooding



Source: Based on evidence from published sources and stakeholder interviews

Standards exist for both strategic road and rail operators to address surface water flooding. For example, for strategic roads, guidance on climate change impacts was included in the latest revisions of highways drainage standards (DMRB HD 33 and HD 45) (HA, 2011b).

With improved understanding of drainage capabilities and information to produce management plans, experts suggest uptake of measures with greater effectiveness is likely to increase on the railways over the next 10 years.

Similarly on the strategic road network, there are multiple examples of efforts to renovate drainage, pumping stations etc. (e.g. TfL, 2011). These are supported by detailed flood-risk maps through co-ordination with the Environment Agency, water companies and others (e.g. TfL, 2011). However, on the highways, there is no requirement to retrofit drainage built prior to the 2006 design standards to cope with climate change unless there is an identified operational risk (HA Asset Management Office, 2011)

The ability to respond and the associated extent and cost depends on the status of the existing infrastructure. For strategic roads, a significant proportion of the

drainage asset will reach the end of its design life over the next thirty years (especially motorways built in the 1970s), (HA, 2011b). This provides opportunities for higher specifications to be implemented, where there is a case for doing so.

Network Rail is developing its knowledge of its assets so as to understand how well its existing drainage facilities are likely to cope with surface water flooding. More systematic responses are also being developed (e.g. through Network Rail's Integrated Drainage Policy)

On strategic road infrastructure an important barrier is ensuring data are captured and categorised appropriately on Highways Agency Drainage Data Management System (HADDMS) (HCR, 2011); while 37,000 drainage assets are recorded on HADDMS, 27,000 had not been assessed and have a recorded risk status (HA Asset Management Office, 2011). Once information is available, experts suggest that the Agency would be capable of producing more detailed management plans. A further barrier relates to the lack of information on the effectiveness of flood adaptation measures, i.e. ex post evaluations. This is needed to learn past lessons and to guide future best practice.

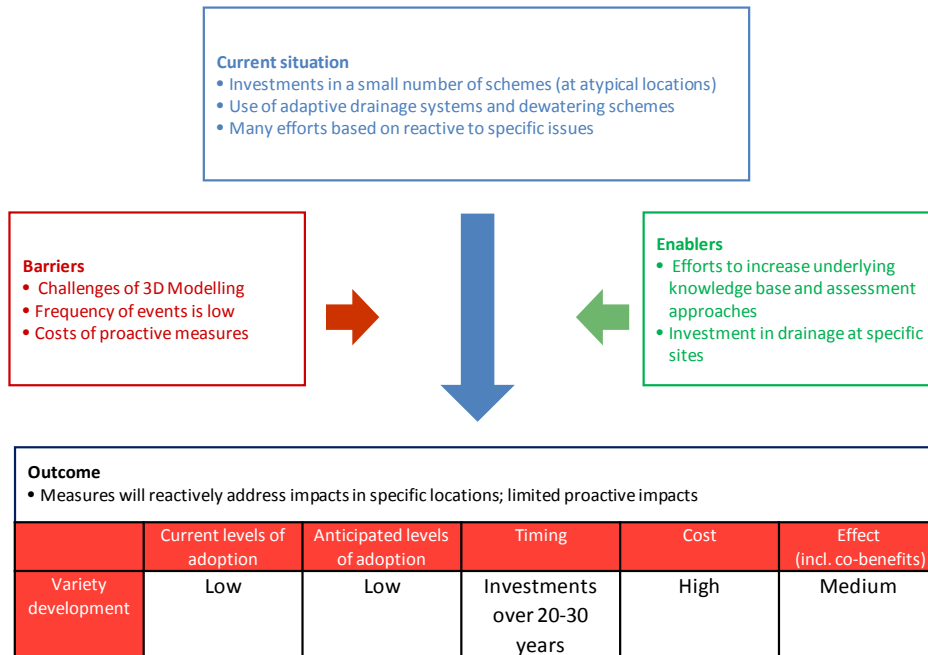
With appropriate prioritisation over its 20-year investment plan, experts within Network Rail have identified the potential to improve resilience of networks and maintain, or slightly improve, the level of performance (despite changes in climate variables).

For road, despite engineering measures, the level of residual risk from surface water flooding identified by the Highways Agency remains high; however for strategic routes, the impacts on road users can be addressed through traffic management (though it is noted that if a road is flooded and closed, traffic management involves a welfare and economic cost because of diversion to another route).

#### 5.1.4 Managing groundwater flooding

Measures involved include adaptive draining systems and dewatering schemes, often combined with on-going monitoring. These measures may be planned or reactive in response to future climate projections and include actions to respond to a specific risk. Key issues are summarised in **Figure 13**.

**Figure 13.** Summary of options to address groundwater flooding



Source: Based on evidence from published sources and stakeholder interviews

Current adoption of these measures is low, largely focused on specific challenges (GLA, 2011; HA, 2011a). For rail, the capacity to respond is expected to improve over the next five years with drainage at additional sites improved during the 2019-2024 control period. Similarly, measures to manage groundwater impacts on roads are increasingly understood and clearly documented (HA, 2011a).

A key barrier is the current limitation of 3D modelling (including implications of long term rainfall and aquifer dynamics). This includes improving the understanding of the effect of climate change upon embankments and cuttings (GLA, 2011).

The underlying data is also a limitation; the geotechnical databases are still being developed for roads as well as rail; the British Geological Survey dataset shows susceptibility of locations to groundwater flooding but does not indicate the degree of risk (HA, 2011a).

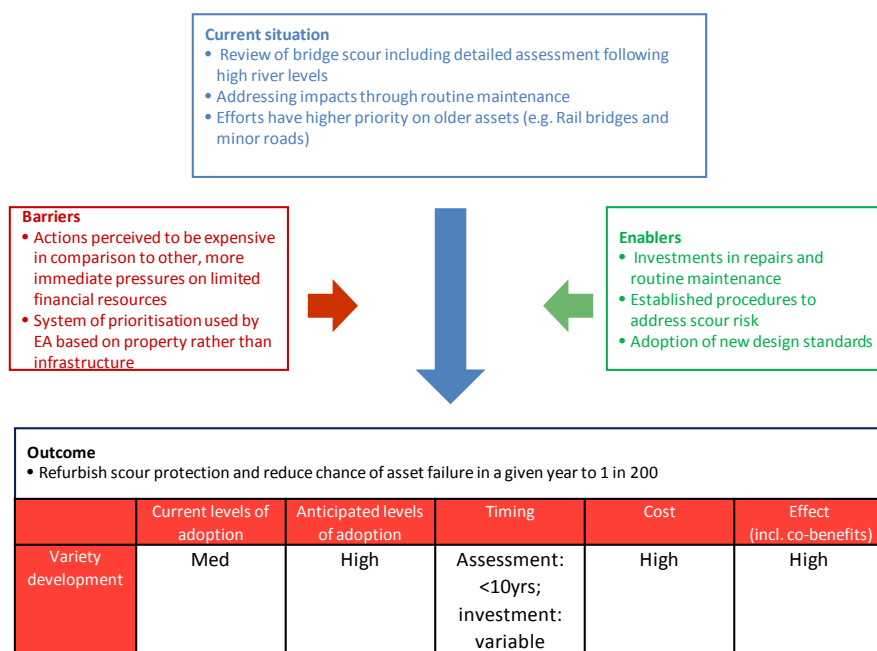
Notwithstanding the barriers, it is likely that existing strategic network performance can be maintained based on adaptive drainage systems (pumped) and dewatering schemes (based on opinions of experts within several different organisations). Nevertheless, even with asset management plans in place, excessive moisture in earthworks will remain (TfL, 2011). This has been shown

through past investments (e.g. Chipping Sodbury tunnel, where millions of pounds of investment have still not yielded an adequate technical solution).

### 5.1.5 Managing fluvial flooding

Measures include reviewing bridges at risk and conducting repairs. Under some circumstances, line/road closures can be required while the work is being carried out. These measures may be planned in response to future climate projections or as a response to a past event and include actions to respond to a specific risk.

**Figure 14.** Summary of options to respond to fluvial flooding



Source: Based on evidence from published sources and stakeholder interviews

Current adoption of these measures is assessed as medium as action is already taken to understand risk of scour on rivers, and responses are typically addressed through routine renewals. In the next control period, Network Rail is looking to identify priority sites and bring investment forward and many monitoring systems are being upgraded to take account of new design standards. Monitoring (and responding to) impacts of scour are priorities in the road network (e.g. HA, 2011a; GLA, 2011).

There are established procedures in the rail sector to address issues of fluvial floods (Standard NR/L3/MTC/TK0167). All Network Rail's bridges over water have been assessed for the likelihood of scour damage, and for those at risk special procedures apply during floods. Network Rail (NR/CS/OPS/021) also manages operational risks through the use of Extreme Weather Action (EWA) Teams, in line with relevant standards.

## Adaptation actions

For strategic roads, existing processes to screen out structures most likely to be at risk from scour are considered to require further development and do not assess risk sufficiently (HA, 2011a). Further work is underway to address this issue.

The approach used to prioritise investment used by the Environment Agency is based on the number of houses protected, and not infrastructure (Dora, 2008); this can serve as a barrier in some cases.

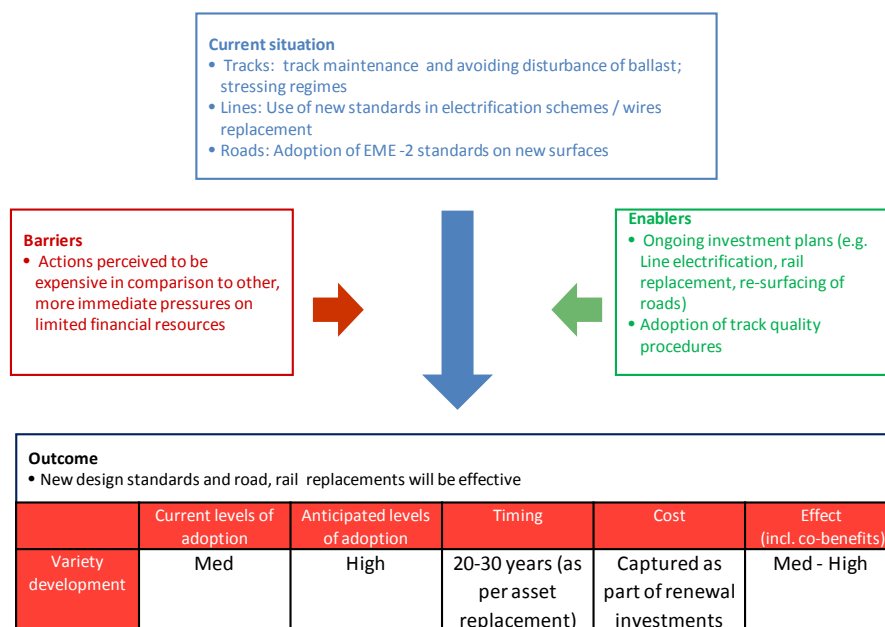
In terms of effectiveness, on rail, the planned programme would refurbish scour protection and revise the design process to allow the asset to withstand a 200 year flood event. This would result in improved network resilience and/or improved weather-related asset performance standards. In particular, serviceability limits or the chance of performance degradation in any given year would be 1 in 50 (Primary routes); 1 in 25 (Secondary routes) and 1 in 10 (Tertiary routes) (Dora, 2008).

#### 5.1.6 Managing overheating

Measures to address overheating – which is more likely to be an issue for rail than strategic roads - include separate responses to three different parts of the road and rail network; these are managing or avoiding buckling in track (through pre-stressing); power lines design, and road surface design. In addition, measures include identification of at-risk sites and possible effects, monitoring, and management of closures.

These measures tend to be planned or reactive in response to future climate projections and respond to a specific risk. Key issues are summarised in **Figure 15**.

**Figure 15.** Summary of options to respond to overheating



Source: Based on evidence from published sources and stakeholder interviews

## Track

There are various track quality procedures that are followed. However not all track needs to be in top condition as long as safety requirements are met. Furthermore, options such as imposing speed restrictions are potentially feasible (though these impose delays on passengers which need to be assessed in terms of costs and probability of their arising). Most rail track in the UK is pre-stressed according to established regimes (e.g. Dobney *et al.*, 2009). New standards such as those based on slab-track could be used within the next 15 years as part of track replacement (replacement period depends on speed or weight of trains).

For tracks, if they are well maintained and the ballast is not disturbed, the risks are substantially reduced. Therefore the use of standards is a critical enabler. Furthermore, where implemented, track stretching and rail replacement programmes are expected to be the principal approaches to respond to projected future peak temperatures and minimise speed restrictions (GLA, 2011). With design measures introduced, experts suggest rail could experience a 10-15% reduction in delays due to overheating of power cables or rails.

## Overhead cables

New standards are applied on new electrification projects and on the renewal of the catenary.

## Adaptation actions

### *Strategic roads*

New road surface specifications, similar to those applied in the south of France, (EME-2) have been introduced on some roads (HA, 2011) and are able to cope with significantly higher temperatures than previous standards. These are expected to roll-out across the country in due course.

