Safe roads, Reliable journeys, Informed travellers

HIGHWAYS AGENCY

Highways Agency **Climate Change Risk Assessment**

August 2011

An Executive Agency of the Department for Transport

Highways Agency
Climate Change Risk Assessment

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Contents

Introduction

This risk assessment document is an update of the interim report submitted to Defra in December 2010 and draws upon earlier work, most notably the **Highways Agency Climate Change Adaptation Strategy and Framework**. In compiling the report, guidance has been taken by Defra and supplemented by a risk assessment framework developed by Cranfield University.

Background - Climate change

Global scientific consensus is that the world's climate is changing. Long term changes in climate have been observed at continental, regional, and ocean basin scales as well as nationally in the UK, and include changes in temperature, patterns of rainfall, of winds, and extreme weather. The **Stern Review** (2007) highlights climate change as a serious and urgent issue and the need for action is widely acknowledged.

In the UK, the ten hottest years on record have occurred since 1995. The 12-month period ending in April 2007 was the warmest period on record. The UK is probably warmer now than it has been at any time in the last thousand years. This trend within the UK is consistent with the wider picture of a general world-wide warming noted by the **Intergovernmental Panel on Climate Change (IPCC)**, whose **4th Assessment Report** concluded that warming of the climate system is unequivocal.

The United Kingdom's position

The UK Government believes that climate change is one of the most serious threats the world faces. There are many uncertainties, but the body of evidence on climate change warns of the challenges we need to prepare for; higher risks of drought and floods, more frequent episodes of extreme weather, rising sea levels, and higher temperatures. These impacts could have wide consequences across the UK, including risks to the functioning of critical infrastructure such as transport networks.

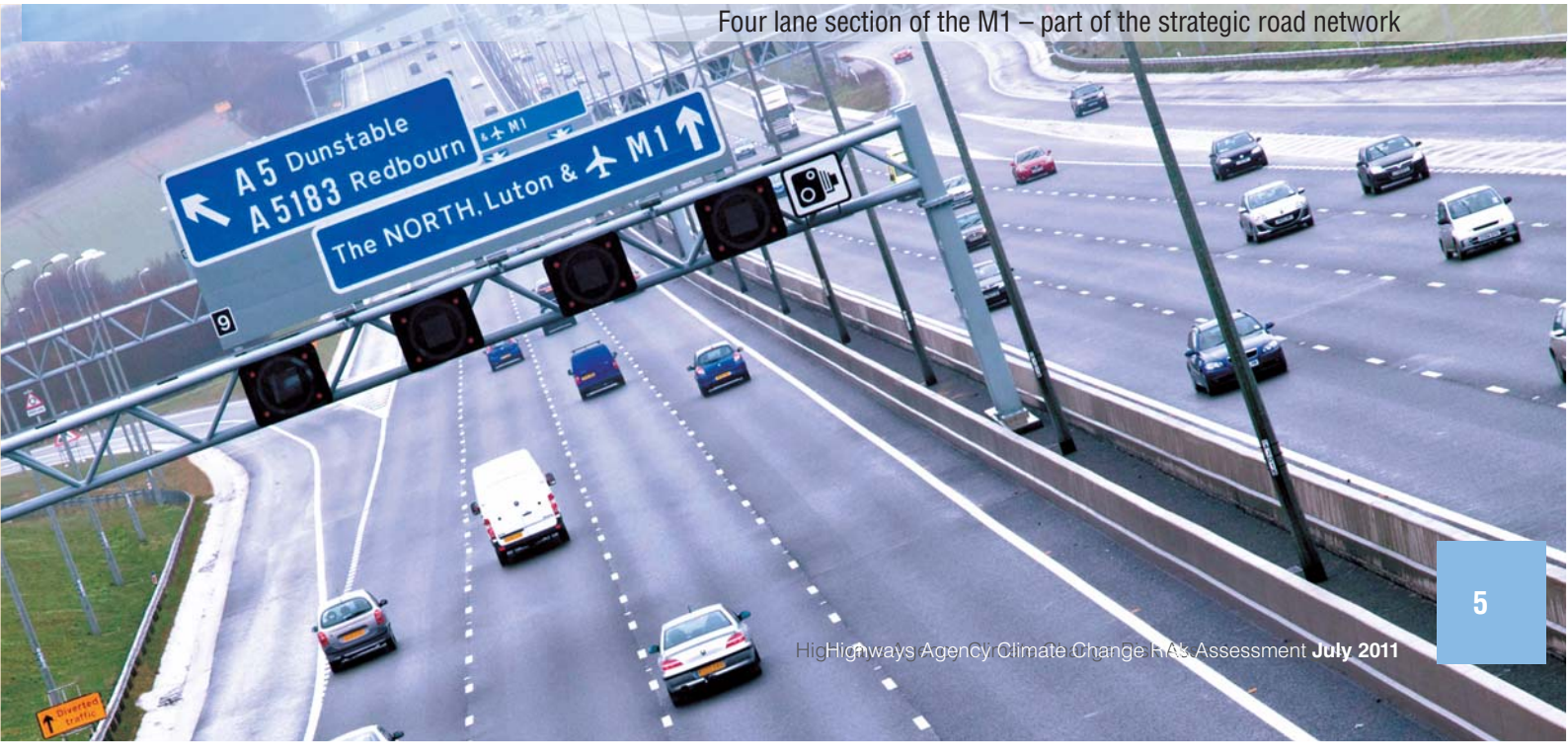
The **Climate Change Act 2008** is widely regarded as a robust statutory framework for adaptation. The Act provides an Adaptation Reporting Power. This power is being used to direct selected infrastructure owners to produce reports which consider their risks from climate change and require them to put together programmes of measures to deal with these risks. The Act establishes regular assessments of our national preparedness to meet the risks and opportunities arising from climate change. Following the first assessment in 2012, a National Adaptation Programme will respond to high priority opportunities and risks. Although the Highways Agency is not one of the organisations obliged to report under the reporting power, as the custodian of nationally significant infrastructure we volunteer this report to inform the National Adaptation Programme and UK Climate Change Risk Assessment.

The Highways Agency – what we do

The Highways Agency operates, maintains and improves England's strategic road network. The network is an £88billion government asset and is essential to economic prosperity. The Highways Agency's network includes over 4300 miles of roads ranging from motorways carrying up to 200,000 vehicles per day to single carriageway trunk roads carrying fewer than 10,000 vehicles per day. This network is a key component of the country's overall transportation infrastructure, linking with local roads and other transportation modes, carrying a third of all traffic in England, and two thirds of all heavy freight traffic.

Along with other national infrastructures, motorways and major A roads are vulnerable to the effects of climate change. Beyond the obvious paved roads, we have an extensive asset base incorporating bridges, junctions, tunnels, culverts and embankments, along with extensive technology infrastructure such as traffic detection equipment, variable message signs, lighting and communications. The Highways Agency has a responsibility on behalf of the Secretary of State for Transport to safeguard the resilience of this strategic asset. We have analysed climate projection models to understand future risks covering the life of our assets which has informed decisions on how best to work in a globally changing climate.

Many of the Highways Agency's activities are either directly affected or influenced by the weather and climate. Many of the impacts will be adverse, but some may be positive (page 29). Our response to the challenge of climate change must involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (adapting and changing behaviour to be more appropriate to the expected future climate). Although we recognise these two areas are highly interdependent, this report is focused on how we adapt to operate within a changing climate and deal with the impacts of such change.



Four lane section of the M1 – part of the strategic road network

Chapter 1: Corporate Risk Appraisal

Climate change – a business priority

In common with most organisations, the Highways Agency manages a corporate risk register. Climate change is identified as a priority risk and one that is central to our organisational planning.

The climate change risk is that:

"We are not prepared for climate changes which occur, threatening both highway asset integrity and availability; and we fail to adequately manage the carbon emissions that lie within the Highways Agency's sphere of influence, leading to loss of reputation and financial impacts from Carbon Reduction Commitment (CRC) penalties and higher energy consumption"

The **cause** of the risk can be identified as not targeting management actions nor timely and demonstrably reducing climate change risks defined by the organisation. Unmanaged, the **consequence** would be a deterioration in network integrity; increased maintenance liability; increased disruption to service from events such as flooding; increased risks to road users and operational staff from extremes in weather and risk to the ability of staff to access their place of work when extreme weather events occur.

The Agency has already experienced problems on the network due to extremes in rainfall and temperature. These occurrences are only likely to increase in their frequency and severity over time as the impacts of climate change increase. The majority of the network remains susceptible to weather events, with detrimental changes in asset integrity adversely affecting journey reliability and safety. In treating the risks posed, some changes to technical standards have already been made to increase resilience to climate changes including HD33 drainage standard and the Enrobé à Module Élevé 2 (EME2) revised pavement specification.

Rainfall on the M25

Strategic Objectives

As an organisation, our approach to climate change is a business priority and critical to achieving our vision of becoming the world's leading road operator. This vision is set out in our **Strategic Plan**, alongside five supporting goals. Climate change impacts each one of the goals:

Strategic Goal	Climate change impacts …
We provide a service that our customers can trust	the experience that customers have of the strategic road network;
We set the standard for delivery	the ability of the Highways Agency to deliver;
We deliver sustainable solutions	efforts to be sustainable in all that we do;
Our roads are the safest in the world	safety of the network for all road users, including the public, hauliers, traffic officers, contractors and maintenance crews;
Our network is a dynamic and resilient asset	the ability of our network and all associated assets to work under testing environmental circumstances.

Table 1: Impact of climate change on Highways Agency strategic goals

Adaptation: 'business as usual'

Embedding adaptation into the organisation is critical to formulating appropriate management and mitigation solutions to remove or reduce climate risks. This has direct bearing on the success of the future operation, maintenance and improvement of the strategic road network (SRN). Climate change adaptation is taken seriously by the Highways Agency Board, and as discussed, is reported on the Agency's corporate risk register. Reporting takes place monthly and the Agency's risk mitigation measures are discussed, including the extent to which they are effective. Good progress has been made, having produced the **Climate Change Adaptation Framework Strategy**. This demonstrates a clear framework for identifying and managing climate change vulnerabilities (page 18). These vulnerabilities have been adopted by resilience staff and critical asset owners in business areas at clear risk of the impacts of climate change including pavements (roads), structures, geotechnics and drainage. Our climate change adaptation action plan is due to be published by the end of the 11/12 financial year.

Business as usual – keeping the network open

Corporate level risk assessment

The Highways Agency has assessed the potential risks that climate change poses to the ongoing operation, maintenance and improvement of the strategic road network. We are factoring in anticipated climatic changes into the delivery of our business and developing appropriate management and mitigation solutions to remove or reduce these risks. These risks are recorded in detail in the vulnerability schedule at Annex A. A snapshot of the high level climate related risks to our corporate objectives can be seen in Table 2.

Highways Agency high-level climate-related risks to corporate objectives	
Risk	Examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in average climatic conditions; assets are more badly damaged as a result of more extreme climatic events.
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for road works.
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive construction /maintenance/repairs/renewal required; new (more expensive) solutions required e.g. designs and materials /components/ construction costs.
Increased safety risk to road workers	Increased risk to construction and maintenance workers and Traffic Officers as a result of climatic change e.g. if need to work on the network more often; if required to work on the network during extreme climatic events or if climate change requires them to perform more 'risky' activities.
Increased programme and quality risks due to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programmes and/or quality.
Current Highways Agency internal operational procedures not appropriate	Effects of climate change require new ways of working - changed or new business processes, new skills/competences.
Increased business management costs	Need for more staff; more frequent (expensive) incidents to pay for; need for more research into ways of coping with climate change.

Table 2, Climate change impacts on Highways Agency corporate objectives

Chapter 2: Climate projections

Source data

The Highways Agency has used a mix of source data in assessing its risk to climate change. The Highways Agency's Adaptation Framework was originally developed in line with the UK Climate Impacts Programme 2002 (UKCIP02). **The Met Office** was consulted to ensure no significant anomalies between the UKCIP02 projections we applied to our risk analysis and the probabilistic outputs of the **UK Climate Projections 2009 (UKCP09)**. UKCP09 provides the latest projections on the future climate of the UK providing significant advances on the previously available scenarios in UKCIP02. UKCP09 uses a cutting edge peer-reviewed methodology to give a measure of the uncertainty in the range of possible outcomes. The projected changes provided by UKCP09 depend on the emissions scenario, the region of the UK and how far in the future is of interest.

The Highways Agency is committed to revising the climate modelling projections used in the adaptation strategy using the latest science from the UK Climate Impacts Programme to determine risks, implications and inform selection of adaptation measures. The Highways Agency recognises the importance and value of using the most robust data, and where necessary this is being used. We are using the latest scenarios from the UK Climate Projections to further inform our work on adaptation, as well as contribute to internal guidance to ensure that the changing climate is factored into our new advice, technical standards and specifications. For example, a review has been undertaken to assess the risks of flooding and scour to our network in the southwest of England. This pilot study utilises the latest UKCP09 data.

Projections

Climate models such as UKCP09 help us understand the relative risks to our assets in the future. The medium emissions scenario of UKCP09 forecasts the following:

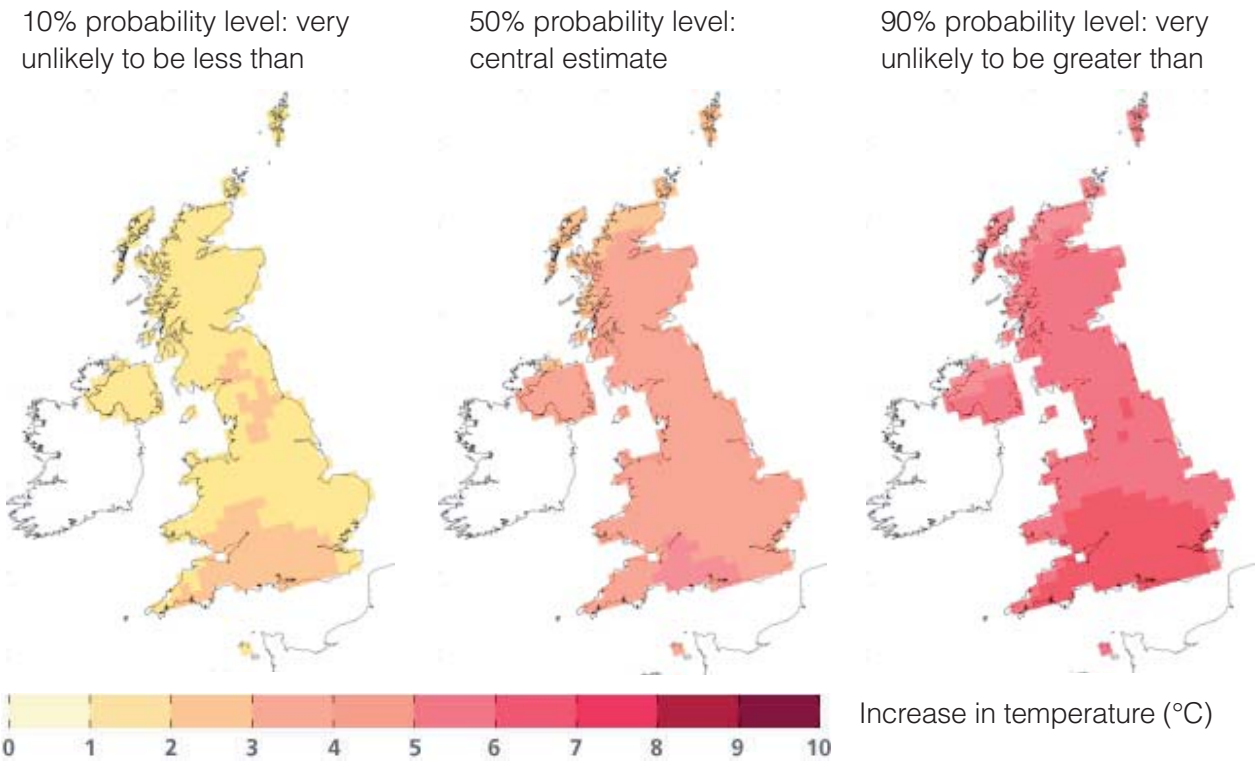
- **Average UK summer temperature is likely to rise by 3-4°C by the 2080s.** In general, greater warming is expected in the southeast than the northwest of the UK, and there may be more warming in the summer and autumn than winter and spring.
- **Average summer rainfall across the UK may decrease by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

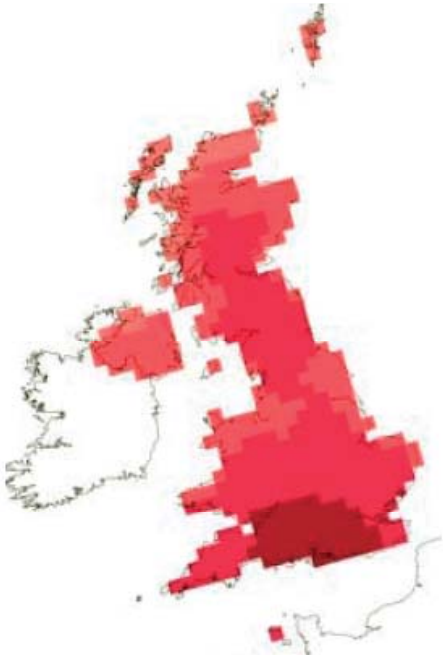
Note these key findings are based on a medium emissions scenario – one of three developed by the IPCC. The IPCC Special Report on Emissions Scenarios

(SRES) provides the global emissions scenarios used in both UKCIP02 and UKCP09. Within UKCP09 the emission scenarios are labelled based on their relative global greenhouse gas emissions levels – High (SRES A1FI), Medium (SRES A1B) and Low (SRES B1) – and comprise a wide range but not the full set of SRES emissions scenarios.

The following pages illustrate the UKCP09 forecasted temporal and spatial changes in temperature and precipitation levels based on a range of probabilities.

Figure 1: Change (increase) in summer mean temperature for the 2080s under a Medium emissions scenario





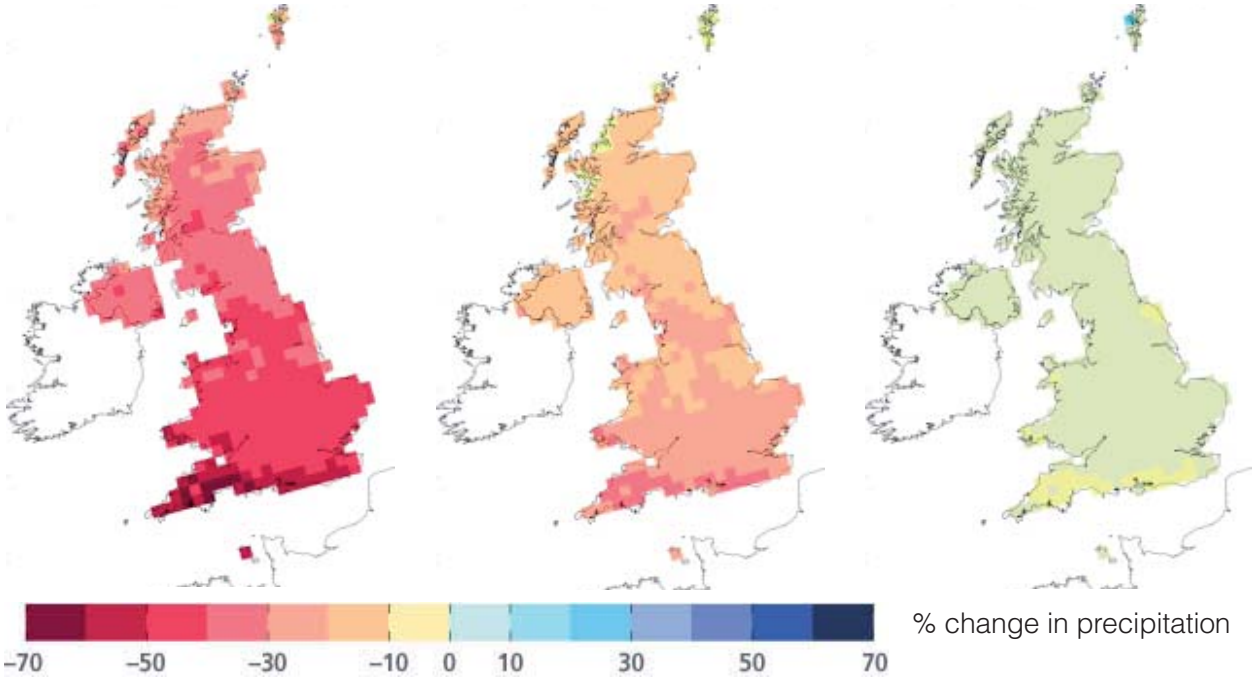
Considering the worst case scenario:
The adjacent map shows the forecasted scenario with high emissions for change in summer mean temperature for the 2080s at a 90% probability level (very unlikely to be greater than)