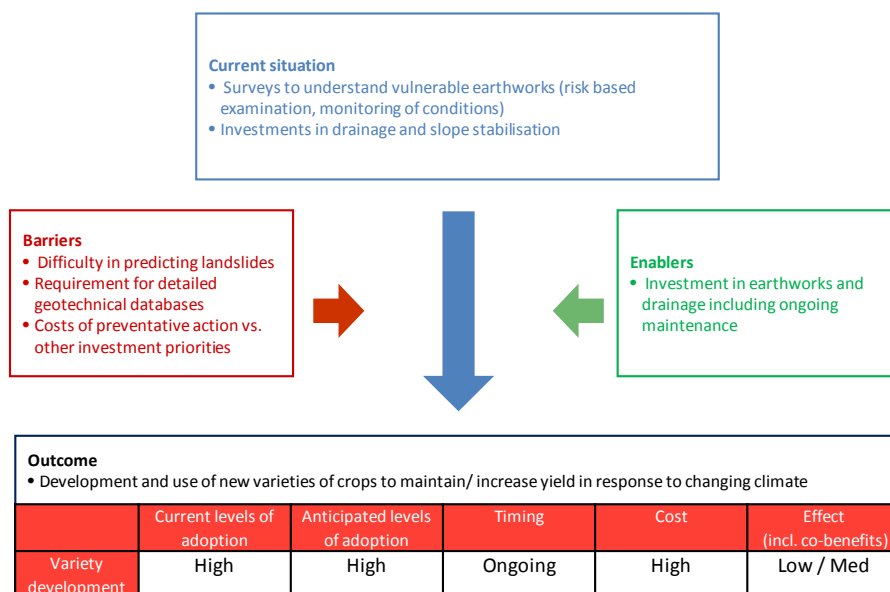
Implementation of these actions depends on the estimated costs and benefits relative to other competing priorities on the network. Financial pressures could affect the timing of action.

In terms of materials specification and construction details, this has been identified by the network operator as a key priority the next five years; and, this is not seen as a major barrier to action (Highways Agency, Aug, 2011). According to experts in the Highways Agency, the implementation of EME-2 standards is intended to make roads resilient to 60°C resulting in extremely low residual impacts.

#### **5.1.7 Managing landslides**

Measures involved include surveys to understand vulnerable earthworks, risk based examination, instrumentation/autonomous monitoring of conditions. Following assessment, investments can be made to improve drainage and bioengineering to strengthen slopes. Measures for road protection and hazard reduction can also be considered (Scottish Government, 2005). These measures may be planned in response to future climate projections or reactive to past landslides; they include actions to respond to a specific risk. Key issues are summarised in **Figure 16**.

**Figure 16.** Summary of options to respond to landslides



Source: Based on evidence from published sources and stakeholder interviews

Generally, geotechnical assets require little routine maintenance with most interventions being ‘long-term’ repairs. At present on strategic roads and rail, a risk-based examination process assigns locations to a 1 year, 5 year, and 10 year inspection regime that is fairly mature. Several interviewees assumed that existing inspection regime and investments are maintained (e.g. HA, 2011a)

It is believed that around half of landslips are due to poor drainage. Stakeholders from DAs as well as other organisations have suggested that investment in drainage is a critical issue. Similarly, maintaining capacity to examine earthworks and avoiding decline in their investment is a critical enabler.

Existing efforts in both roads and rail to develop geotechnical databases and inspections should pre-empt land-slips.

Given the length of rail involved and road (especially in Scotland and Wales) and unpredictability of landslides, residual impacts are still significant (Scottish Government, 2005). However where there is awareness of potential impacts, experts suggest drainage improvements can reduce impacts by up to 50%

Residual risks can be managed effectively by rail/road closures after landslides, for example, minimising closure time and providing alternative routes, and pre-emptive road closures.

## Adaptation actions



## 5.2 Uncertainties and limitations in the analysis

There are a number of uncertainties and limitations of the analysis of adaptation actions including:

- **Interactions across measures:** The measures discussed in this section are in many cases closely related. For instance, different types of flooding can occur together; managing transport demand will influence the effectiveness of other infrastructure-based measures.
- **Nature of the evidence:** Although there is some evidence on isolated costs of specific options, there is little readily available evidence as to the economic impacts of different options compared with others. There are little data generally available on the quantified impacts of adaptation decisions and whether or not, and to what extent, decisions will mitigate climate risks. In particular, data on behavioural responses are considerably less detailed than that of infrastructure investment assessments.
- **Subjective assessments:** Assessing the extent of adaptation measures and their likelihood of increasing in extent in the future is subjective and informed by the views and opinions of stakeholders and experts. In many cases the effectiveness of different measures is dependent on expert opinion
- **Comprehensiveness:** Available evidence is not comprehensive in scope and is limited by the expertise of the particular experts and stakeholders.

## 5.3 Cross-sectoral links

In many of the measures discussed above, the impacts are cross-sectoral, and the responses therefore need to consider other sectors. Examples identified through this project include:

- **Transport management:** Measures in this category could interface closely with systems used in health and building community resilience (e.g. early warning systems), as well as systems used by businesses and industry (e.g. logistics management).
- **Management of fluvial flooding:** Interventions in the transport sector can be influenced by flood defences in other sectors (both hard engineering and natural flood management). Similarly, interventions can affect receptors downstream.
- **Management of surface water flooding** can be affected by changes in land-use upstream and infrastructure of others (e.g. use of sustainable urban

drainage systems. Interventions can also affect flood risk of others based in the same catchment

- **Management of coastal flooding** for transport has to be closely linked to other infrastructure providers, communities, businesses and others as discussed above.

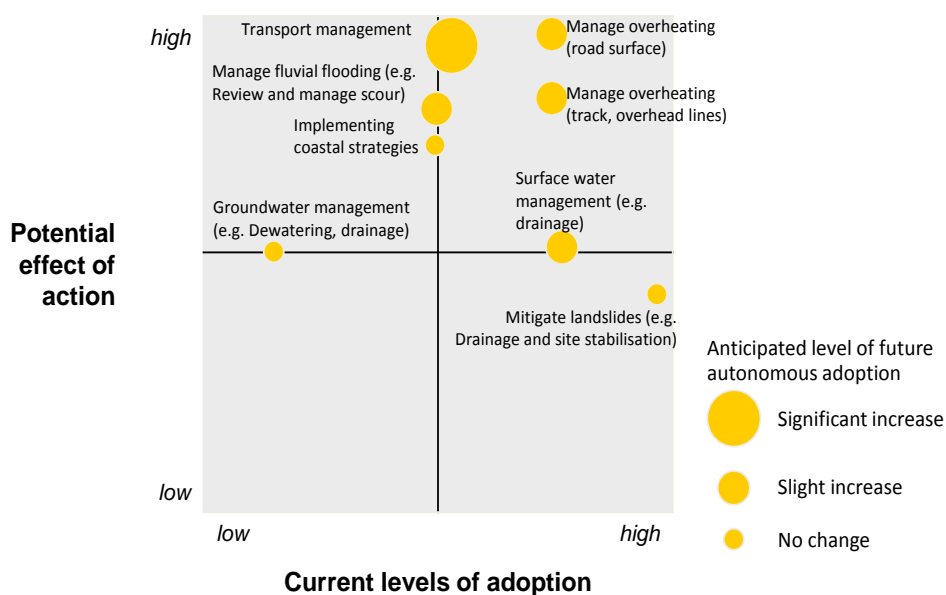
## 5.4 Extent of adaptation

In order to illustrate the extent to which adaptation is likely to occur given the current understanding of adaptive capacity, the policy framework and incentives provided by the market or other factors, this Section draws the evidence together into a simple framework. An assessment has been made of the contribution different actions would be expected to make towards addressing climate change risks (effectiveness), the current levels of adoption and levels of adoption anticipated by the 2020s.

**Figure 17** provides a simplified summary based on the “high, medium and low” classifications used within **Figure 10** to **Figure 16**. Those classifications were determined based on the published evidence investigated and stakeholder expert views.

The figure is intended to be a summary of the findings set out in this report rather than a further analysis. It is intended to provide a basis for further discussions as part of future stakeholder engagement.

**Figure 17:** Summary of current and anticipated effects of different adaptation actions



Note: Scales are qualitative and relative to the sectors included. The position of each category of measure – indicated with a yellow marker – is based on the classification within main text in this Section and, given

## Adaptation actions

the factors discussed above and will vary across different parts of the strategic road and rail transport sectors.

Each yellow marker represents a category of adaptation action discussed above. “Current levels of adoption” reflects the extent to which types of measures are currently being implemented (either planned or reactively, or both). It is also influenced by the frequency of decisions made. “Effectiveness” varies from ‘limited’ at the lower end of the scale to having a major beneficial impact on the operation of strategic transport infrastructure. Increases in future adoption assumes no further intervention to increase adoption and is essentially over the next 10 years or so. The position of each category of measure is based on the classification within this report. Some key points are:

- Where actions are in the top-right quadrant, they have been assessed as relatively effective in addressing a particular climate threat or in maximising an opportunity and are currently being implemented. A cost-benefit analysis of actions would need to be undertaken to guide the extent to which actions should be implemented more widely.
- In the top-left, the current low levels of adoption imply that despite actions being relatively effective, they are not widely implemented. This could indicate barriers to implementation or that the costs would outweigh the benefits of doing so.
- In the bottom-left, actions are not likely to be particularly effective and are not widely implemented.
- In the bottom-right, actions are widely implemented but are not likely to be very effective in managing climate risk. This could indicate barriers to enhancing effectiveness.

It is important to note that if adaptation is not necessarily effective, it can lead to maladaptation if action is taken without full consideration of the longer-term risks. Furthermore, there is an optimal level of adaptation beyond which the costs of measures exceed the probable value of the benefits.

The high levels of adaptation activity are expected to be driven by the incentive for Network Rail to meet its licence conditions (linked to the reliability target), and the responsibility of the strategic highways operators across the UK to ensure a safe and reliable transport system. The effectiveness of the actions is likely to be relatively high owing to the internal expertise of the organisations and therefore the ability to ensure appropriate design based on robust evidence and engineering.

## 5.5 Barriers to effective adaptation

**Figure 17** illustrates that some measures are in or close to the top-left quadrant (implying a barrier to uptake of effective measures where they may be justified on cost-benefit assessment grounds) or in the bottom right (implying actions are being implemented but their effectiveness could be improved).

Understanding these barriers is important because overcoming them is likely to need intervention – by government or other bodies – to build adaptive capacity and facilitate effective adaptation.

Section 2 discussed the types of barriers to effective adaptation that can be identified. These are: market failures (information problems, external costs or benefits imposed on others that are not accounted for by the decision maker, public goods or monopoly situations); policy constraints (for example, conflicting objectives or regulatory constraints); behavioural constraints (for example, inertia); and governance issues (including institutional decision making). The analysis in this Section and Section 4 relating to the context for adaptation allows a series of priority barriers to be identified.

### *Market failures*

**Interdependencies and external costs or benefits:** In many of the categories of measure, there are strong interdependencies and cross-sectoral linkages that act to both support and impede adaptation actions. Examples identified through this report include:

- **Intra-sector interdependency:** transport is a network and as such there are several interdependencies (i) with other links of the same category, for example, an interruption to traffic flows on one strategic route can cause re-routing to nearby alternative routes; (ii) with other road traffic networks, for example where traffic management may divert traffic to local roads and results in an increase in congestion and wear and tear, accident risk or other impacts on those routes; and, (iii) across modes, for example, a closure of a strategic interurban road link could increase the demand for substitute services on interurban rail links. These interdependencies mean that the resilience of one part of the network can affect the resilience of another. The implications of such interdependencies are not likely to be transparent unless, for example, one organisation has oversight of different parts to the transport network and can ensure co-ordination. The number of transport authorities involved means the nature of risk and interdependencies may not be understood, however the DfT, as the only agent with oversight of the entire network, has the opportunity when the situation demands (e.g. after a major incident) to coordinate effective responses. It should be noted that several links may be affected simultaneously in the event of a flood, so the

### *Adaptation actions*

impacts on other networks could reach widely across other parts of the transport network.

- **Inter-sector interdependency:** the reliance of the strategic road and rail sectors on other sectors, such as information and communications technology (ICT) and the power sector (for example, for managing traffic flow, railway signalling and, in the case of electric trains, current for traction) means that the strategic road and rail sectors are vulnerable to a failure in related sectors. This is likely to become increasingly important as real time information and smart technologies are further embedded within strategic transport functions. This could be an increasingly important issue as the provision of real-time information and smart technologies are embedded within the functions of strategic transport.
- **Information and uncertainty:** Decision-making in the strategic road and rail sector is affected by uncertainties over the extent of climate change and its potential impacts, likely future technological developments and non-climate related drivers, such as socio-economic development and travel demand. Barriers identified particularly relate to:
  - Uncertainty over the impacts of climate change given the long asset lifetimes being considered; and,
  - The relative lack of ex-post analysis of the costs and benefits of adaptation actions, with which to guide decision-makers. Although efforts are underway to develop this, evidence currently remains limited.