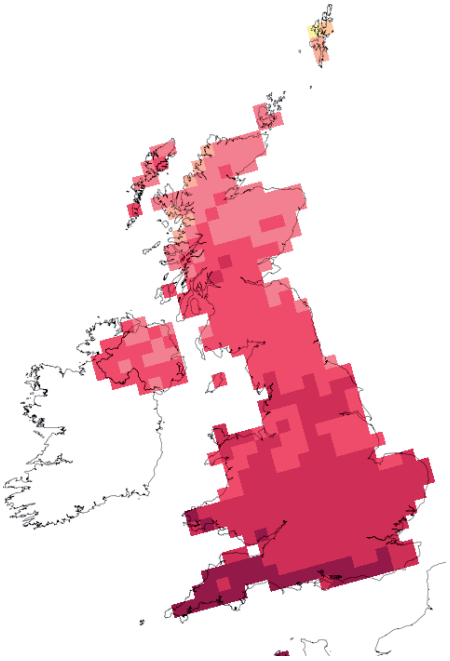
Figure 2: Change (reduction) in summer mean precipitation for the 2080s under a Medium emissions scenario

10% probability level: very unlikely to be less than

50% probability level: central estimate

90% probability level: very unlikely to be greater than





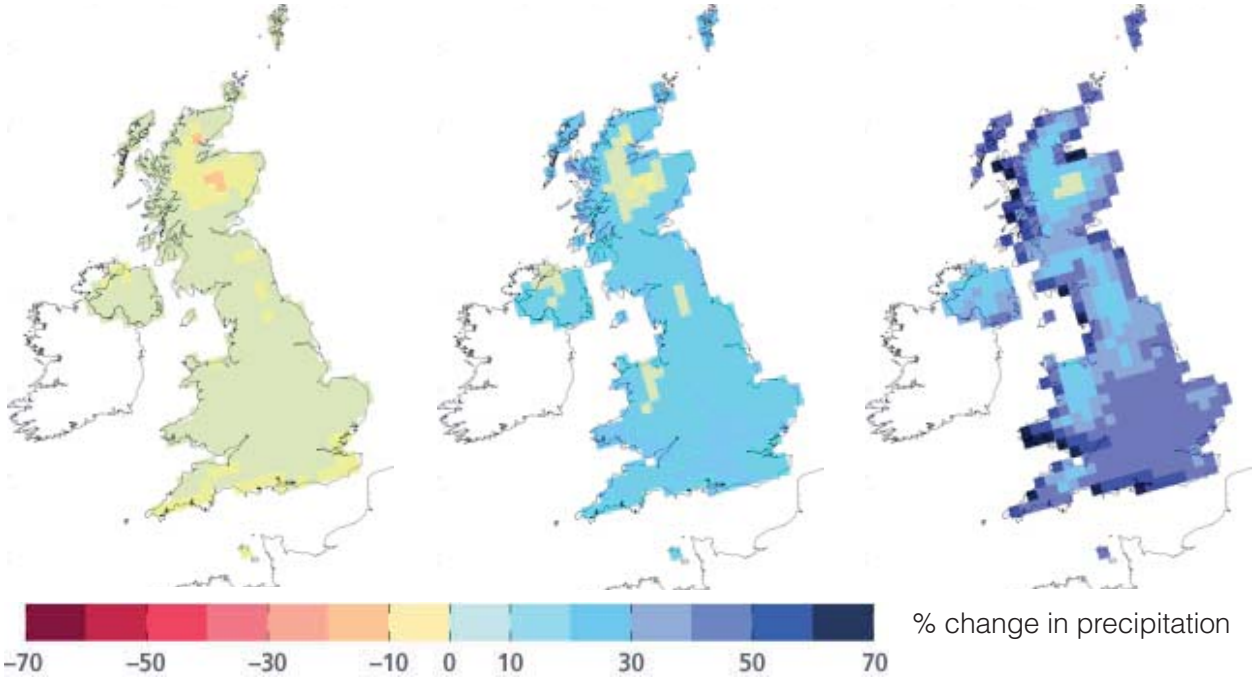
Considering the worst case scenario:
The adjacent map shows the forecasted scenario with high emissions for change in summer mean precipitation for the 2080s at a 10% probability level (very unlikely to be less than)

Figure 3: Change (increase) in winter mean precipitation for the 2080s under a Medium emissions scenario

10% probability level: very unlikely to be less than

50% probability level: central estimate

90% probability level: very unlikely to be greater than



Considering the worst case scenario:
The adjacent map shows the forecasted scenario with high emissions for change in winter mean precipitation for the 2080s at a 90% probability level (very unlikely to be greater than)

Climate variables and impacts

Climate change is a risk issue; we need to understand the risks to the asset, to our operations and to our main stakeholders including the road user – our customer. Now and for the future, we need to take appropriate, measured and timely action to manage these risks. The primary impacts of climate change are listed in Table 3 together with high level outcomes, impact on asset and impact on customers.

The Highways Agency's response to a changing climate

In recent years the UK has experienced some unusual weather patterns which fit the projected impacts for future years. These have included harsh winters with lower temperatures which have resulted in more snow and ice; a higher incidence of intense rainfall events during summer months leading to pluvial and fluvial flooding; and higher than average 'peak' temperatures. Some of the projected effects of climate change for the UK, including the higher temperatures are already experienced elsewhere in the world. This has allowed the Agency to share best practice and learn from the experiences of other national road authorities (NRAs).

In the case of pavement design for example, the Highways Agency has already adopted French temperature standards for road surfaces (EME-2). This is an example of the Agency putting in place adaptation to ensure that design standards and operating practices can adapt to the changing climate expected over the lifetime and replacement cycle of the Agency's highways infrastructure.

Climate models suggest that we should expect to see a continuation of the changes that have been observed in the UK, albeit at an increased rate. Consequently, services that are demonstrably sensitive to current weather events are likely to become increasingly vulnerable in the future. UKCP09 projections will provide the Highways Agency with the tools to undertake ongoing analysis. Within long term general climate trends, extreme and untypical weather events will occur. Increasing average temperatures do not preclude cold spells. Similarly dry summers are very likely to have high rainfall events and winter precipitation may fall as snow.

Winter precipitation may fall as snow

Climate variables and impacts			
Primary climatic changes	Outcome	Impact on asset	Impact on customers
Increase in average temperature	Longer growing season and reduction in soil moisture Reduction in fog days in winter Reduction in icy days in winter	Planting establishment and maintenance regime Less need to set warning signs Reduced winter maintenance	Visual impact Enhanced visibility/safety Enhanced safety
Increase in maximum temperature	Extreme summer temperatures	Pavement integrity	Affected by maintenance/ renewals works/ welfare issue for stranded road users
Increase in winter precipitation	Greater snowfall if combined with near sub zero temperatures Fluvial/Pluvial Flooding	Potentially a need for enhanced severe winter weather capability Drainage capacity tested	Potential for higher incidence of snow on network/welfare issue for stranded road users Standing water (aquaplaning)/safety and lane/road closure
Reduction in summer rainfall	Low receiving watercourse levels	Drainage dilution levels a concern	Water quality
More extreme rainfall events	Fluvial/Pluvial flooding	Drainage capacity tested	Standing water (aquaplaning)/safety and lane/carriageway closure
Increased wind speed for worst gales	Wind speed more frequently exceeding operational limits	Integrity of structures and signs/signals	Closure of exposed structures to e.g. HGVs/motorcycles
Sea level rise	Higher frequency of extreme storm surges	Flooding of coastal assets	Restricted access to network

Table 3: Climate change variables and their impacts on the asset and customers

Flood risk to the Highways Agency network

The strategic road network is integral to the effective running of the economy and a compromised network has the potential to present a serious loss in economic wealth for the nation. Flooding is expected to be an increasing risk facing the highways infrastructure and has the potential for significant consequences, as witnessed in recent years. Figure 4 illustrates the impacts experienced by the floods of July 2007.

Figure 4: The 2007 flood disruption to the HA network

Unprecedented downpours across the country caused widespread flooding in July 2007, resulting in travel disruption for many drivers. Closures affected the motorway network (M1, M4, M5, M18, M25, M40, M50, and M54) and many local and trunk roads were also disrupted. The repair costs for all roads (including non-HA roads) were estimated at £40–60 million. Flooding on one day alone – 20 July – caused 2 per cent of the delays for the whole year. The flooding of what was a small part of the road network led to almost 10,000 people being stranded. Particularly hard hit were the M5 and M50, which were closed in both directions. Traffic officers turned drivers around in the opposite direction where possible, and diverted drivers to Strensham Services where they provided emergency food and water. The Highways Agency issued travel advice to drivers via the media and websites in advance of the forecast rainfall and 24/7 throughout the flooding. Highways Agency traffic officers and contractors also provided aid to flood prevention operations beyond the strategic road network. This included transporting emergency services staff, implementing local road closures and diversions, and provision of sandbags.

Traffic officer is seen on TV rescuing people stranded on the M5.

The flooding events of autumn 2000, summer 2007 and November 2009 are a reminder of the risks posed by extreme precipitation events, not only to residential and commercial properties, but also to nationally strategic infrastructure. Following recommendations in the **Pitt Review** the Highways Agency has reviewed the vulnerability of the network and the measures to manage the risk. This work gives a snapshot of the current risks and ways to manage them. The possible impact of climate change on flooding risks is well established and guidance on climate change impacts was included in the latest revisions of highways drainage standards within the *Design Manual for Roads and Bridges* (DMRB HD 33 and HD 45).

Scour to structures from more intense rainfall is a priority area for research. A revised highway structures inspection and maintenance assessment for the assessment of scour and other hydraulic actions is under consideration for implementation across the motorway and major A road network. The severe rainfall and flooding events in Cumbria in November 2009 that resulted in the loss of several local authority bridges underline the need to make progress on this matter. So while increased scour risk features as a design and maintenance concern within our vulnerabilities, focus has turned to identify critical infrastructure at risk from flooding incidents under climate change scenarios.

Case study - Highways Agency and the Cumbrian floods

In November 2009, Cumbria suffered extreme rainfall which contributed to one of the worst flooding events in the UK in recent years. Homes were evacuated and people temporarily re-homed in local welfare centres, which were established by the emergency services. In addition, roads were closed and bridges severely damaged, which led to many local towns becoming isolated from the local area's infrastructure, such as shops, schools and hospitals.

Much of the flooding in Cumbria took place on the local road network, operated by the local authority and parts of the all purpose trunk road which are managed by the Highways Agency's Area 13 service provider. The M6, which passes through Cumbria, was largely unaffected and traffic continued to travel on both carriageways during the event.

The Highways Agency was part of the Infrastructure Recovery Group, which included our service providers, Cumbria County Council (and its service providers), the emergency services, the Military, utility companies, and district councils.

In November 2009 the Agency offered the following assistance to the council:

- Geotechnical engineers.
- Fluid engineers (modelling floods and impact - potential solutions).
- Topographical surveys.
- Project managers.
- Vehicles/plant.
- Lighting units/generators.
- Access to the Highways Agency supply chain.

The council took up the offer of vehicles, plant machinery, and lighting units/generators, but did not need to take up the remainder of the assistance offered. The Agency provided the council with an Under-Bridge Inspection Unit (a significantly large and specialised piece of machinery). This was sourced and delivered to site, from Brighton, within 12 hours of the request and remained in place for one week.

National Flood Register

The Highways Agency has developed a National Flood Register to improve emergency post-flood response. The Highways Agency has already identified motorways and trunk roads vulnerable to flooding and has recruited emergency planning managers. The Agency launched the National Flood Register in 2009 and is undertaking schemes to provide better emergency access to motorways. The National Resilience Team acts as national coordination for the Highways Agency in managing the National Risk Register.

Chapter 3: Climate change risk assessment

Risk assessment allows the Highways Agency to prioritise the threats posed by climate change by assessing asset vulnerabilities against a number of criteria. This supports the Agency's climate change adaptation planning by allowing us to make decisions on how we treat risk based on scientific projections of future climate scenarios. Furthermore it underpins future investment decisions in how we operate, maintain and improve the nation's highways infrastructure in a changing climate.

Adaptation Framework

We have developed a climate change risk assessment methodology as part of our approach to adaptation. This has led to the development of the **Highways Agency Climate Change Adaptation Strategy and Framework** which enables us to incorporate climate change considerations into our design standards and specifications, routine maintenance, operating procedures, and the development of contingency plans.

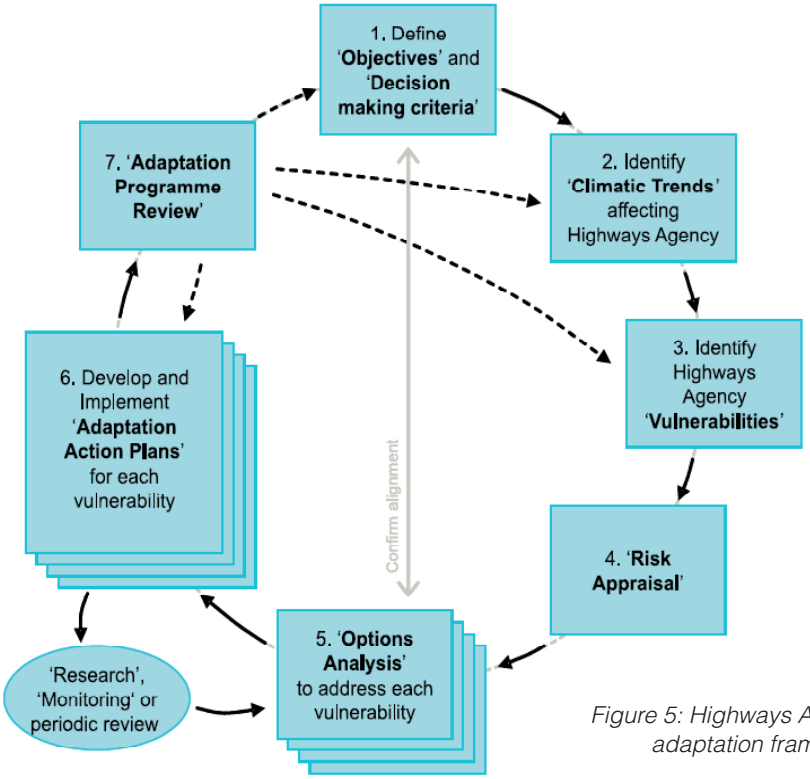


Figure 5: Highways Agency adaptation framework

The framework model in Figure 5 provides a systematic process to identify the activities of the Highways Agency that would be affected by climate change, determine associated risks and opportunities; and identify preferred options to systematically address them. Preferred options would be implemented through adaptation action plans designed to embed changes within Highways Agency standards, specifications and the operating procedures. Together these would form an overall adaptation programme covering the full range of assets on the Highways Agency's roads.

Vulnerabilities

Within the adaptation framework, vulnerabilities are defined as Highways Agency activities that could be affected by climate change. Thus, whilst the Highways Agency's assets are receptors of climatic events, it is the way in which these assets are designed; maintained and operated that is defined as vulnerabilities. This definition of vulnerabilities has been used to reflect the fact that it is the way the Highways Agency works that needs to be adapted to meet the challenges of a changing climate.

This emphasis on vulnerabilities also enables responsibilities for identifying, analysing and managing the risks associated with specific vulnerabilities to be assigned effectively to technical and operational staff who specialise in the relevant field of activity. To stimulate the identification of vulnerabilities and enable them to be catalogued in a consistent manner, a vulnerability schedule has been developed (Annex A) which maps Highways Agency activities to associated climate change hazards. Over eighty Highways Agency activities, or vulnerabilities, have initially been identified which may be affected by climate change.

Prioritisation of risk

The vulnerability schedule provides a detailed narrative of Highways Agency risks resulting from identified climatic changes. A preliminary appraisal of the risks associated with these vulnerabilities has found that many are expected to be materially affected by current predicted levels of climate change within their relevant asset life or activity time horizon. The risk appraisal process allows us to determine where to focus our efforts in adapting to climate change. Essentially, it provides a basis for future planning and prioritisation – an area for ongoing work.

The primary criteria used to assess vulnerabilities are shown below:

- **Uncertainty** – compound measure of current uncertainty in climate change predictions and the effects of climate change on the asset/activity.
- **Extent of disruption** – measure taking account of the number of locations across the network where this asset or activity occurs and/or the number of users affected if an associated climate related event occurs. Therefore, an activity could be important if it affects a high proportion of the network, or a small number of highly strategic points on the network.
- **Severity of disruption** – measure of the recovery time in the event of a climate related event e.g. flood, or landslip. This is separate from 'how bad' the actual event is when it occurs e.g. how many running lanes you lose; it focuses on how easy/difficult it is to recover from the event i.e. how long it takes to get those running lanes back into use.
- **Rate of climate change** – measure of the time horizon within which any currently predicted climate changes are likely to become material, relative to the expected life/time horizon of the asset or activity.

Criteria for risk appraisal

The risk appraisal has therefore enabled vulnerabilities to be prioritised for attention, based upon several criteria including their potential to disrupt the operation of the strategic road network. For example, it may be appropriate to prioritise action on the risks that have greatest potential effect on road users; or those expected to materialise first; or those with greatest uncertainty for which further research would be particularly beneficial; or some combination of these and other factors. The following sections take a closer look at the primary criteria for risk appraisal - uncertainty, extent of disruption, severity of disruption and the rate of climate change.

Uncertainty

The Highways Agency's risk assessment is sensitive to the uncertainties in the climate change models which are used to determine asset vulnerability. Embedded within the risk assessment is an uncertainty criterion which evaluates both the confidence of climate change predictions and the climate change impact on the asset/activity. Risk appraisal scores for uncertainty are determined from a review of climate change trends information and from expert opinion of how well the effect of climate change on a particular vulnerability is understood. Two sub-indicators corresponding to the uncertainty levels in climate change predictions and in climate change effects are assigned a High/Medium/Low score and the overall uncertainty score is determined.

		Uncertainty level – effects of climate change on asset/activity		
		High	Medium	Low
Uncertainty level – climate change predictions	High	H	H	M
	Medium	M	H	L
	Low	M	L	L

Figure 6: Uncertainty matrix

Extent of disruption

In determining the extent of disruption it is important to take account of the spatial variation of the relevant climatic event. If the vulnerability is sensitive to an extreme event, the event may be relatively localised, as could be the case for extreme rainfall, or may be highly correlated over a large area, as may be the case for extreme temperatures. Thus, a risk event associated with extreme temperatures may well occur at several places on the network at the same time thereby increasing the extent of disruption.

The assumptions applied to scores for the extent of disruption are defined as:	Criterion: Extent of network affected
High	>80% of network/users affected, or any specific highly strategic routes/locations
Medium	20-80% of network/users affected
Low	<20% of network/users affected

Figure 7: Extent of disruption matrix

(The criterion above is subject to a review. They have been applied to the existing vulnerabilities assessment to give parity of *extent of disruption* alongside the other three criteria.)

Severity of disruption

The severity of disruption is a measure of how long it takes to restore network functionality. It is not a measure of the duration of the event itself, as this is not under Highways Agency control. Responsive actions following extreme events can be particularly disruptive because their timing cannot be controlled. In the cases of vulnerabilities that give rise to managed interventions, such as maintenance actions, the severity of disruption is a measure of how much disruption would arise if current practices are retained. For managed interventions, the degree of disruption can typically be controlled to a degree that is not possible for responsive actions following extreme climatic events.

The assumptions applied to scores for the extent of disruption are defined as:	Criterion: Severity of disruption
High	Disruption time > 1 week
Medium	Disruption time 1 day – 1 week
Low	Disruption time < 1 day

Figure 8: Severity of disruption matrix

Rate of change

The time horizon for climate change effects to become material is determined using predicted climate change trends and considering the timescale over which such changes are expected to impact on the vulnerability. It reflects the time period within which it is expected that it would be necessary to do something differently, for any of the following reasons:

- climate change drives action sooner/more often than would be done currently e.g. something as simple as increased frequency of grass cutting;
- climate change results in damage to an existing asset e.g. because current (climate related) design criteria have been exceeded; and,
- climate change results in unacceptable frequency of network disruption e.g. because of flooding

The asset life/activity time horizon sub-indicator reflects the duration of the consequences of decisions concerning the vulnerability. Thus for example, decisions about the design criteria for new 'structures' typically have consequences that remain throughout the design life of the asset, 120 years. In contrast, decisions concerning the implementation of an operational management process can be more short-lived. Asset life/activity time horizon is assessed against two broad categories; short-term (defined as less than 30 years) and longer-term (defined as greater than 30 years).

		Uncertainty level – effects of climate change on asset / activity	
		Short term < 30 years	Long term > 30 years
Time horizon for climate change effects to become material	Short term	H	H
	Mid to longer term	M	H
	Longer term	L	M

Figure 9: Rate of climate change matrix

Figure 9 shows that for a short-term asset/activity, changes that become material further into the future are less of a priority for early attention, as the renewals cycle will enable adaptation measures to be implemented nearer the time that climate change effects actually become material. For long-term assets/activities, there may be no such intervening opportunities even for effects that do not become material until the mid-to-long term, thus activities associated with these types of assets are a higher priority for early attention. Figure 10 shows the typical design life of some of the Highways Agency's key assets.