### *Policy failure*

Public ownership, management and operation of strategic routes will enhance further adoption of effective adaptation action, as licensing requirements set by the Office of rail Regulation (ORR) and safety and reliability targets set by the DfT and Highway Agency (HA) will incentivise change. However, it is important to ensure that full account is taken of climate change adaptation in decision-making processes and appraisal.

### *Behavioural constraints*

The effectiveness of adaptation actions such as traffic management and demand management rests on the assumption that travellers will behave 'rationally' and respond to pricing, information or policy signals. However, it remains likely that some travellers would not be willing to change their behaviour owing to habits or if travellers choose to believe some other non-official sources of information.

In addition, journey travellers would be expected to adapt their behaviour over time depending on their expectations of the likelihood of, for example, a flooding event. Short term reactions to one-off events could differ to those in the longer-

## **Adaptation actions**

term, when travellers may begin to use alternative routes, modes, ways of working or travelling at different times of the day, or not at all.

### *Governance barriers*

The number of interdependent organisations involved in the strategic road / rail sectors means that the networks are particularly vulnerable to communication failure.

### *Adaptation actions*

## 6 Case for intervention

### 6.1 Introduction

This Section presents analysis to demonstrate the case for intervention to both build adaptive capacity of organisations in the UK, and to facilitate the implementation of effective adaptation strategies by those organisations and others.

The potential case for intervention could be identified where:

- **Organisations lack the adaptive capacity** to be able to prepare for climate change.
- **There are significant barriers or constraints** to taking effective adaptation action. This may be because markets lack the required information to allow appropriate signals to be sent to parties to take appropriate action.
- **The UK may become ‘locked in’** to a path that could lead to maladaptation or removes **the flexibility required effectively to manage uncertainty**.

The barriers to effective adaptation were discussed in Section 5. This Section focuses on those that are most likely to be important for strategic road and rail to the 2020s and beyond, and suggests interventions that would address them. Such interventions may require businesses, government and stakeholders working together to achieve effectively.

The focus of this Section is therefore on the following:

- Continuing to manage uncertainty as evidence on the potential implications of climate change remain uncertain: an approach is suggested to allow effective action to be taken while avoiding ‘lock-in’ to a potentially maladaptive course of action; and,
- Overcoming potential barriers in, for example, information on effectiveness of action to target high risk areas.

### 6.2 Managing uncertainty: adaptive management

There are three types of uncertainty associated with climate change projections – (Annex 3), as well as associated impacts on the UK transport system at a local, regional and national scale. Such uncertainties are particularly problematic for planning large, high cost adaptation options with long lifetimes as such investments are costly to reverse and their design is dependent on what

assumptions are made today about climate over its lifetime. Nonetheless, uncertainty should not prevent adaptive action being taken, as this could risk 'locking in' the UK to maladapted investments or actions.

In the ECR, a pragmatic and evidence-based approach is suggested through illustrative adaptation roadmaps. These allow **flexibility to be incorporated into adaptation measures from the start**, where possible, (e.g. by using measures that are suitable over a broad range of possible future climates or by designing the adaptation measure so it can be adjusted over time: Fankhauser *et al.*, 1999). **Flexibility is also incorporated into the overall adaptation strategy**, by sequencing the adaptation over time, so that the system adapts to climate change, but options are left open to deal with a range of possible future scenarios.

**It is important to recognise that before adaptation actions are taken, there should be a detailed assessment of their relative costs and benefits. This will indicate whether the action is justifiable. This analysis should be undertaken at the appropriate level i.e. for a given location or set of conditions.**

### 6.3 Illustrative strategic road and rail adaptation roadmaps

The adaptation roadmaps developed here are intended to illustrate "packages" of measures that can be implemented over time. Prioritising adaptation options in the face of uncertainty leads to focus on those options that are:

- **No-regrets:** those actions which are worthwhile (i.e. they deliver net socio-economic benefits) whatever the extent of future climate change. These types of measures include those justified under current climate conditions. This may include building adaptive capacity - enhancing climate knowledge, technical skills, improving use of building space;
- **Win wins:** actions that minimise climate risks or exploit opportunities, but also have other social, environmental or economic benefits (UKCIP, 2007). For example, actions may increase resilience to climate change as well as make asset maintenance more efficient;
- **Low-regrets/low cost:** actions with relatively low associated costs, and with relatively large associated benefits, although the benefits will primarily be realised under projected future climate change (UKCIP, 2007). For example, enhancing real-time information to travellers; and,
- **Strategic options:** These can include longer-term decisions related to investments in new physical infrastructure.

### Case for intervention



These options are then classified into adaptation roadmaps that address the evolving nature of climate change risks over time, and the development of policy (such as the CCRA and the National Adaptation Programme). It is intended that these roadmaps will be iterated over time. This aims to ensure that actions undertaken will not be maladaptive if climate change progresses at a rate different from that expected today, and to review any and all unintended consequences.

It should also be recognised that any action chosen should be taken with the engagement of stakeholders and availability of data to allow progress and emerging outcomes to be monitored and reviewed.

**Figure 18** is intended to be an indicative roadmap which sets out some of the adaptation actions that are currently being taken and could be effective by the 2050s, along with when key review points will occur. The actions in **Figure 18** were chosen based on the actions identified in published literature and stakeholder evidence as set out in Section 5. The column to the right of the figure shows where the example measures fit within the categories used in Section 5. Building adaptive capacity is included within the actions, as illustrated by a dark outline around the relevant actions. Some of the actions within the roadmap will occur reactively, whilst others will require further support.

The roadmaps are not intended to be comprehensive or exhaustive, as there are many other roadmaps the sector will need to consider. In particular, this report has not set out a detailed adaptation pathway such as the Thames Estuary 2100 Report Project because the “known thresholds” for climate change (Reeder and Ranger, 2011) have not been assessed and there are multiple risks and receptors (those operators in the sector affected by climate change) that are considered in the scope of this report. An analysis to assess the thresholds should be undertaken in future iterations of the ECR, supplementing existing work being done by Highways Agency, Network Rail and others.

**The adaptation roadmaps incorporate review points, where policy and practice can be assessed and evaluated in light of recent developments, new information and better understanding of climate risks and research outputs.** This includes on-going review of adaptation (as part of all adaptation processes) to ensure trade-offs, conflicts or synergies are identified. The review points are designed to coincide with policy cycles (e.g. NAP, CCRA as well as specific planning cycles for the Highways Agency and Network Rail) and points where adaptation actions should be maturing. Earlier review points allow analysis of short-term measures, with no regret/win-win characteristics, and particularly those that build adaptive capacity. The review points will also allow for consideration of the options in the context of developing evidence on evolving climate risks. Some options may be more or less appropriate in future time periods, depending on the level of projected change in terms of climate risk, but also socio-economic and technological developments. At each review point, the options must be considered as portfolios of short-term, medium-term and long-

term responses, to identify early actions to address long-term issues and to ensure there is enough time for decisions with long lead-in times. There may be additional review points where major review and consultation is required, if there is an extreme event, or if the upper end of climate projections and uncertainty ranges were approached.

Underpinning these roadmaps is the need to consider the conditions under which adaptation actions as a whole are likely to be effective. Adequately mitigating the impacts of climate threats, and making the most of opportunities, requires a range of conditions to be in place, such as a supportive policy framework, analytical tools to deliver the required evidence and information on which actions are likely to be effective and when and co-ordination of activities across modes and areas, recognising that all transport infrastructure operates within a wider system – each mode and area able to influence another.

The chart is a horizontal timeline from 2015 to 2050+, divided into four main periods: 2015, 2020, 2030, and 2050+. It tracks various actions and milestones across nine categories: Coastal Flooding, Surface Water Flooding, Ground-Water Flooding, Fluvial Flooding, Landslide, Heat-Stress, Demand-Management, Adaptive Capacity, and Policy Cycles. A legend at the bottom explains the symbols used: blue boxes for actions, red diamonds for potential opportunities, blue diamonds for assess & review milestones, and green boxes for replacement periods.

Category	2015	2020	2030	2050+
COASTAL FLOODING	Development of 20, 30, 50 year strategies	NR:/ HA: investment plans: cost-effective measures based on current climate		Coastal defences: 50- 100+ years
SURFACE WATER FLOODING	Information to produce management plans	Investment plans for drainage		Culverts: 100+ yrs Drainage: 60 yrs
GROUND-WATER FLOODING	Build underlying capacity	Identify sites for further action	Implement measures to address priorities	Geotechnical assets: >30 yrs Tunnels: 100+ yrs
FLUVIAL FLOODING	Identify priority sites and bring investment forward	Replace monitoring systems to reflect new design standards		Bridges: 100+ yrs Drainage: 60 yrs
LANDSLIDE	Develop remote scour assessment approaches			
	Instrument sites to understand movements	Risk based examination process (1 yr, 5 yr 10 yr inspection regimes).		Geotechnical assets: >30 yrs
HEAT-STRESS	Standards for overhead cables	Implement standards according to electrification investment plans including 15-20 replacement plans		Overhead cables: 15-20 yrs Masts: 150 yrs Surfaces: 40 yrs
DEMAND-MANAGEMENT	Risk based examination process (1 yr, 5 yr 10 yr inspection regimes).			
	Ongoing track maintenance and avoiding disturbance of ballasts			
ADAPTIVE CAPACITY	Track policy assessment (identifying topical/geographical differences)	Application of new policy (e.g. Concrete slab track)		
	Ongoing road surface replacement with materials to EME-2 (decision to fast-track investment at made at control periods)			
POLICY CYCLES	Further roll-out of active transport measures			
	Piloting transport management initiatives	Roll-out of successful breakthrough projects		
ASSESS & REVIEW	Build capacity in ex-post assessment (esp Roads)			
	Sharing best practice between HA, NR, TfL with local authorities			
POLICY CYCLES	Develop specification for database;	Consistent application of database		
	Review of Climate risk assessment approaches			
POLICY CYCLES	NAP 2013	2 <sup>nd</sup> CCRA 2 <sup>nd</sup> NAP	3 <sup>rd</sup> CCRA 3 <sup>rd</sup> NAP	4 <sup>th</sup> CCRA 4 <sup>th</sup> NAP
	NR: Control period 2014	NR: Control period 2019	NR: Control period 2024	NR: Control period 2029
POLICY CYCLES	HA: Future delivery programmes			
	Sector resilience plan for critical infrastructure (reviewed annually)			
ASSESS & REVIEW				

**KEY:**

- Blue box: Actions for development of adaptive capacity
- Red diamond: Potential opportunities for innovative/breakthrough projects
- Blue diamond: Assess & review milestone
- Green box: Replacement periods for example assets

## Case for intervention

As shown, most of the actions in the short term (over the next 5-10 years) relate to building capacity to enhance the future ability of those in the sector to adapt. This can include knowledge management, sharing of best practices, and developing research and development capabilities.

Other adaptation actions will also be happening at the same time driven by, for example, incentives to infrastructure owners and appropriate standards. These are no-regrets actions including (among others) developing assessment approaches (e.g. remote scour assessment) and rolling-out active transport measures.

Actions in the medium term could be those that need to be taken because irreversible decisions may be made which could lead to maladapted outcomes if they are not. These involve long-term assets and include the design and specifications for drainage/culverts, bridges, tunnels and coastal defences. Furthermore, adaptation measures should be incorporated into routine maintenance processes as well as lifecycle replacement of assets. Examples of medium-term actions include:

- Integrating adaptation measures into the renewals cycle of shorter term assets; and
- Implementing new standards/specification based on risk-based examination and monitoring processes.

In the longer term, it is likely that transformational changes in the structure of the sector would emerge, some of which would be in response to climate change. For example, the provision and management of infrastructure assets may change, or travel demand may not arise as projected. These changes would be likely to affect adaptation and would influence decisions around the longer-term replacement of assets and their design. In the roadmap, many of the short-term actions to build adaptive capacity will contribute to setting up the sector to make these changes as required.

**Figure 18** also shows that some actions are likely to be innovative or breakthrough initiatives. This would refer to those that would be more transformation in nature, rather than just incremental changes to current processes or decisions. These could include examples such as emerging transport management initiatives.

There are important interdependencies between the options in the roadmaps. For example, many of the options (e.g. management of surface water flooding) rely on the capacity building (e.g. knowledge management) and the framework for adaptation. This base must be established before more costly options can be taken later on. The adaptation roadmaps focus on the risks of flooding and overheating in the transport sector, but there are many connections to other sectors that need to be considered in order to lead to effective adaptation. There

## Case for intervention

needs to be coordination of responses between actions and sectors, with other risks to be considered – within other ECR reports, and more broadly. For example, coastal management above will also relate to health and wellbeing in coastal communities.