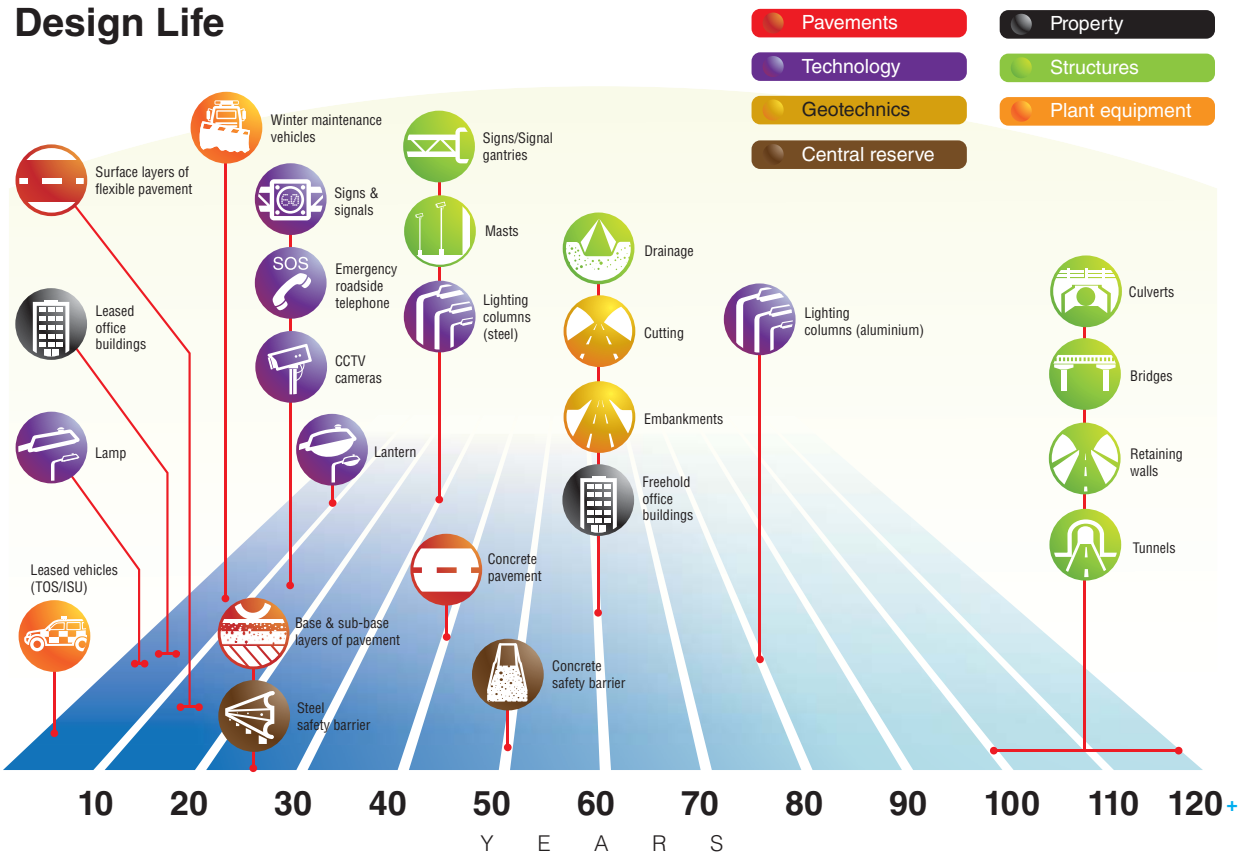


Figure 10: Design life of Highways Agency assets

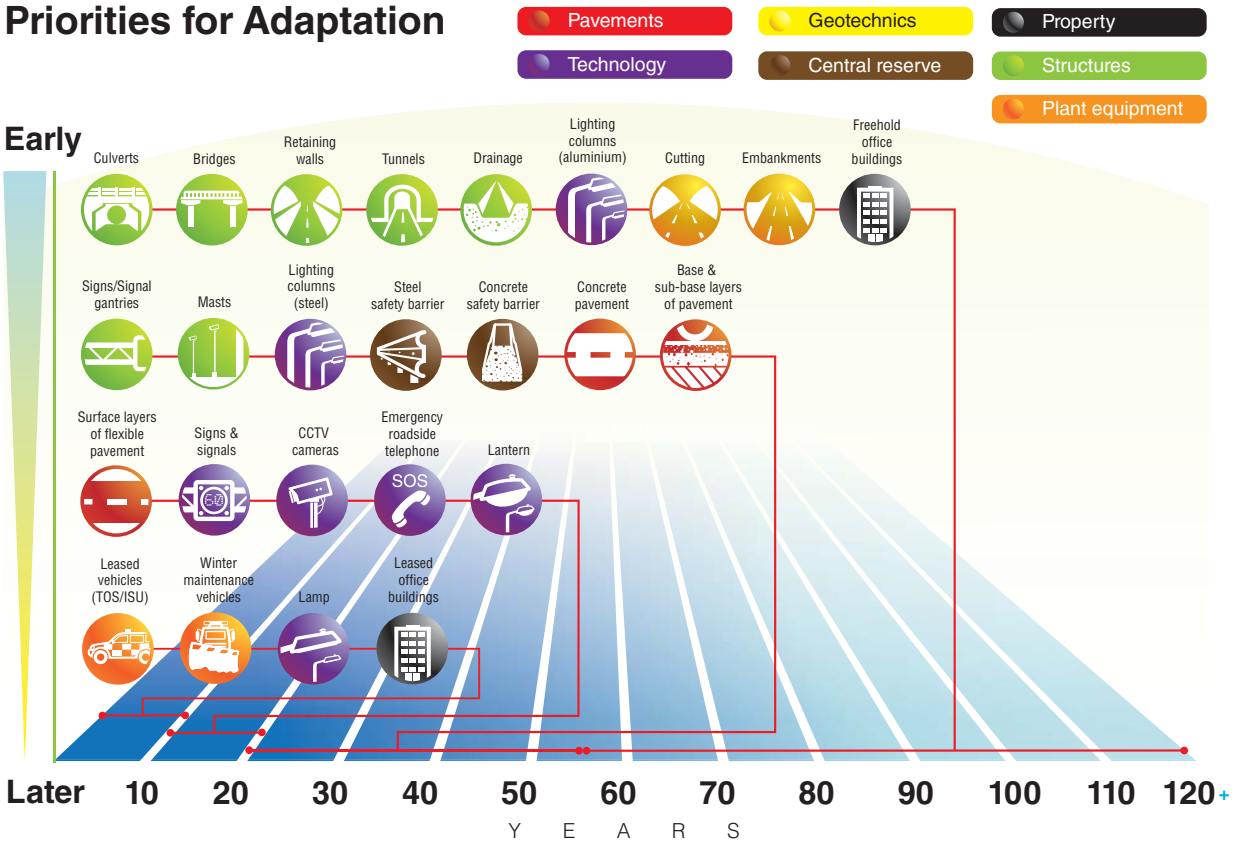


Figure 11: Priorities for adaptation of Highways Agency assets

Prioritisation of vulnerabilities for action

Prioritisation of vulnerabilities informs timescales for action (figure 11) and provides priority areas for early focus in devising adaptation strategies.

Typically in undertaking a risk appraisal it is possible to identify priority areas through considering a composite measure of extent and severity. This is not the case for the Highways Agency climate change risk assessment. There are several reasons why a vulnerability could be a priority for action but for the purpose of this report, a ranking has been used based on those vulnerabilities which are 'highly disruptive' and 'time critical' with 'high confidence'. They have both high extent and high disruption duration.

Even if a vulnerability receives a low risk-ranking based on the risk appraisal scoring (see Annex A), it may still be sensible to undertake early adaptation for reasons associated with the nature of the likely adaptation strategy, rather than due to the nature of the climate change risk itself. For example, if early action is straightforward and potentially highly cost-effective. In support of the prioritisation process, vulnerabilities are flagged in the risk appraisal process as early adaptation action advisable, if any of the following criteria are met:

- long lead-time needed to plan adaptation (e.g. to enable research or required changes to policy/standards to be introduced);
- significant planning/smoothing would be needed because many different locations on the network need to be worked on (e.g. lengthy national programme of works needed in order to adapt); or,
- adaptation is concerned with a long-life, expensive asset where it is suspected that there would be clear benefit derived from future-proofing new designs now (e.g. because of marginal cost implications to future-proof now, but high expense to address retrospectively).

In support of the prioritisation process, vulnerabilities are considered as *'early adaptation action advisable'* if any of the following criteria are met:

- There is a long lead time needed to plan adaptation
- Significant planning/smoothing would be needed due to the many different locations on the network need to be treated
- Adaptation is concerned with a long life, expensive asset where it is suggested that there would be clear benefit from future proofing new designs now.

Managed motorways

Vulnerabilities are identified as *'early adaptation advisable'* if some action is required or advisable within five years. Table 4 shows vulnerabilities which are highly disruptive and time critical – the basis for risks captured in annex A.

Category	Area	Aspect
Internal business Management	Staff costs	Staff numbers
Design and construction of new or replacement assets	Pavements	Materials specification and construction details
		Construction details
		Design of foundations
	Structures (including gantries)	Wind actions (loads) applied to Superstructure
		Design for increased scour risk for Foundations
		Design of bearings and expansion joints
	Drainage	Surface Water Drainage Systems
		Attenuation
		Outfalls
		Skid resistance
	Pavements	Integrity of materials
		Foundations
		Maintenance
Maintenance and management of existing assets	Structures (including gantries)	Wind actions (loads) applied to Superstructure
		Management of increased scour risk for foundations
		Management and maintenance of bearings and expansion joints
	Drainage	Surface Water Drainage Systems
		Outfalls
Managing network operations	Restricting network use	Flooding
Defining and managing network strategy, planning	Investment appraisal	Identifying best ways of investing resources/investment appraisal
		Critical geographic importance
	Strategic resilience	Impact from 3rd parties
	Network resilience	Demand and operation (rail system fail)
	Budgeting (spending reviews)	Budgeting (spending reviews)

Table 4: Vulnerabilities assessed as highly disruptive/time critical

Vulnerability rankings

To help illustrate the ranking of vulnerabilities, graphs have been developed showing the scores generated for the numerous 'aspects' of each asset type. The formulae used to generate the scoring gives a score of between 0 and 1.

The graph below shows an example of vulnerability ranking scores for the pavement asset where it is considered that the climate change impact is highly disruptive, time-critical, with high confidence. Annex B contains further graphs including structures, geotechnics, and drainage.

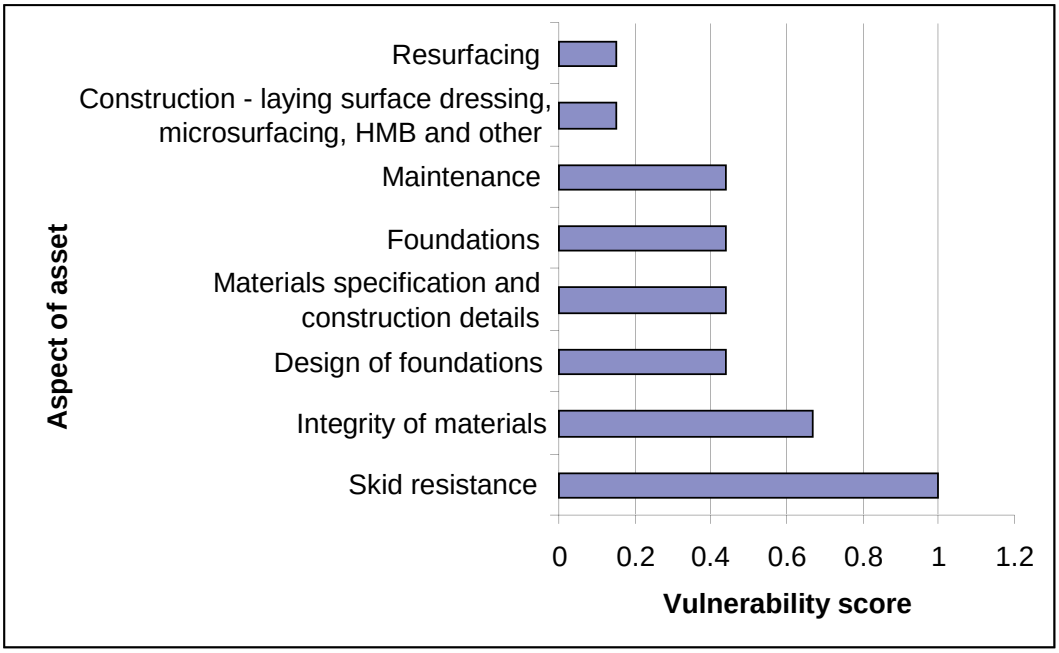


Figure 12: Vulnerability of pavement asset

The above graph illustrates the prioritisation of vulnerabilities within pavements. The top two risks identified are skid resistance and integrity of materials.

Skid Resistance (SCRIM) surveys are carried out by service providers using specialist vehicles under contract to the Agency. The contracts specify the data collection requirements in terms of both technical specification of the data and network coverage. The data recorded by the vehicles to determine the level of network condition is based on the agreed thresholds for good condition, set out within the Agency's Design Manual for Roads and Bridges. GPS functionality will be added to SCRIM vehicles as part of the scope of the next SCRIM contract. This addition will bring about more effective and efficient climate change adaptation planning.

Chapter 4: Further Actions

This chapter looks at areas which the Highways Agency has identified as having potential to add value to its ongoing work on climate change.

UKCP09 – scope for further action

Improvements incorporated within UKCP09 can offer value to the Highways Agency in the following ways:

- The probabilistic methodology provides a basis for risk based decision-making within the Highways Agency.
- Higher resolution adds to the realism of projections at the local scale and aids the modelling of specific impacts on Highways Agency operations.
- The outputs of the integrated weather generator, when interpreted appropriately, would allow investigation of changes in the incidence of frost, fog, and extremely hot days, all of which impact upon the performance of the strategic road network.
- The dedicated UKCP09 web portal could provide useful guidance on how the Highways Agency can interpret the scenarios and exploit them to best effect.

Key to optimising the value of UKCP09 will be to identify operational or other thresholds that are important to the Highways Agency. Examples might include (but are not limited to):

- incidence of ground frost
- temperatures below which rock salt is ineffective
- temperatures above which asphalt surfaces rut or stripping occurs
- the length of the frost-free season (allowing reduction in winter maintenance standby requirements)

The probabilistic language of UKCP09 can then be used to translate these thresholds into risk levels allowing the Highways Agency to make decisions as to whether the indicated risks are acceptable. For example, information on the possible future length of the frost-free period would allow the risk of reducing the winter period of operations (currently October to April) to be quantified to some extent, and it may be possible to make a substantial saving in resources without a significant increase in risk.

UKCP09 provides a very rich data resource, and puts a premium on being able to identify the most suitable data, the limitations associated with it, and the conditions under which its use is valid. This is particularly the case with outputs from the integrated weather generator, which would need appropriate care to ensure they are used correctly. Once identified, the appropriate data can then be used to drive impacts models. A relevant impact model for the Highways Agency is the JULES model which analyses the behaviour of various land surface parameters, and can be used to investigate changes in the stability of earthworks and the risk of subsidence of road surfaces under climatic variation.

Development of adaptation plans

Work is ongoing to develop a series of adaptation plans covering each area of the Highways Agency's asset base (structures, pavements, geotechnics, drainage etc). The plans base themselves on the Adaptation Framework discussed in this report. They will identify and compare options to manage the risks associated with the Agency's vulnerabilities. The methodology provides a tiered approach enabling the assessment of options to be kept as simple as is required for the preferred option to become clear:

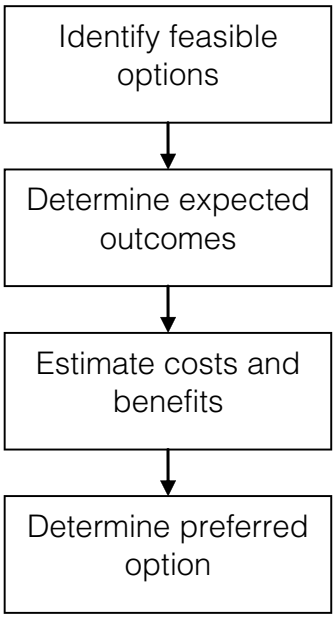


Figure 13: Stages in the options assessment

In some cases the preferred option may be to undertake some further research or monitoring, after which it may be appropriate to re-assess options for adaptation utilising the findings of this work. Similarly, the adaptation action plan may identify the need for a periodic review of the adaptation option being pursued. The identification of the preferred option is informed through determining the minimum whole-life-cost option taking account of the direct and indirect costs of adaptation and of the consequences of climate related incidents. The likelihood and severity of climate related incidents would be dependent on the adaptation option being considered. Thus an investment in adaptation actions would typically lead to a benefit through reducing the likelihood and severity of climate related incidents, and therefore reducing the corresponding direct and indirect consequence costs. It is not, however, appropriate for whole-life-cost to be used as the sole indicator of the preferred option. Because adaptation and the developing strategy and framework are being built into Highways Agency business processes, risk registers etc., climate change adaptation will be an on-going consideration.

Uncertainties

Further work will be undertaken both within the Highways Agency and externally to more fully understand the broader uncertainties facing the strategic road network it operates. Methods such as PESTLE analysis have been used in visioning workshops to gain a better understanding of the conditions under which we operate. Some of the issues identified include:

Financing adaptation

In addition to the climate uncertainty, the Highways Agency's ability to deliver adaptation solutions will in part be dependant on available financial resources. The long time horizon to significant climate change affecting the highway asset makes current investment and future appraisal a challenging aspect of planning. Current and emerging network resilience measures (focusing on weather prediction, meteorological subsystems detection, communication, response and contingency planning) serve short-term needs. The relatively short-term life of the road pavement (surfacing) means predicted rising temperatures are not a significant concern at current resurfacing rates of 10-12 years. Nevertheless, the double benefit of greater durability and temperature tolerance prompted the alteration of the Highways Agency pavement specification in 2008. Similarly, the road drainage design standard was altered in 2006 responding to the threats of climate change and increased precipitation. The design life of a road drainage system is some 60 years, so an additional capacity of up to 20% was required by the revised standard and represents a cost effective action respecting both asset life and climate change prediction.

Future demand

Arguably greater uncertainty exists over future transport and road user demand, particularly over the long term. Existing Department for Transport (DfT) project appraisal seeks to account for costs and benefits over a 60 year period. Within this period there are a range of inputs into forecasting; GDP growth, fuel price trends, vehicle efficiency changes and other national trends generally assessed and reported at a national level. Road user behaviour could change and generate new challenges. Not enough is known about the possible impact of long term changes from weather on driver behaviour. It is possible that both hot and cold extremes could increase road traffic while driver responses to the changing situations may lead to an increase in accidents and delays. These scenarios have been presented to DfT private sector rail colleagues as well as to the Highways Agency customer research co-ordination group.

Public awareness

While there is a growing awareness of the need to adopt climate change mitigation behaviour, supported in the transport sector by actions in recent years, the public awareness of adaptation is perhaps limited. The Highways Agency's seasonal driving guides have been published for a number of years. The Agency is committed to ensuring there are regular revisions of the seasonal driving advice and use the climate scenarios to determine how driving behaviour might change in the future and what the Highways Agency would need to do to ensure continued safety on the network. Vehicles are, in this context, assumed to be relatively short-lived artefacts (5-10 years typically) and it is considered that they would be adapted by manufacturers.

Interdependencies

Climate change risk assessments and adaptation plans cannot be treated in isolation. There are many interdependencies that exist beyond the transport infrastructure. When the UK's key national infrastructure providers have submitted their plans for the future resilience of their assets, assurance must be sought that the actions of each asset owner would align with the plans of others to mitigate the risk of cascade failure. Where interdependencies exist between infrastructure types there is a risk that failures could have knock-on or cascading effects. The Highways Agency recognises the technical and operational risks and shares information with other sectors to manage these.

Opportunities

Along with examining the uncertainties the Agency faces, there is a clear need to examine in more detail the possible benefits and opportunities brought about by the projected changes to our climate. A number of potential business opportunities have been identified:

Benefits to be realised from climate change

Operation:

- Increase in mean temperature would lead to less salt needing to be spread on the network during winter months
- Changes in weather conditions which reduce the incidence and/or severity of incidents would place less demands on traffic management, including the traffic officer service.
- For journeys of short distances, warmer summers could attract some road users away from private cars. This has potential benefits of reducing the levels of localised congestion and air pollution.

Maintenance:

- A reduction in the frequency of freeze-thaw events would benefit the integrity of the pavement surface. We can expect less degradation with a reduction in surface cracking/pot holes.

Customer satisfaction:

- Reduction in summer rainfall should create better driving conditions
- A reduction in the number of fog days during the winter months is likely to have a beneficial impact in reducing the number of serious incidents
- A reduction in the number of icy days during the winter months is likely to have a beneficial impact in reducing the number of serious incidents
- Fewer days with salt on the road would mean less corroded vehicles and highways assets
- A longer growing season would mean that the soft estate (verges) could look greener for longer, enhancing the aesthetic of the network.
- Secondary benefits include potential health gains of a shift from private motorised transport to walking, cycling and rapid transit/public transport

Highways Agency Expertise:

- Export of intellectual property to other national road authorities. The Agency works closely with NRAs across the globe. We are recognised as leading the way in identifying risks that face our transport infrastructure, including the potential impact on operations and the approaches considered in adapting to future climate projections.
- The fact that we are one of the UK overseeing organisations setting design and maintenance standards for the trunk (strategic) road network is an opportunity for embedding adaptation without having to create anything new.