## 6.4 Overcoming barriers to deliver effective adaptation actions

The illustrative adaptation roadmaps in **Figure 18** show packages of actions that could address particular climate change threats in the presence of uncertainty. Roadmaps do not, however, provide an indication of the extent to which the adverse impacts of those threats could be reduced. To capture this, **illustrative** ‘what if?’ scenarios have been explored to show the potential gain from targeting adaptation action where it is most likely to be effective.

The scenarios are not intended to show the cost effectiveness or value for money of particular actions – that would require more detailed analysis than has been possible in this two-month period of work. They are intended to be indicative of the relative impacts of different actions by comparing outcomes that might be expected without an adaptation action with those that might be expected with adaptation. These in turn can be considered relative to the ‘no climate change’ case.

**The lack of evidence of the scale of the impacts and the effects of adaptation measures in this emerging field has required illustrative analysis to be used. Drawing on defined indices, rather than monetisation, this analysis provides an indication of the scale of effects. The indices used have been tested with experts and stakeholders through focus groups and discussions; as such results are considered indicative of the relative effects.** This approach is not ideal as monetisation would be preferable. However, this approach is intended to illustrate relative effects to guide policy makers on priorities.

Analytical tools are currently being developed to address the lack of evidence. For example, the FutureNet project will help assess the relative impacts of floods in more detail.

### Futurenet

Futurenet is a 4-year research programme jointly funded by the Engineering and Physical Research Council and the Economic and Social Research Council. It forms part of the “Adaptation and Resilience to a Changing Climate” (ARCC) programme, which aims to provide a vision and tools to assess and plan for the resilience of transport systems in future.

The aim of the project is to provide tools to assess and ensure the resilience of transport networks in the future. Changes in technology and infrastructure are being considered in addition to changes in climate and extreme weather events. The project specifically focuses on determining what the UK transport network will look like in 2050 and what a resilient network would look like.

Source: <http://www.arcc-futurenet.org/>

## 6.4.2 Definition of scenarios and results

The analysis in this report has focused on the strategic road and rail networks. The most likely climate threats facing the sector are rising average temperatures, changes in rainfall patterns along with extreme weather events, such as floods.

Indicative severity indices have been developed to illustrate the impacts of adaptation actions. These indices are defined slightly differently for strategic road and rail given the information available. For strategic routes, the severity index has been based on the Flood Severity Index used for the classification of roads and events in the Highways Agency’s flood database (HADDMS) and discussions with experts in the sector. This is shown in **Figure 19**.

**Figure 19.** Impact severity indicator on roads

Strategic roads	0-2	Relatively low traffic, quiet times of day/night, impact on traffic minimised, relatively low repair costs
	2-4	Light-moderate traffic, quiet times of day/night, impact on road or rail travel is low-moderate, low repair costs
	4-6	Moderate traffic, congested times of day, hard shoulder only affected, moderate repair costs
	6-8	Heavy traffic, congested times of day, partial closure less than 2 hours; significant repair costs
	8-10	Heavy traffic, congested times of day, full/partial closure more than 2 hours; significant repair costs

On rail it is slightly differently defined as advised by transport experts in order to reflect the available information and data. This is in **Figure 20**.

## Case for intervention

**Figure 20.** Impact severity indicator on rail

Strategic rail	0-2	Impact on services is minimised, relatively low repair costs
	2-4	Impact on services is low-moderate, low repair costs
	4-6	Impact on services is moderate – high, moderate repair costs
	6-8	Impacts on services is high (lengthy) with high repair costs
	8-10	Very significant impact on services for long period, high-very high repair costs

No indicator is perfect and it is important to recognise that these indicators only generically account for the impacts – they are not able to account for the extent of welfare costs to travellers from re-routing, for example. They are however, useful for indicative purposes.

In order to reflect the impacts of adaptation over time, ‘what if?’ scenarios have been explored looking at climate change impacts in the 2020s and then shown how they may develop to the 2050s. The effectiveness of the expected adaptation action within each time period is illustrated. The scenarios do not focus on specific emissions scenarios.

On this basis the scenarios explored are:

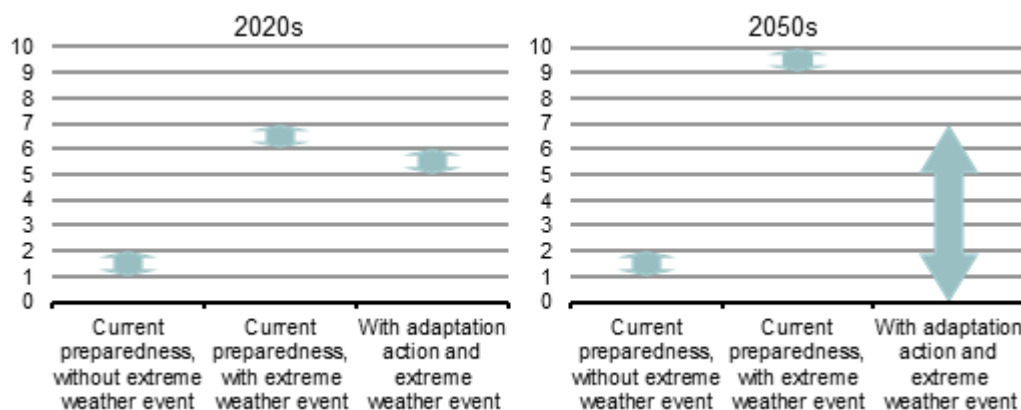
- **Scenario 1:** a motorway in an area prone to flooding as a result of climate change is subject to heavy rainfall over a prolonged period causing more than 1 hour of delay in the 2020s and more than 2 hours by the 2050s. This is illustratively assumed to be the South West of England. For context, under a low emissions (p10) scenario to a high emissions (p90) scenario, winter mean precipitation could increase 0% to 41% (UKCP09).
- **Scenario 2:** a strategic rail route in the South East is subject to higher temperatures because of climate change. Under low (p10) to high (p90) emissions scenarios, temperatures could increase between 1.2°C and 7.4°C (UKCP09).
- **Scenario 3:** a strategic rail route in the South East is subject to moderate flooding causing delays and cancellations to services. This causes moderate delays (defined in **Figure 20**) in the 2020s and moderate-high delays by the 2050s. For context, under the low emissions (p10) to high emissions (p90) scenario winter mean precipitation is projected to increase between 1% and 40% (UKCP09)

- **Scenario 4:** a dual carriageway in the South West is subject to flooding for more than an hour in the middle of the day. Without adaptation actions, this causes a partial closure in the 2020s and a total closure by the 2050s (rainfall projections as per scenario 1).
- **Scenario 5:** an extreme heat wave causes temperatures in the South East to rise substantially more than the averages of scenario 2. Without adaptation, delays are very high by the 2050s. This is not based on a specific climate change scenario. Instead, the indices have been used to indicate the potential effectiveness of an adaptation action if a heatwave occurs similar to those experienced in the UK in the past, such as in 2003.

### *Scenario 1: managing the impacts of floods on motorways in zones at high risk of flooding*

The flood impact is illustrated to be relatively low without climate change (using the rating above) rated 1-2. With climate change, it rises to 6-7 in the 2020s, then to 9-10 by the 2050s owing to higher rainfall. Adaptation actions would be expected to be taken by the Highways Agency.

**Figure 21.** Scenario 1: adaptation to motorway flood (scale of impact is indicated using the index ranging from 0 to 10 in the Y-axis)



Source: Based on expert judgement

As a result of the actions taken in the 2020s, the flood impact is shown to have reduced to a rating of 5-6 based on the criteria described above. Actions to achieve this include traffic management measures, which allow traffic to be diverted and re-routed, and speed restrictions which allow traffic to move through the area. To the 2020s, existing drainage is assumed which allows the flood to be contained to the hard shoulder only for the assumed severity of flood.

### **Case for intervention**



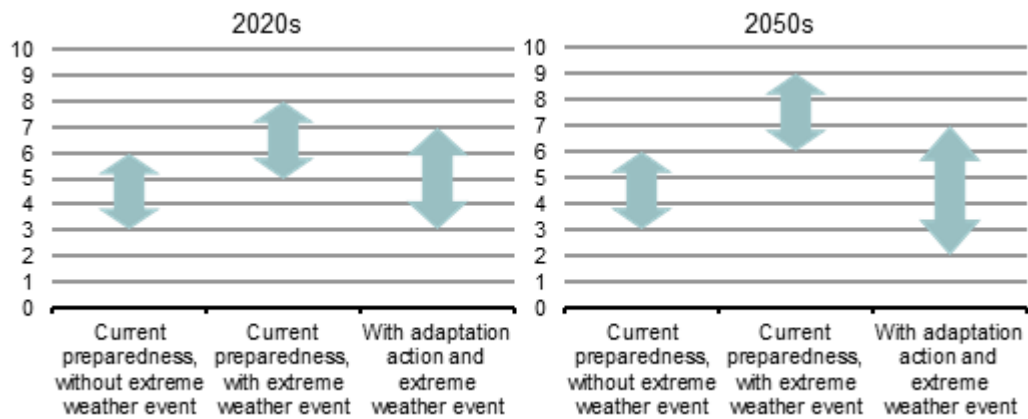
By the 2050s, traffic management can be relied on primarily, and action can be taken by the HA to prevent the closure of the road that may otherwise occur given the higher severity of flood assumed by that time. The large range of impact is because if traffic management and existing drainage alone are relied on then impacts rated using the criteria above may be in the range 6-7 with adaptation (falling from the rating of the original 9-10). However, high specification drainage would be expected to allow traffic to remain free-flowing, hence a possibility of zero impact.

This shows that if action is targeted to improve drainage where risks are greater, the adverse impacts could be minimal.

### *Scenario 2: managing rail buckling given rising temperatures*

Without adaptation actions, this scenario assumes the impact on buckling rated in a particular location is 3-6. With climate change, this is shown to rise to about 5-8 by the 2020s and to 6-9 by the 2050s. Actions to replace the track in line with higher specification standards would mean that by 2020, the impact could be reduced to about 3-7. In the short term, restrictions on the maintenance schedule mean that improvement beyond this is unlikely. By the 2050s however, rail replacement and higher design standards mean that the impact on passengers and services could actually be lower than under current climate conditions (i.e. if there had been no climate change and hence no increase in design standards to withstand heat). It should be noted that although the impact on travellers may be lower (in terms of time delays they experience, for example), the value of that time overall could be higher owing to rising demand and values of time. The scenario outcomes are shown in **Figure 22**.

**Figure 22.** Scenario 2: managing rail buckling (impact scores are as described in Figure 20, in the Y-axis)

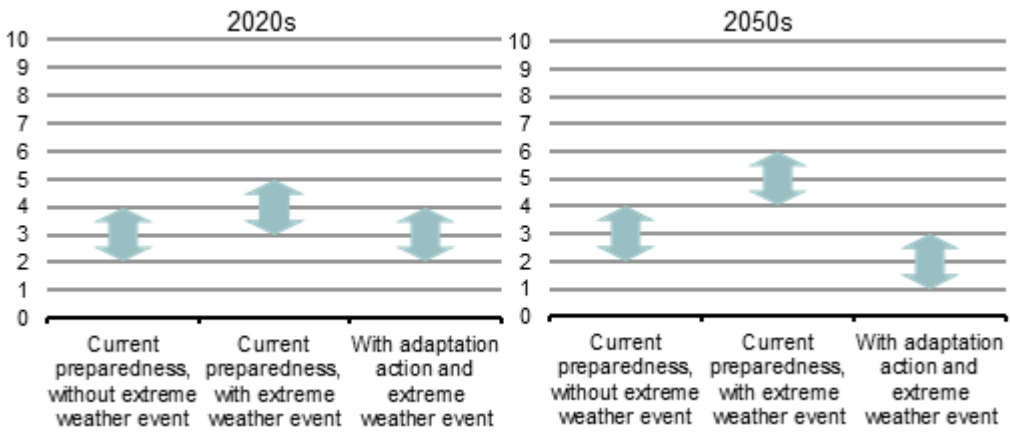


Source: Based on expert judgement

### Scenario 3: managing floods on rail

In the absence of climate change (i.e. under current climate conditions), the flood impact in this scenario is illustrated to be in the range of impact rated 2-4 in a particular location. With climate change, the impact has risen to 3-5 by the 2020s and 3-5 by the 2050s. Expected adaptation actions, including drainage and passenger information would be expected to ameliorate the impacts. In the 2020s, the effect is shown to fall to 3-7 because mechanisms are in place to prioritise action on those parts of the network at greatest risk. By the 2050s, the impact of the flood is lower than it would have been without climate change because of the improved drainage systems assumed to be in place. This is shown in **Figure 23**.