Stakeholders

The Highways Agency has close links with a large number of stakeholders, including owners of other UK infrastructure systems. To effectively manage the wider uncertainties and opportunities discussed, the Highways Agency is committed to maximising value from stakeholder engagement. Priority stakeholders have account managers, e.g. UK Network Power and National Trust. Terms of reference for partnerships are being used with statutory utilities. An example is provided by the Highways Agency – EDF energy partnership forum. Productive relationships have also been developed with Network Rail, The Camping and Caravanning Club, Freight Transport Association and the Environment Agency. Memoranda of Understanding (MoU) have been signed with Natural England and the Camping and Caravanning Club, and the Highways Agency's MoU with the Environment Agency has been reviewed.

Case study – Memorandum of Understanding (MoU) between the Environment Agency and the Highways Agency

Signed by Paul Leinster and Graham Dalton, Chief Executive of the Highways Agency in November 2009, the purpose of the refreshed MoU included: To minimise flood risk, ensure compliance with relevant legislation and reduce the environmental impact of the road network.

Key Benefits to External Customers:

- Reduced environmental impact on the existing network by promoting sustainable design and build
- New roads are planned and developed to minimise the impact on the environment
- A quicker and more efficient response to incidents that threaten the environment and safety of road users

Key Benefits for Addressing Future Challenges:

- Adapting to climate change
- Implementation of the Water Framework Directive
- Joint initiatives on environmental crime
- Further developing the use of sustainability and sustainable drainage techniques

An example of consultation to date

The 'Engineering the Future' group, led by The Royal Academy of Engineering, the Institution of Engineering and Technology (IET), Institute of Civil Engineers (ICE), Institute of Mechanical Engineers (IMechE) and Institute of Chemical Engineers (IChemE), carried out a study on the changes needed to make critical infrastructure robust against threats posed by climate change. This study looked at vulnerabilities in the transport, energy, water and communications infrastructure, to identify interdependencies between these elements of the UK's infrastructure, and identify strategies to increase the resilience of the entire infrastructure system.

The Highways Agency took a part in directing this initiative to try to identify the key factors in estimating the damage to infrastructure under different climate models. The Highways Agency also contributed to a second phase of work at a workshop in July 2010, to examine how to improve the long-term adaptive capacity of the transport infrastructure against future climate change impacts. This looked explicitly from an engineering perspective at the challenges, barriers, opportunities and options going forward, while recognising that there would be a wider context of regulation, policy, and finance.

European partnerships

Contributions have been made to the Conference of European Directors of Roads (CEDR). Information has been shared among the member road authorities to support the CEDR report on adaptation to climate change. Risks relating to climate change have been shared and received, along with proposed adaptation planning and examples of good practice.

Conclusion

The Highways Agency is responsible for the operation, maintenance, and improvement of England's strategic road network, which provides a vital service to industry, communities, and individuals.

The organisation's climate change commitment is to assess the potential risks that climatic changes pose to the ongoing management, maintenance, improvement, and operation of the strategic road network. The Agency will factor anticipated climatic changes into the delivery of our business and develop appropriate management and mitigation solutions to remove or reduce these risks.

The desired adaptation outcomes are as follows:

- Climate change considerations are factored into Highways Agency investment controls and business as usual, including design, construction, maintenance, and operations;
- Early consideration of climate change risks will lead to greatly reduced costs over asset life;
- A move away from reliance on historical weather record as basis for standards and specifications;
- Residual climate change risks are assigned appropriate management action; and,
- The Highways Agency can demonstrate an effective approach to climate change risk management and fulfil our reporting obligations.

ANNEX A: Vulnerability schedule

The table within this annex captures the following information:

1. Activity category – the broad function of the business that is considered
2. Area – the particular asset type such as pavements, structures, geotechnics.
3. Aspect – the specific business activity within the business area.
4. Primary climatic change – the actual change in climate
5. Secondary climatic change – the effects brought about by the primary climatic change
6. Highways Agency risks – description of risks to the Highways Agency from climate change.
7. *Vulnerability score of between 0 and 1 (based on vulnerabilities which are highly disruptive, time critical with high confidence)

*For individual scores for the drainage asset please refer to annex B.3.

This annex has been included to provide visibility of the approach to identify those parts of the Highways Agency asset which are of high value, have a high cost associated with mitigation / adaptation and have the potential to cause significant impact to the road user.

Vulnerability schedule

Activity Category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways Agency risks resulting from identified climatic changes	Score (0-1)
Internal business management	Facilities management	Facility energy	Increase in mean temperature	Reduction in icy days in winter	For the Highways Agency estate, an increase in the mean temperature would affect the energy consumption used within the offices for climate control (air conditioning/heating). This directly impacts the facilities management costs for each of the Agency's 8 offices, the National Traffic Control Centre (National Traffic Information Service from September 2011), 7 Regional Control Centres and 35 outstations.	0.11
Internal business management	Staff costs	Staff numbers			No significant risks identified to staff numbers as a consequence of climate change	0.67
Defining and managing network strategy and planning	Property management	Property management	Increase in winter precipitation Increase in extreme precipitation	Change in ground water level Flooding	There is a risk that some of the Highways Agency estate is at risk of flooding.	0.11
Design and construction of new and replacement assets	Pavements	Design of foundations	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level and soil moisture	Costs are associated with designing/ constructing pavements with foundations more resilient to climate change impacts. This includes effectively maintained drainage network to remove sub-surface moisture.	0.44
Design and construction of new and replacement assets	Pavements	Materials specification and construction details	Increase in mean temperature Increase in extreme temperature		Areas of the network most susceptible to extreme temperatures (e.g. higher temperatures for southern regions) will be at risk from a greater degree of surface failure or deterioration under periods of extreme temperature. Revised standards can be adopted to treat this risk. EME2 pavement specification has been introduced on parts of the network to manage this specific risk. There is a cost to procuring materials that withstand higher temperatures. Business management costs are invloved in changing materials specification and defining changes to construction practices. For concrete pavements, thermal gradients can create uneven internal stresses which can then give rise to curling or warping, sometimes called hogging, of the slabs. These can be compounded by loading from passing traffic. Large changes in temperature generate thermal contraction and expansion of the slabs which, if not taken into consideration at the design stage, can generate unacceptably large longitudinal internal stresses and excessive movements at joints.	0.44

Design and construction of new and replacement assets	Pavements	Construction - laying, microsurfacing, high modulus base and other temperature susceptible materials	Increase in mean temperature Increase in extreme temperature		During extended periods of hot, sunny conditions, asphalt can remain workable for a considerable time, making it difficult to maintain profile during compaction and, in the case of hot rolled asphalt surface course with added pre-coated chippings, it may be difficult to achieve the required texture depth. The newly laid surfacing layers of a pavement may also maintain temperatures after opening to traffic that are high enough to allow excessive rutting and the rapid embedment of any chippings, with the latter again causing a reduction of texture depth. These conditions would be compounded in conditions where traffic intensity is high and speeds are restricted.	0.15
Design and construction of new and replacement assets	Structures (including gantries)	Thermal actions (loads) applied to superstructure	Increase in extreme temperature		Provided information is known prior to the design, then design can accommodate projected temperature changes. However, more expensive components like joints, bearings, paint systems etc may be required. Also, greater care will be required to set the gaps, to ensure that movement does not cause a problem. This may require rescheduling works to night or at specific times of the year. Gantries and minor structures should not be affected as the design standards require a reduced design life (30 years) and it is unlikely that climate change impacts will present significant risks over this period.	0.22
Design and construction of new and replacement assets	Structures (including gantries)	Wind actions (loads) applied to superstructure	Increase in wind speed for worst gales		There is a potential for minor structures and gantries to have to be designed larger, to withstand larger loads (more expensive). The effect on bridges should be minimal, as wind is rarely a dominant load. There is an increased risk of disruption to construction work – (unable to operate in high winds).	0.67
Design and construction of new and replacement assets	Structures (including gantries)	Increased thermal range giving rise to increased earth pressures for integral bridges	Increase in mean temperature Increase in extreme temperature		May require more excavation of material and replacement with stronger fill material, leading to increased costs and amount of waste.	0.15
Design and construction of new and replacement assets	Structures (including gantries)	Earth pressures used in design affected by change in ground water level	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level	Possible larger ground movement/ heave may occur. This could mean additional drainage and stronger materials are required, which in turn would have cost/time implications.	0.07
Design and construction of new and replacement assets	Structures (including gantries)	Foundation settlement affected by change in ground water level	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level	Possible larger ground movement/heave may occur, again meaning additional drainage, stronger materials may be required (cost/time). More robust foundations would need to be designed for increased settlement.	0.07

Design and construction of new and replacement assets	Structures (including gantries)	Design for increased scour risk for foundations	Increase in extreme precipitation	Flooding	Additional design considerations required. More extensive works with time and cost implications.	0.67
Design and construction of new and replacement assets	Structures (including gantries)	Design of structure drainage	Increase in extreme precipitation		May require additional drainage, larger components and more extensive works. Detailing may need to be changed to shed additional water. This represents an additional cost.	0.11
Design and construction of new and replacement assets	Structures (including gantries)	Use of temperature sensitive components or materials in construction or rehabilitation (e.g. FRP strengthening)	Increase in extreme temperature		There should not be any risks associated with new structures as designers should set appropriate performance requirements. Increases in extreme temperatures could mean that certain materials may not be useable.	0.22
Design and construction of new and replacement assets	Structures (including gantries)	Design of bearings and expansion joints	Increase in extreme temperature		Larger bearings would be required, with additional provision for transfer of loads/ moments from deck to abutment/piers. These would be more difficult to install and may require adjustment before installation. Time and cost implications.	0.44
Design and construction of new and replacement assets	Structures (including gantries)	Climatic constraints on construction activities	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales		We can assume that under extreme temperature, certain construction activities may be required to be undertaken at night to keep project build to schedule. This will incur higher programme costs (e.g. labour and illumination). We can also assume that extreme precipitation / gale force winds have the potential to alter construction activities and cause delay.	0.07
Design and construction of new and replacement assets	Drainage	Surface water drainage systems. Cross-culverts. Road-edge drainage. Attenuation Outfalls Drainage ditches	Increase in winter precipitation Decrease in summer precipitation Increase in extreme precipitation	Flooding Change in ground water level Frequency of extreme storm surges	In the design and construction of new and replacement Highways Agency drainage assets, it will be necessary to consider the raised flood risk and erosion of the following: banks and footings, construction of culvert crossings, embankments, rivers, bridges, coasts, and other points on the strategic road network vulnerable to flooding.	
Design and construction of new and replacement assets	Geotechnics	Erosion	Increase in winter precipitation	Flooding	This is not a significant risk in the design and construction of new and replacement geotechnics assets. Any risks are addressed on a project specific basis.	0.15