**Figure 23.** Scenario 3: managing rail floods (impact scores are as described in Figure 20, in the Y-axis)

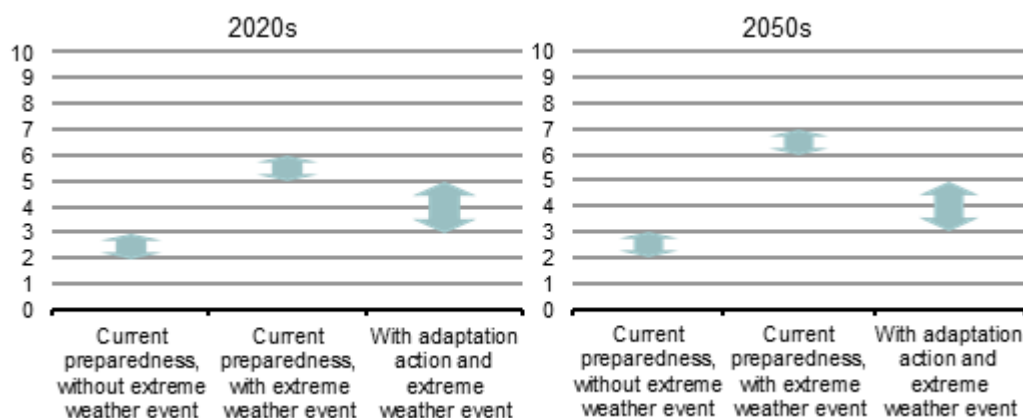


Source: Based on expert judgement

*Scenario 4: managing flood risks on trunk roads*

Without climate change, the impact of a flood in this scenario is rated in the range 2-3 on the trunk road in a particular area. With climate change, the impact is illustrated to have risen to 5-6 by the 2020s, assuming that the flood creates a partial closure for over 2 hours. By the 2050s, this impact is more severe, with a rating of 6-7 as the road is closed for over 2 hours. Adaptation is expected in the form of improved drainage, which is able to reduce the flood impact in the 2020s to about 3-5, and the same in the 2050s.

**Figure 24.** Scenario 4: managing flood on trunk roads (impact scores are those as described in **Figure 19**, in the Y-axis)



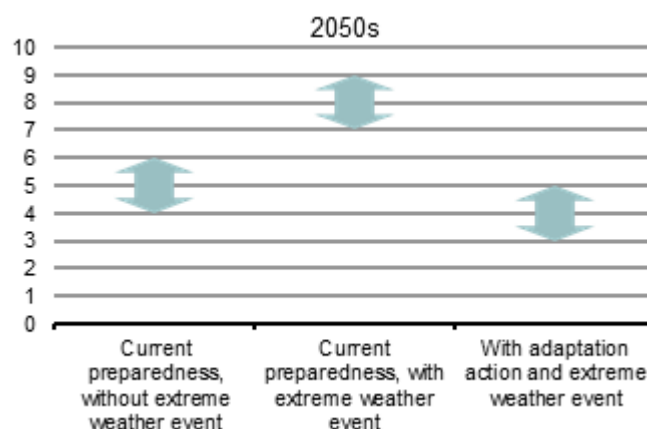
Source: Based on expert judgement

Two points of particular interest here are: (i) the relative reduction in the impact of the flood on the trunk road as a result of the adaptation action is not as great as on the motorway. Thus traffic demand management is not likely to be as effective because there are no automated signage boards or Traffic Officers, unlike on the England's motorways (though information sent to local travel information services can, of course, still be used). (ii) The installation of high specification drainage may be less likely if other routes are prioritised for such upgrades (where they are implemented, the impact of the flood would be rated from 0 to 5 instead).

### *Scenario 5: managing the impact of a heatwave on rail*

This scenario predicts that a heatwave will cause buckling to the rail track with an impact rating of 4-5 by the 2050s without climate change (i.e. temperatures do not rise as much). With climate change, the impact is assumed to be 7-9. Adaptation to such effects would be expected through optimised rail maintenance and improved prioritisation, reducing the risk of buckling. The costs of heat impact on rail more widely would be lower because maintenance schedules could be re-aligned to ensure work takes place at cooler times of the year (hence reducing the costs associated with temperature preventing works). This has the potential to reduce rail buckling impact on services to around 3-5. This is below the level that might otherwise have occurred, even in the absence of climate change. This is shown in **Figure 25**.

**Figure 25.** Scenario 5: managing a heat wave on rail (impact scores are those in Figure 20, on the Y-axis)



Source: Based on expert judgement

### 6.4.3 Impacts illustrated

These ‘what if?’ scenarios show that:

- Given the plans and research already in place, the **expected effectiveness of adaptation actions is likely to be greater in the longer term (2050s) than by the 2020s**. This is owing to the building of resilience through actions as part of the maintenance, upgrade and renewal cycles, where feasible. By the 2050s therefore, higher specification design standards will be used and implemented on a widespread basis.
- **Travel demand management and flow management** (reduced traffic growth, re-routing, alternative options etc.) **has an important role to play within any package of adaptation measures** because the impacts of climate change and associated costs are likely to be much greater for users (time delay and journeys not taken) than for the infrastructure itself (i.e. cost of repair). This is particularly true in the future as the value of time for travellers increases (with incomes) and the need to re-route, manage congestion or plan journeys differently increases.
- **Targeting action where the risks are greater** is likely to be more cost-effective.

## 6.5 Recommendations

It should be noted that substantial work is already underway in the relevant organisations so the case for intervention is relatively low. This notwithstanding,

### Case for intervention

the following summarises the key barriers to effective adaptation and the recommended interventions to address them.

### *Barriers*

**Interdependencies and external costs or benefits:** In many of the categories of measure, there are strong interdependencies and cross-sectoral linkages that act to both support and impede adaptation actions. Examples identified through this report include:

- **Intra-sector interdependency:** transport is a network and as such there are several interdependencies:
  - with other links of the same category, (for example, an interruption to traffic flows on one strategic route can cause re-routing to nearby alternative routes);
  - with other road traffic networks, (for example, where traffic management may divert traffic to local roads and results in an increase in congestion and wear and tear, accident risk or other impacts on those routes); and,
  - across modes, (for example, a closure of a strategic interurban road link could increase the demand for substitute services on interurban rail links).

These interdependencies mean that the resilience of one part of the network can affect the resilience of another. The implications of such interdependencies are not likely to be transparent unless, for example, one organisation has oversight of different parts to the transport network and can ensure co-ordination. The number of transport authorities involved means the nature of risk and interdependencies may not be understood, however the DfT, as the only agent with oversight of the entire network, has the opportunity when the situation demands (e.g. after a major incident) to coordinate effective responses. It should be noted that several links may be affected simultaneously in the event of a flood, so the impacts on other networks could be extensive across other parts of the transport network.

- **Inter-sector interdependency:** the reliance of the strategic road and rail sectors on other sectors, such as ICT and the power sector, mean that a failure in any one of those other networks can cascade onto transport. This could be an increasingly important issue as the provision of real-time information and smart technologies become further embedded within the sector. For example, motorway signage to manage traffic flows relies on ICT and power, as does railway signalling and, in the case of electric trains, current for traction. In addition, other sectors can affect the strategic

### *Case for intervention*

transport network by impacting the demand for travel – hence affecting the costs associated with a weather-related service interruption. For example, work pattern, school patterns or housing locations can all affect the nature of travel demand.

**Information and uncertainty:** the uncertainty over climate change and its potential impacts, likely developments in technology over future decades and non-climate change drivers such as socio-economic developments and demand means that uncertainty underpins decisions in the sector. Barriers relate to two factors in particular:

- Uncertainty over the impacts of climate change given the long asset lifetimes being considered; and,
- There is currently little ex post analysis of adaptation actions to guide decision-makers in terms of the relative costs and benefits, and the conditions under which actions are likely to be effective. Efforts are currently underway to undertake such action but it is not widespread.

### *Recommended intervention*

#### **Build adaptive capacity by:**

- **Undertaking case study research in areas at risk of flooding or landslides to understand better the nature of interdependencies** within and across sectors. Case studies should include areas where single, or a limited number of, links are relied upon for access or to connect locations. Such case studies should be used to inform the development of cross-sectoral adaptation roadmaps at the appropriate geographical (or other) scale for strategic road and rail. Case studies could focus on the effects of flooding or landslides on major and minor roads and the cross-sectoral interactions between strategic road and rail and other policy areas such as business, land-use planning and other infrastructure providers
- **Undertaking a series ex-post evaluations of adaptation actions that improve the climate resilience of strategic road and rail.** This information should be collated into a common and accessible format to share with transport agencies and enhance best practice. For example, on the supply-side, this should include the impacts of improved drainage on travel reliability and delays, and the costs and benefits of bridge scour action. On the demand-side, it should include the effectiveness of demand management and traffic flow management during times of floods.
- **Developing further the evidence-base on the risk of bridge scour** for strategic motorway and, importantly, non-motorway routes.

### *Case for intervention*

- **Incorporate a requirement within the Department for Transport's transport appraisal guidance (WebTAG) for appraisal scenarios to reflect different probabilities of disruption** which may result from a range of projected extreme weather events, where appropriate. This would ensure that the associated costs are reflected in the 'do minimum' option, against which the relative costs and benefits of the intervention can be assessed.

### *Barrier*

Public ownership, management and operation of strategic routes will enhance further adoption of effective adaptation action, as licensing requirements set by the Office of rail Regulation (ORR) and safety and reliability targets set by the DfT and Highway Agency (HA) will incentivise change. However, it is important to ensure that full account is taken of climate change adaptation in decision-making processes and appraisal.

### *Recommended intervention*

**Maximise opportunities from renewal programmes to enhance resilience in an iterative way.** Given the level of investment in maintenance and renewal programmes on key strategic infrastructure, it is important that programmes build sufficient infrastructural resilience as new information emerges on the climate risk. For example, by considering alternative climate change emissions scenarios – including severe weather events - when planning the work.

### *Barrier*

The effectiveness of adaptation actions such as traffic management and demand management rests on the assumption that travellers will behave 'rationally' and respond to pricing, information or policy signals. However, it is likely that some travellers will be unwilling to change their behaviour owing to habits, personal travel preferences or a lack of willingness to accept official information.

### *Recommended intervention*

**Maximise opportunities from traffic and travel demand management as an adaptation action.** Undertake research to:

- Explore the use of traffic and travel management on non-motorway routes to manage flood-related delays; and,
- Better understand traveller behaviour in response to traffic and demand management initiatives.

## **Case for intervention**



### *Barrier*

The number of organisations involved in adaptation decision-making both within and between strategic and non-strategic networks may hamper the co-ordination of adaptation actions

### *Recommended intervention*

<p><b>Develop adaptation roadmaps collaboratively</b> involving local and national networks, and appropriate stakeholders across sectors.</p>
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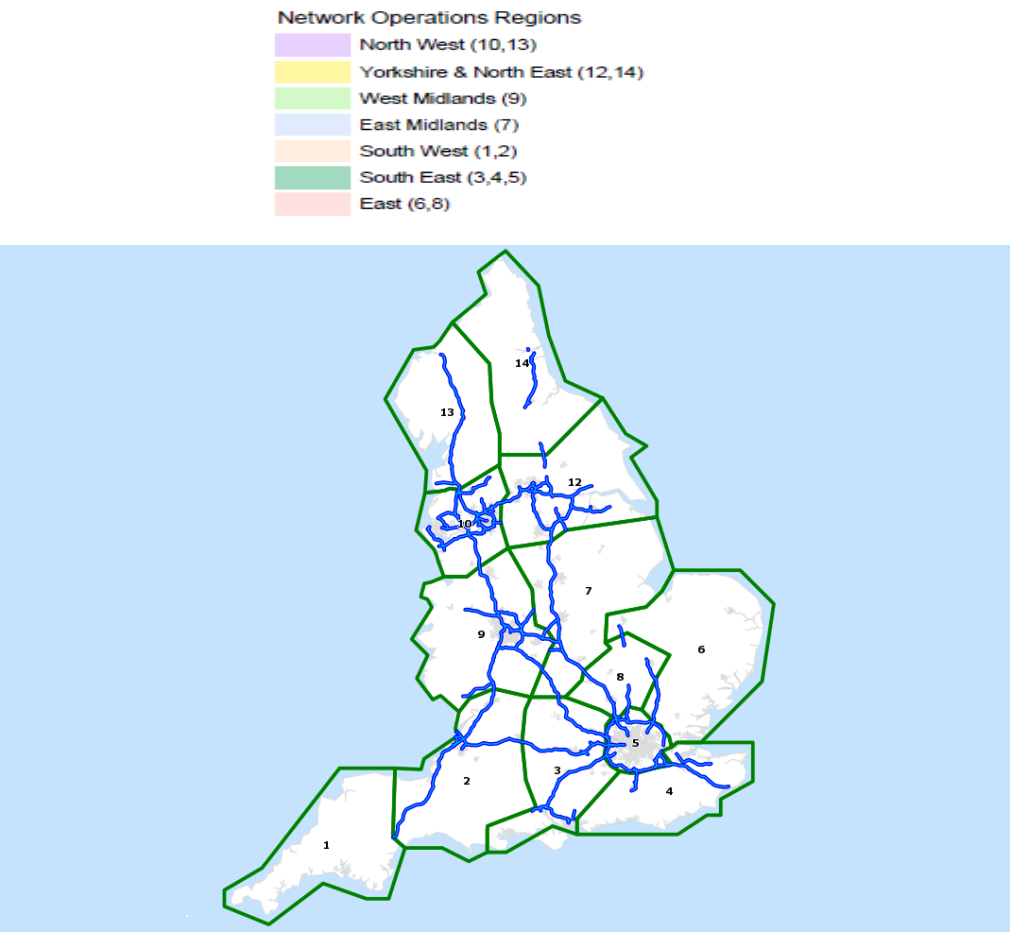
## Annex 1: Stakeholders

The ECR team is grateful to the following for their valuable input to this work:

- John Amooore - Network Rail
- Kate Avery - TRL
- Professor Chris Baker - University of Birmingham
- Chris Brown - DfT
- Laurent Denys - Eurotunnel
- John Dora - Network Rail:
- Malcolm Drury – Welsh Government
- Graham Edmond – Transport Scotland
- Dean Kerwick-Chrisp - Highways agency
- Chris Littlewood - Office of Rail Regulation (ORR):
- Gordon MacLeod - Transport Scotland
- Richard Morgan - Welsh Government
- Neil Ridley - Knowledge Transfer Network
- Jonathan Saks - DfT
- Clare Severn – Welsh Government
- Ramish Sihal - Highways agency
- Stephen Tweed - Northern Ireland
- Stephen Thomson – Transport Scotland
- Mike Whitehead - Highways agency
- Helen Woolston - TfL

## Annex 2: Highways Agency Areas

Figure 26. Map of Highways Agency areas



Source: Highways Agency



## Annex 3: Background on UKCP09

### UKCP09 projections<sup>35</sup>

The UK Climate Projections (UKCP09) provides projections of climate change for the UK. These projections cover changes in a number of atmospheric variables, using different temporal and spatial averaging. They are given for several future time periods under three future emission scenarios. Climate change over land includes more variables, at a higher resolution, than those over sea.

Projections of the climate variables in UKCP09 methodology are made using multiple climate models. The output of the climate models is used to estimate probabilities, rather than giving single values of possible changes. Probabilities are introduced to treat uncertainties associated with climate projections.

This annex begins with an explanation on the background on uncertainties associated with climate projections. It is followed by a paragraph that explains the UKCP09 methodology and how uncertainties are accounted for. The next paragraph explains how to interpret probabilities in UKCP09 output and the annex ends with a discussion on the limitations of UKCP09.

### Background on uncertainties in climate projections

There are three major sources of uncertainties in estimating future climate change:

- Natural Climate Variability;
- Incomplete understanding of Earth System process and the inability to model the climate perfectly; and,
- Uncertainty in future greenhouse gas emissions

The major sources are discussed individually below.

#### *Natural Climate Variability*

Natural variability has two principle causes. One arises from natural internal variability which is caused by the chaotic nature of the climate system. Ranging from individual storms, which affect weather, to large scale variability due to interactions between the ocean and the atmosphere (such as El Nino). Climate can also vary due to natural external factors. The main causes are changes in solar radiation and in the amount of aerosols released (small particles) from volcanoes.

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<sup>35</sup> This annex is largely based on Murphy et al., 2009 and UKCP09, © UK Climate Projections, 2009.

### *Representation of Earth's System in Climate Models*

The second main source of uncertainty arises due to modelling of the future climate. The only way we can calculate how the climate will change due to human activity is through the use of mathematical models of the earth's climate system. These models are known as Global Climate Models (GCMs). They describe the behaviour of different climate components and interactions between them. The components include the atmosphere, the oceans, the land and the cryosphere. Each interact to produce many types of feedbacks, both positive and negative. The net effect will determine how climate evolves in response to changes in greenhouse gasses.

Uncertainty in models is caused by an incomplete knowledge of the climate system and the inability to model it perfectly. Representations of physical processes within the climate system are based on a mixture of theory, observations and representation. Representations may be limited by physical knowledge, as well as by computing power, and lead to errors, which inevitably cause uncertainty. All modelling groups seek to represent climate processes in the best possible way in their models. This is based on subjective judgement, which causes different strengths of feedbacks in different models. This means that different models give different results, although they all use plausible representations of climate processes.

### *Future Greenhouse Gas Emissions and SRES*

The final source of uncertainty arises due to future emission scenarios of greenhouse gases and aerosols. This will depend on many socio-economic factors such as changes in population, GDP, energy use and energy mix. The Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart, 2000), in which climate-relevant emissions were calculated based on a number of storylines. Each of these storylines describes a possible way of how the world might develop. Differences between them arise due to the different assumptions about future socio-economic changes. They assume no political action to reduce emissions in order to mitigate climate change.

### *UKCP09 methodology*

In UKCP09, uncertainties mentioned above are accounted for when doing climate projections. Uncertainties are treated by generating projections of change as estimated probabilities of different outcomes. This means that probabilities are attached to different climate change outcomes, which provides information on the estimated relative likelihood of different future results.

## **Annex 3: Background on UKCP09**



To do this, UKCP09 assumes that uncertainties manifest themselves in different climate projections from different climate models. Probability distributions of the future climate can then be generated by using projections from a large number of models or variants from a single model.

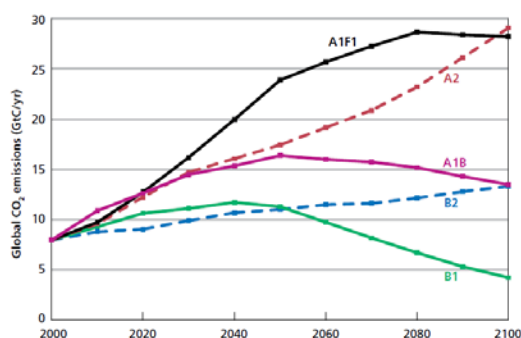
UKCP09 use a combination of projections from the following models:

- A very large number of variants of the Meteorological Office Hadley Centre model; and
- 12 international models used in inter-comparison studies of the fourth IPCC report.

Probabilities are based on a large number (ensembles) of climate model simulations, but adjusted according to how well different simulations fit historical climate observations. This is done in order to make them relevant to the real world. By presenting probabilities based on ensembles of climate models, UKCP09 takes into account both modelling uncertainty and uncertainty due to natural variability.

It does not however include uncertainty due to future emissions. Currently there is no accepted method of assigning relative likelihoods to alternative future emissions. UKCP09 therefore presents probabilistic projections of future climate change for 3 future emission scenarios. They are selected from three scenarios developed in SRES and referred to as Low, Medium and High emissions, which corresponds to A1FI, A1B and B1 scenarios in SRES. **Figure 27** indicates these scenarios in terms of CO<sub>2</sub> emissions with solid lines (black: High Emissions, purple: Medium Emissions, green: Low Emissions). Each scenario also includes emissions of other greenhouse gases. Although the three UKCIP emission scenarios span the range of marker scenarios in SRES, there are additional scenarios, both higher and lower, that they do not encompass.

**Figure 27.** Global annual CO<sub>2</sub> emissions under the three IPCC SRES scenarios



Source: Murphy *et al.*, 2009

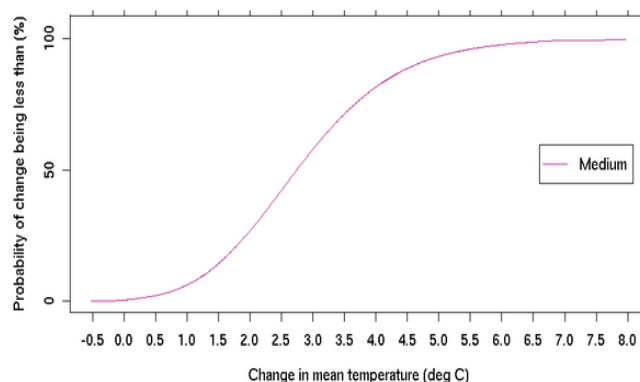
Note: The dotted lines are two SRES emission scenarios used in previous UK Climate Projections, but not in UKCP09.

### Probability in UKCP09

Probabilistic projections assign a probability to different possible climate change outcomes. Probability given in UKCP09 output is seen as the relative degree to which each possible climate outcome is supported by the evidence available. It takes into account the current understanding of climate science and observations.

Probability in UKCP09 does not indicate the absolute value of climate changing by some exact value. Instead it states the probability of climate change being less than or greater than a certain value using the Cumulative Distribution Function (CDF). This is defined as probability of climate change being less than a given amount. An example is given in **Figure 28**. The CDF (for the 2050s mean summer temperatures in the London area, with a medium emission scenario) shows that there is a 10% probability of temperature change being less than 1 degree and 90% probability of temperature change being less than 5 degrees. These statements also work inversely, where one could say there is a 10% probability of temperature change being greater than 5 degrees and a 90% probability of temperature change exceeding 1 degree.

**Figure 28.** Example of cumulative distribution function for 2050s mean summer temperatures in the London area for the medium emission scenario



Source: UKCP09

The figure above does not say that the temperature rise will be less than 5 degrees in 90% of the future climates, because there will only be one climate. It rather indicates that there is 90% probability (based on data and chosen methodology) that the temperature rise will be less than 5 degrees.

### Limitations

The procedure used in UKCP09 to convert ensembles of climate models into probabilistic estimates of future climate also includes some subjective choices and assumptions. This means that the probabilities themselves are uncertain, because they are dependent on the information used and how the methodology is formulated. Furthermore, the system cannot be verified on a large sample of past cases. Current models are, however, capable of simulating many aspects of global and regional climate with considerable skill. They do capture all major physical and biochemical systems that are known to influence our climate.

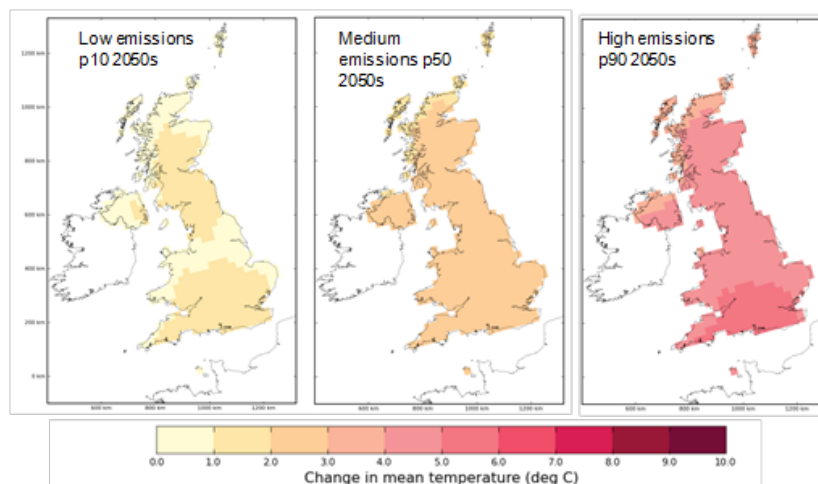
### Key climate drivers for the strategic road and rail sector

#### Mean summer temperature

Climate projections indicate an increase in summer temperature. By the 2050s, for the central estimate (p50) of the UKCP09 medium emissions scenario, the southern part of England could see temperature rises of between 2.3 °C and 2.7 °C (Murphy *et al.*, 2009). However, temperature increases will vary regionally. Parts of northern Scotland could experience temperature increases of around 1.5 °C for the p50 medium emissions scenario. UK-wide, the projections for increases in mean summer temperatures range from 0.9 °C under the p10 low emissions scenario, to 5.2 °C under the p90 high emissions scenario.

The projected changes in mean summer temperature in the UK for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are shown in **Figure 29**.

**Figure 29.** Projected changes in mean summer temperature



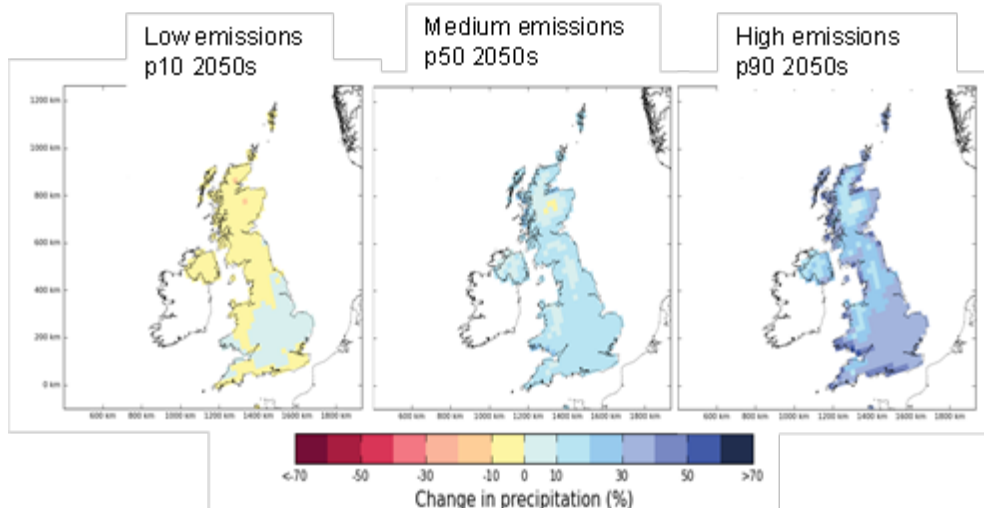
Source: UKCP09

### *Mean winter precipitation*

In the p50 medium emissions scenario, mean winter precipitation is projected to increase by 9 - 17% (depending on location) in the 2050s, relative to the 1961-1990 baseline. The spread in projections is wide however, ranging from -2% for the lower bound of the UKCP09 low emissions scenario in Scotland East to +41% for the upper bound high emissions scenario in South West England (Murphy et al., 2009).

Changes in winter precipitation for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are presented in **Figure 30**.

**Figure 30.** Projected changes in mean winter precipitation by the 2050s (emissions scenario from left to right: low p10; medium p50; high p90)



Source: UKCP09

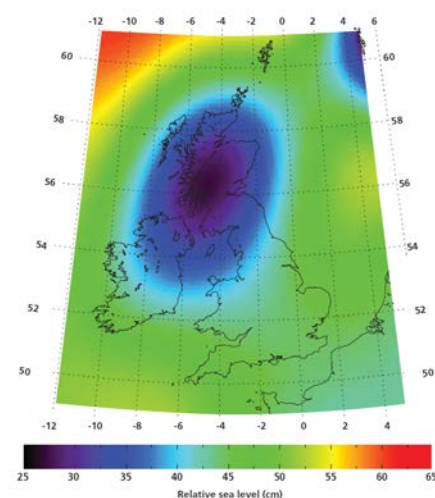
### Sea level rise

According to the central estimates of relative sea level changes with respect to 1990s, sea level will rise between 18 and 26 cm between the low and high scenario in London and between 11 and 18cm in Edinburgh (Lowe *et al.*, 2009).

As the earth's crust is moving upward in the northern parts of the UK, relative sea level rise will differ over the regions. The north will be less affected by sea level rise compared to the south (Lowe *et al.*, 2009).

**Figure 31** combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095 (Lowe *et al.*, 2009).

**Figure 31.** Relative sea level rise (cm) around the UK for the 21st century



Source: Lowe *et al.*, 2009

Note: This combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095

**Table 4** displays the sea level rise forecast by the UKCP09 models by 2050, for the central estimates of the emissions scenarios. These estimates are equivalent to a sea level rise of roughly 1.8-4.3 mm per year.

**Table 4.** Central estimates of relative sea level changes (in cm) by 2050 compared to 1990 levels

	Low	Medium	High
<b>London</b>	18.4	21.8	25.8
<b>Edinburgh</b>	10.5	13.9	18.0

Source: Lowe *et al.*, 2009

### Extreme weather events

As the climate warms, weather patterns and the frequency of extreme events may also change (Solomon *et al.*, 2007). Heavy rain days (>25 mm) will likely to be more frequent over most of the lowland UK, central estimates show an increase by a factor of 2 – 3.5 in winter and 1 – 2 in summer by the 2080s under the medium emissions scenario (UKCP09).

The frequency and intensity of heatwaves could increase in future, especially in southern parts of England. The results of the ARCADIA project suggest that by the 2050s, one third of London's summer may exceed the Met Office heatwave

## Annex 3: Background on UKCP09

temperature threshold (32 °C). (CCRA: Capon and Oakley, 2012; Hall *et al.*, 2009).





## Annex 4: Additional discussion of climate impacts

### Flooding

#### *Length of road and rail at risk of flooding*

The CCRA Floods and Coastal Erosion Sector Report (Ramsbottom *et al.*, 2012) projected fluvial and tidal flood risk to road and rail in England and Wales by estimating the length of road and rail which will be at ‘significant’ risk of flooding in the future. ‘Significant’ risk is defined as a 1.3% annual probability of flooding, or equivalently a 1 in 75 year flood event. Current probabilities of flooding were obtained for 50 m grid cells for England and Wales, and aggregated to 100 m grid cells. Additionally, a hectare grid of the road and rail network was obtained from the Environment Agency’s National Receptor Database. The number of cells in this grid where the probability of flooding is above 1.3% annually was calculated. Each cell was counted once for rail and once for each road type (motorway, A-road, B-road, minor road). The mean length of road and rail through each of these cells was assumed to be 85.25 m. This length and the number of grid cells at significant risk of flooding were multiplied to reach a figure for the total length of rail and road at significant risk. To project the risk in future, current flood probabilities are uplifted for future years.

The results are in **Table 5** and show that for the UKCP09 p50 medium emissions scenario, the length of motorway at significant risk of flooding could increase by around 48% by the 2050s<sup>36</sup>. The length of A-road at significant risk could increase by around 30%. The length of rail at significant likelihood of flooding could increase by around 28% by the 2050s.

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<sup>36</sup> Percentage increases calculated by the ECR team based on data in CCRA: Ramsbottom *et al.*, 2012.

**Table 5.** Length of road and rail at significant risk of flooding (km) in England and Wales for the p50 medium emissions scenario (range between low p10 to high p90 scenarios shown in brackets)

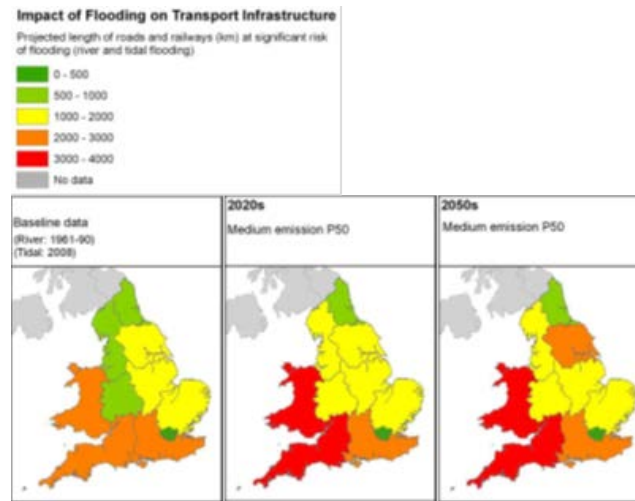
Route type	Flooding type	1961-90	2008	2020s	2050s
<b>Motorway</b>	Fluvial	165		216	244 (170–300)
	Tidal		81	95	120 (100–140)
<b>A-road</b>	Fluvial	2,318		2,804	3,004 (2,300–3,450)
	Tidal		818	919	1,084 (950–1,200)
<b>Rail</b>	Fluvial	1,325		1,598	1,716 (1,330–1,980)
	Tidal		675	749	842 (780–920)

Source: Ramsbottom *et al.*, (2012)

It is clear from the results that the length of rail and road at risk of fluvial flooding could continue to exceed significantly the length at risk of tidal flooding. Motorways could experience the most significant increase in flood risk, while A-roads and rail could experience smaller but nevertheless sizeable increases in risk.

The above estimates do not fully reflect the regional variation in flood risk that could be experienced in future (and is currently experienced). **Figure 32** illustrates this regional variation. It is clear that the impacts will be largest in South West England and Wales. Note that the maps in the figure do not account for the different lengths of existing road and rail in different areas, and so they do not reflect the relative risk that will be experienced across the country.

**Figure 32.** Regional distribution of length of road and rail at significant risk of flooding in England and Wales for the p50 medium emissions scenario



Source: CCRA: Ramsbottom *et al.*, (2012)

The CCRA analysis covers England and Wales. Increased flood risk will also be experienced in Scotland and Northern Ireland. The projection method does not take into account the fact that many routes run side by side. This could result in underestimates of the flood risk in areas with major interchanges. Some roads and rail routes are built on embankments, and so they may not flood despite the fact that they are located in a flood zone. Finally, the analysis provides estimates of a subset of flood types and risk levels, and so does not reflect overall flood risk for the countries considered.

The Highways Agency have analysed the impacts of climate change on fluvial and pluvial flooding to the South West England region of their road network (Highways Consultancy and Research Group, 2011). The aim of the analysis was to project changes in flood risk. Roads were classified according to three levels of flood risk. Hotspot risk status A was defined as an annual probability of flooding that is greater than 50% (very high risk), risk status B was defined as an annual probability of flooding of between 25% and 50% (high risk), and risk status C was defined as an annual probability of flooding of between 10% and 25% (moderate risk). The current and projected length of road at these risk levels within Area 2 is shown in **Table 6**. The results are calculated for the central estimate of the UKCP09 medium emissions scenario.

**Table 6.** Length of road in Area 2 at risk of flooding (percentage of total length)

Risk level	Present day	2050s
<b>A</b>	45 (7%)	56 (8%)
<b>B</b>	95 (14%)	84 (13%)
<b>C</b>	71 (11%)	106 (16%)
<b>Total</b>	211 (32%)	246 (37%)

Source: Highways Consultancy and Research Group, 2011

The results indicate that more road length will move to risk level A over time than will move from risk level C to B. This indicates that changes in flood risk could be concentrated around roads that are currently at low risk of flooding. Overall, the length of road with an annual probability of flooding of 10% and above will increase by around 17%. This is broadly similar to the results of the CCRA, although the risk levels analysed differ for the two studies.

The results of the analysis for South West England were compared with earlier work, as shown in **Table 7**. This demonstrates that results can vary significantly between methods, and indicates the difficulty in projecting flood risk accurately.

**Table 7.** Current length of road classified as flood hotspots in Area 2 (km)

Risk level	HRG method	DPoE method	Proposed method
<b>A</b>	48	80	45
<b>B</b>	40	165	95
<b>C</b>	73	1	71
<b>Total</b>	161	246	211

Source: Highways Consultancy and Research Group, 2011

The results in **Table 7** were extrapolated to the national level. This analysis indicates that around 200 km of road is currently at risk of flooding with an annual probability of 50%. This could increase to 250 km by the 2050s. This is a significant increase relative to the starting point, but not large in absolute terms.

The length of road in the South West of England at risk of tidal flooding was also projected. Currently, 0.2% of the network is at risk, and this could rise to 6% in the 2080s. Again, this is a substantial relative increase, but may not be large in absolute terms.

## Annex 4: Additional discussion of climate impacts

### Road delays due to flooding

The CCRA Transport Sector Report (Thornes *et al.*, 2012) qualitatively estimated the costs of road delays that could occur in England in the future due to flooding, using expert opinion. These could rise from less than £1 million to between £1 million and £10 million by the 2050s under the UKCP09 p50 medium emissions scenario, as illustrated in **Table 8**. This is a relatively small cost, but the range indicates the uncertainty with which estimates can be made, due to the many factors that influence delays described in the previous section. Under the p50 high emissions scenario, the costs could be between £10 million and £100 million. This further illustrates the uncertainty associated with the costs of delay in the future. These estimates only consider floods caused by precipitation. Estimates could be higher if other flooding types and risk levels were included. Furthermore, the estimates apply only to England.

**Table 8.** The future impacts of delays from flooding on the road network (£m)

	Low Emissions			Medium Emissions			High Emissions		
	p10 (dry)	p50 (mid)	p90 (wet)	p10 (dry)	p50 (mid)	p90 (wet)	p10 (dry)	p50 (mid)	p90 (wet)
<b>2020s</b>	<1	1-10	1-10	<1	1-10	1-10	<1	1-10	1-10
<b>2050s</b>	<1	1-10	1-10	<1	1-10	10- 100	<1	1-10	10- 100

Source: CCRA: Thornes *et al.*, 2012

The CCRA Floods and Coastal Erosion Sector Report (Ramsbottom *et al.*, 2012) generated estimates of the future costs of delays on the road network from fluvial and tidal flooding. Floods with an annual probability of 1.3% were considered for England and Wales. Thus, the analysis does not estimate the total costs from all types of flooding to the UK as a whole. **Table 9** summarises the total damage costs under the UKCP09 p50 medium emissions scenario. These costs are within the range indicated in the CCRA Transport Sector Report. They also indicate the varying levels of impact that will be caused by different types of flooding. The range of uncertainty in these costs across scenarios is reflected by the percentage increases in the length of road at risk of flooding for each scenario.

Note that the analysis used a per km cost figure to quantify the impacts of delays, which does not fully take into account the varying scale of risk due to congestion and alternative transport modes. The cost estimates also do not take into account future increases in traffic levels, or changes in the value of time as GDP and productivity rises.

## Annex 4: Additional discussion of climate impacts

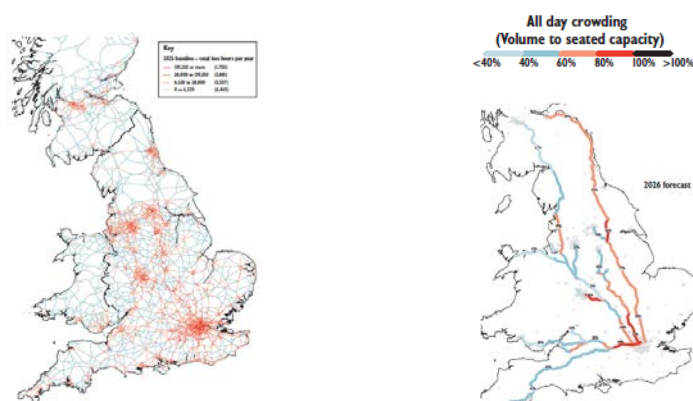
**Table 9.** Projected flood disruption costs to roads under p50 medium emissions scenario

Road type	2020s		2050s	
	River	Tidal	River	Tidal
<b>Motorway</b>	£130,000	£40,000	£200,000	£100,000
<b>A-road</b>	£430,000	£90,000	£600,000	£230,000

Source: Ramsbottom *et al.*, 2012

The impacts associated with flooding will also depend on traffic levels. While comparison of the regional CCRA results with congestion maps (**Figure 33**) indicates that the most heavily congested areas are unlikely to be as affected by flooding as other areas, any flooding in these areas would have a greater economic impact than in less congested areas.

**Figure 33.** Congestion on the road network in 2025 (left) and overcrowding on the rail network in 2026



Source: Eddington (2006)

### Rail delays due to flooding

The CCRA Floods and Coastal Erosion Sector Report (Ramsbottom *et al.*, 2012) projected the total disruption costs for flooding events with a 1.3% annual probability using the same method as for roads. **Table 10** displays the cost figures under the UKCP09 p50 medium emissions scenario. The costs are similar to those for A-roads, and greater than those for motorways. This reflects differences in the length of rail track and road, and the greater costs of repairing railways. It is clear that the costs are not significant even in the 2050s. However, these results are subject to the same caveats as the CCRA analysis of flood delays

## Annex 4: Additional discussion of climate impacts

on roads. The uncertainty in rail delay costs across scenarios is represented by the percentage increases in the length of road at risk of flooding for each scenario, which are presented in Section 3.

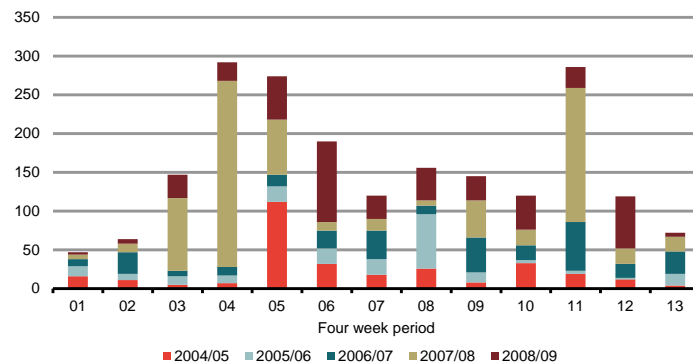
**Table 10.** Projected flood disruption costs to rail under p50 medium emissions scenario

2020s		2050s	
River	Tidal	River	Tidal
£370,000	£90,000	£540,000	£210,000

Source: CCRA: Ramsbotton *et al.*, (2012)

As with the analysis of flooding delays on roads, there can be significant variation in the impacts of flooding on the rail network. Network Rail collects detailed information on the delays caused by flooding. **Figure 34** shows the number of past flooding events for each four week period for a selection of past years. It is clear from this figure that there can be large variations in the frequency of flood events. There is a peak in autumn in many years, which demonstrates the effects of seasonal climate on delays.

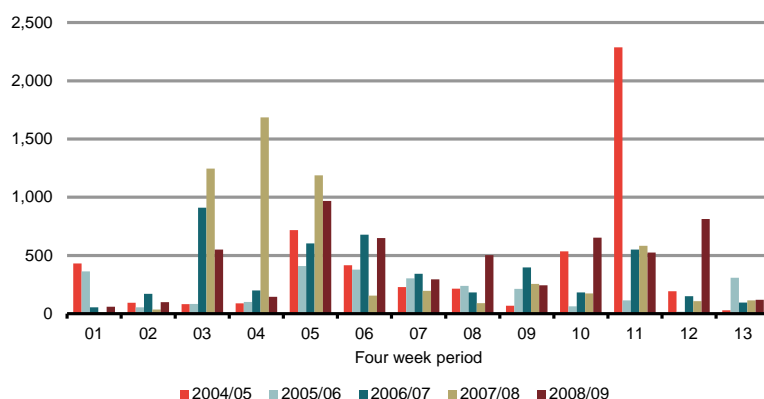
**Figure 34.** Number of rail flood events on the GB rail network for each 4 week period (period 01 signifies the first week in April)



Source: Data provided by Network Rail

**Figure 35** displays average flooding delay minutes for the rail network in past years. This graph demonstrates the variation in flood intensity that can occur. For example, in 2007-08, there were a number of significant flooding events that caused a substantial increase in total delay minutes.

**Figure 35.** Average rail delay minutes on the GB rail network per incident, for 4 week periods



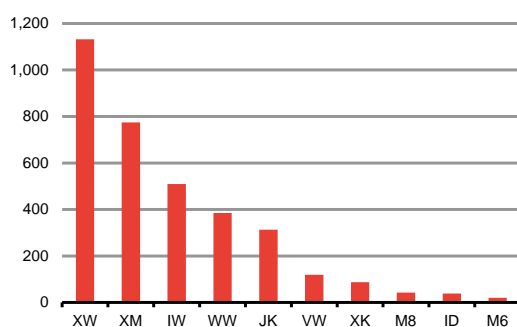
Source: Data provided by Network Rail

The types of incident that flooding causes can also vary. **Figure 36** shows the ten most common delay types, and the associated average delay time, for 2004 to 2009.

**Table 11.** Railway flooding incident codes explained

**Table 11** describes the incident type codes displayed in this figure. The figure demonstrates that the average delay can vary significantly, depending on the effects of flooding on the network. This will in turn depend on the type of flooding encountered.

**Figure 36.** Average minute delays for the ten most common incident types on the GB rail network, 2004 to 2009



Source: Data provided by Network Rail data



**Table 11.** Railway flooding incident codes explained

Code	Description
<b>XW</b>	Severe weather (not snow) affecting Network Rail infrastructure
<b>XM</b>	Flooding not due to exceptional weather
<b>IW</b>	Effect of weather on infrastructure equipment
<b>WW</b>	Level crossing failure including barrow/foot crossings and crossing treadles
<b>JK</b>	Gas/water mains/overhead power lines
<b>VW</b>	Severe weather other than snow affecting infrastructure the responsibility of IMC
<b>XK</b>	Electricity Board power failures
<b>M8</b>	EMU failure/defect/attention: other
<b>ID</b>	DMU (including HST/MPV) failure/defect/attention: other
<b>M6</b>	Severe weather affecting passenger fleet equipment

Source: Information provided by Network Rail

## Overheating

### *Effect of heat on roads*

The CCRA Transport Sector Report (Thornes *et al.*, 2012) estimated the repair costs of overheating on the Highways Agency road network. They used a repair cost of £115 per km, which was based on current expenditure by Leicestershire County Council. This implies the Highways Agency spends £34 million per year on heat-related repairs.

**Table 12** and **Table 13** set out the cost of carriageway repairs for England and Northern Ireland, respectively. These costs are not significant in any of the emission scenarios except the high emissions p90 scenario. Thus, carriageway repairs are unlikely to be large in future for the Highways Agency. This is due to the fact that Highways Agency roads are currently designed to withstand temperatures higher than those which will be experienced under most climate change scenarios. It should be noted that the analysis does not take into account heatwaves, which could cause additional heat repair costs.

**Table 12.** The future cost of carriageway repairs in England (£m)

	Low Emissions			Medium Emissions			High Emissions		
	p10	p50	p90	p10	p50	p90	p10	p50	p90
<b>2020s</b>	<1	<1	<1	<1	<1	<1	<1	<1	<1
<b>2050s</b>	<1	<1	1-10	<1	<1	1-10	<1	<1	1-10

Source: CCRA: Thornes *et al.*, 2012

In Northern Ireland, temperatures are typically lower than those than in England, and increases in temperature are not projected to be as significant. The future costs of carriageway repairs are therefore projected to be small.

**Table 13.** The future cost of carriageway repairs in Northern Ireland (£m)

	Low Emissions			Medium Emissions			High Emissions		
	p10	p50	p90	p10	p50	p90	p10	p50	p90
<b>2020s</b>	<1	<1	<1	<1	<1	<1	<1	<1	<1
<b>2050s</b>	<1	<1	<1	<1	<1	<1	<1	<1	<1

Source: CCRA: Thornes *et al.*, 2012.

### *Effect of heat on rail*

The CCRA Transport Sector Report (Thornes *et al.*, 2012) estimated the number of incidences of rail buckling that may occur in the future. A correlation between the number of rail buckling incidents and summer temperature for 1997 to 2009 was estimated, and used to calculate the future number of rail buckling incidents using climate change scenarios for temperature.

**Table 14** shows the correlation between the number of rail buckling incidents and regional temperatures for each area of Great Britain, based on data from 1997 to 2009. The overall correlation for Great Britain is relatively high. The correlation for Scotland is low, due to the fact that fewer buckling incidents occurred in this region in the time period examined.

**Table 14.** Regional correlation between track buckling incidents and temperature

Region	Correlation
East Midlands	0.76
East of England	0.78
Scotland	0.39
London	0.76
North East	0.67
North West	0.82
South East	0.66
South West	0.82
Wales	0.57
West Midlands	0.73
Yorkshire and Humber	0.62
Great Britain	0.84

Source: CCRA: Thornes *et al.*, 2012

The results indicate that rail buckling incidents are more likely in the South of England than in other regions of the UK. This is due to the higher temperatures that are typically experienced in this region.

**Table 15** presents the projections of the number of buckling incidents for Great Britain under various climate change scenarios. Under a medium emissions scenario, the number of rail buckling incidents could increase by 150%.

The average delay time associated with each incident was estimated to be two hours. Applying National Audit Office defined values of passenger delay costs, this results in an incident incurring £9,000 in total delay costs on average. Repair costs for each incident are estimated to be £10,000 by Network Rail. These figures were applied to the projected number of incidents, and the results are displayed in **Table 15**. Despite the high percentage increase in the number of buckling incidents, the absolute monetary cost is still low, at £2.6 million per year for the p50 high emissions scenario. However, as with many weather events, extremes in temperature could cause significantly higher costs than those calculated in the CCRA analysis, which are based on mean temperatures.

**Table 15.** Projections of the average annual number of rail buckling incidents in Great Britain and total costs

Scenario (all p50)	1995-2009	2020s (Med)	2050s (Low)	2050s (Med)	2050s (High)
Number of incidents	50	66	113	123	139
Total cost	£950,000	£1,254,000	£2,147,000	£2,337,000	£2,641,000

Source: CCRA: Thornes *et al.*, 2012

The CCRA analysis uses the number of incidents, rather than the length of rail affected. This effectively results in assuming that each incident affects the same length of rail. The analysis was performed for Great Britain, rather than the UK. Impacts of climate change on rail buckling in Northern Ireland would add to this figure, although not significantly due to the limited extent of the network and low projected temperature increases. The analysis assumes that current demand levels do not change in the future, and does not consider the effects of heatwaves on the number of buckling incidents. The inclusion of these developments may increase the costs of rail buckling further.

In Greater London alone, projections suggest there could be an average of 10.9 rail buckling incidents per year in the 2050s under a high emissions climate change scenario (ARCADIA, 2012). This would result in repair costs of £151,481 per year, based on a repair and maintenance cost of £13,400 per incident (higher than the estimate employed in the CCRA of £10,000). Delay costs to travellers would increase this cost further.

The extent to which a rail will buckle and the delay costs that causes depends on a range of factors, which indicate the uncertainty associated with projections of rail buckling in the future. These factors include:

- The air temperature reached (the higher the temperature then generally, the higher the risk<sup>37</sup>).
- The condition of the track: track in good condition would not be expected to buckle until ~39 °C ambient air temperature. However, for track in bad condition the track is at risk at ~25 °C (Dobney *et al.*, 2009).
- The length of route affected by the buckle.

<sup>37</sup> Beyond a certain temperature however, additional buckles would not be expected until a further high temperature is reached.

- The number of passengers on board as the delay costs would be higher on more congested and heavily used routes, such as those commuter routes in the South East.
- The value of time of the passengers on board – this is expected to rise substantially to 2050 as the value of time generally rises with incomes (DfT, 2011i).

### Landslides in Scotland and Wales

As part of the CCRA analysis, estimates were made for the proportion of the road network that could be considered to be at risk due to slope stability concerns. The approach used was different for each administration. For England, estimates were derived through expert elicitation with the Highways Agency and a local UK Roads Board representative. Estimates for Northern Ireland were based on the same rates of risk as provided for England, while the Department for Regional Development provided quantitative data on the extent of ‘risk slopes’ adjacent to roads in this area. For Scotland, a response function was developed using a climate change study published by the Scottish Executive in 2005 (Scottish Executive, 2005). Only data applicable to trunk roads were available from this study. All response functions are related to winter precipitation, the main climate driver contributing to slope stability (CCRA: Thornes *et al.*, 2012).

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