Design and construction of new and replacement assets	Geotechnics	Stability of earthworks	Increase in extreme temperature Increase in winter precipitation Increase in extreme precipitation		In the design and construction of new and replacement geotechnical assets, the risks to the stability of earthworks from an increase in extreme temperature are not likely to be an issue with respect to stability of new earthworks. The risks from an increase in winter precipitation and an increase in extreme precipitation are the need to ensure that the design incorporates appropriate drainage measures to deal with the anticipated precipitation both in the temporary and permanent condition.	0.11
Design and construction of new and replacement assets	Geotechnics	Earthworks stability and compaction	Increase in extreme temperature Decrease in summer precipitation	Reduction in soil moisture	As above - in the design and construction of new and replacement geotechnical assets, the risks to the stability of earthworks from an increase in extreme temperature are not likely to be an issue with respect to stability of new earthworks. Risks to compaction relate to the need for greater compactive effort being required with potential increased costs, delays etc. This is not considered a significant risk as it is already dealt with on a project-specific basis.	0.11
Design and construction of new and replacement assets	Geotechnics	Earthworks construction across existing landslip	Increase in winter precipitation Increase in extreme precipitation	Change in ground water level	This is a rare event and unlikely to be significant given the programme of works in the near future.	0.22
Design and construction of new and replacement assets	Signs and signals	Stability	Increase in extreme precipitation Increase in wind speed for worst gales		Minimal wind loading risks for design life of the asset .	0.10
Design and construction of new and replacement assets	Technology	Wind loading	Increase in wind speed for worst gales		The wind loading standards incorporate site specific criteria, based on a number of factors including wind direction, altitude and topography. No significant risk within service life of the asset.	0.10
Design and construction of new and replacement assets	Road markings	Design / specification	Increase in winter precipitation Increase in extreme precipitation		No significant risks associated with the design and construction of road markings.	0.15

Design and construction of new and replacement assets	Soft estate	Capital investment landscape	Increase in mean temperature Decrease in summer precipitation	Longer growing season Reduction in soil moisture	Cultural heritage may be affected by the drier summers through exposure to greater extremes in weather (i.e. dryer summers - dryer soil conditions, more cracking and exposure to the elements; potential for some assets to be exposed to increased subsidence issues). Potential for increased costs to mitigation works to try and prevent this Drainage will be affected with the increased need for greater attenuation ponds and greater land take which may have a greater environmental impact and could result in greater mitigation needs as a result.	0.22
Design and construction of new and replacement assets	Soft estate	Capital investment ecology	Increase in mean temperature Decrease in summer precipitation	Longer growing season Reduction in soil moisture	There are a number of potential risks to habitats to consider over a period of time. The Defra White Paper looks at the importance of the Highways Agency's soft estate acting as habitat corridors. Climate change may result in more migration of species both along the Strategic Road Network and across it. Risk is more migration may result in more road deaths and potential safety related issues resulting in the requirement for more mitigation to compensate - greater costs. Climate change could result in more species rich grassland areas which results in less maintenance frequencies and less costs. Local providence will change over time which may have an impact what can or should be planted.	0.07
Design and construction of new and replacement assets	NMU facilities (Non Motorised User)	Shelter provision	Increase in extreme temperature Increase in winter precipitation		No significant risks identified for shelter provision In the design and construction of new and replacement non motorised user (NMU) facilities.	0.11
Design and construction of new and replacement assets	NMU facilities (Non Motorised User)	Underpass	Increase in winter precipitation Increase in extreme precipitation		Flooding risk to underpasses for non motorised users.	0.22
Design and construction of new and replacement assets	NMU facilities (Non Motorised User)	Drainage design	Increase in winter precipitation Increase in extreme precipitation		Flooding risk to non motorised users to be considered in the design of drainage.	0.11

Maintenance and management of existing assets	Pavements	Skid resistance	Increase in winter precipitation Decrease in summer precipitation	Flooding	Skid resistance of the surface course decreases significantly in areas where it is flooded. The impact of flooding is not significant if drainage network capacity is adequate and is regularly maintained. Decrease in summer precipitation can lead to a build up of particulates in the road surface which, when the first rainfall event occurs, creates a surface which could compromise skid resistance of the surface course.	1.00
Maintenance and management of existing assets	Pavements	Foundations	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level Reduction in soil moisture	Ineffective sub-surface drainage can lead to saturation of the unbound pavement construction, loss of fine material, settlement and premature pavement failure. Apart from the effect of water on the strength of the subgrade, prolonged water saturation will also have adverse effects on the stability of granular foundation layers and can result in substantial deformation. Where cracks propagate through the pavement layers, water ingress into the lower layers and the subsequent action of the traffic will cause pumping of material from the lower layers. This both decreases the support from the lower layers and weakens the material. Large changes in moisture content can cause soil to expand and shrink substantially, causing the pavement layers above to heave and subside.	0.44
Maintenance and management of existing assets	Pavements	Integrity of materials	Increase in mean temperature Increase in extreme temperature Decrease in summer precipitation	Reduction in soil moisture	Concrete pavements: Thermal gradients in concrete pavements can create uneven internal stresses which can then give rise to curling or warping, sometimes called hogging, of the slabs. These can be compounded by loading from passing traffic. Large changes in temperature generate thermal contraction and expansion of the slabs which, if not taken into consideration at the design stage, can generate unacceptably large longitudinal internal stresses and excessive movements at joints. With the requirement to cover concrete surfaces with asphalt, higher temperatures in the underlying concrete may be created. The specific effects on concrete of an overlying layer at a higher temperature have yet to be assessed. Compression failures have also been noticed where a series of transverse joints have not been constructed satisfactorily and so do not allow any thermal movement. Overall ride quality would be poor and potentially compromise safety and road user comfort.	0.67

Maintenance and management of existing assets	Pavements	Maintenance	Increase in mean temperature Increase in extreme temperature		During extended periods of hot, sunny conditions, asphalt can remain workable for a considerable time, making it difficult to maintain profile during compaction and, in the case of hot rolled asphalt surface course (not used at present on the trunk roads) with added pre-coated chippings, it may be difficult to achieve the required texture depth. The newly laid surfacing layers of a pavement may also maintain temperatures after opening to traffic that are high enough to allow excessive rutting and the rapid embedment of any chippings, with the latter again causing a reduction of texture depth. These conditions would be compounded in conditions where traffic intensity is high and speeds are restricted. Overall ride quality would be poor and potentially compromise safety and road user comfort.	0.44
Maintenance and management of existing assets	Pavements	Resurfacing	Increase in mean temperature Increase in extreme temperature		As above…During extended periods of hot, sunny conditions, asphalt can remain workable for a considerable time, making it difficult to maintain profile during compaction and, in the case of hot rolled asphalt surface course (not used at present on the trunk roads) with added pre-coated chippings, it may be difficult to achieve the required texture depth. The newly laid surfacing layers of a pavement may also maintain temperatures after opening to traffic that are high enough to allow excessive rutting and the rapid embedment of any chippings, with the latter again causing a reduction of texture depth. These conditions would be compounded in conditions where traffic intensity is high and speeds are restricted. Overall ride quality would be poor and potentially compromise safety and road user comfort. A risk of maintenance liability increasing to meet the current /future standards.	0.15
Maintenance and management of existing assets	Structures (including gantries)	Thermal actions (loads) applied to superstructure	Increase in extreme temperature		Some structures may fail to operate within original design parameters. This may induce failures meaning additional works would then be required to strengthen them.	0.22
Maintenance and management of existing assets	Structures (including gantries)	Wind actions (loads) applied to superstructure	Increase in wind speed for worst gales		Additional loading may be applied to structures (generally for smaller structures and gantries). This may induce greater deflections and there will be the risk that signs might be unreadable, cameras may be affected or that certain elements could fail. Assessments may need to be carried out to determine requirements/risk.	0.67

Maintenance and management of existing assets	Structures (including gantries)	Increased thermal range giving rise to increased earth pressures for integral bridges	Increase in mean temperature Increase in extreme temperature		Additional loading may be applied to structures. This may induce greater stress within structures, increasing the risk of deterioration.	0.22
Maintenance and management of existing assets	Structures (including gantries)	Earth pressures used in design affected by change in ground water level	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level	Possible larger ground movement/ heave may occur which would result in additional drainage, stronger materials being required - cost/time implications.	0.07
Maintenance and management of existing assets	Structures (including gantries)	Foundation settlement affected by change in ground water level	Increase in winter precipitation Decrease in summer precipitation	Change in ground water level	May reduce headroom and cause differential settlement. It could result in an additional stress being induced into the structure, causing failure of components.	0.07
Maintenance and management of existing assets	Structures (including gantries)	Management of increased scour risk for foundations	Increase in extreme precipitation	Flooding	Greater requirement for assessment and inspection to manage structures. Shorter intervention/strengthening intervals required to protect existing structures.	0.67
Maintenance and management of existing assets	Structures (including gantries)	Management of structure drainage	Increase in extreme precipitation		Increased risk of blockages, affecting large areas and causing disruption. May require replacement of existing drainage at regular intervals – Cost/disruption.	0.11
Maintenance and management of existing assets	Structures (including gantries)	Management of temperature sensitive components or materials (e.g. epoxies used in FRP strengthening)	Increase in extreme temperature		An increase in extreme temperature would require increased assessment, ongoing inspections/monitoring and may require strengthening/replacement.	0.22
Design and construction of new and replacement assets	Structures (including gantries)	Management and mainteneance of bearings and expansion joints	Increase in extreme temperature		Would require increased assessment and ongoing inspections/monitoring. May require replacement of bearings or strengthening the bridge.	0.44
Maintenance and management of existing assets	Structures (including gantries)	Climatic constraints on maintenance activities	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales		Under extreme temperature, certain maintenance activities may be required to be undertaken at night, to keep work to schedule, thus incurring higher programme costs (e.g. labour and illumination). Extreme precipitation / gale force winds have the potential to alter construction activities and cause delay.	0.04
Maintenance and management of existing assets	Structures (including gantries)	Optimum timing of maintenance interventions, in response to changes in deterioration rates	Increase in mean temperature Increase in winter precipitation Reduction in snowfall		Risks to the optimum timing of maintenance interventions include increased inspections/monitoring; strengthening works or more frequent maintenance required, and a shorter lifespan of structures than expected.	0.05

Maintenance and management of existing assets	Drainage	Surface water drainage systems. Cross-culverts. Road-edge drainage. Attenuation Outfalls Drainage ditches	Increase in winter precipitation Decrease in summer precipitation Increase in extreme precipitation	Flooding Change in ground water level Frequency of extreme storm surges	In the maintenance and management of existing assets, the risks to the HA include: Congestion and accidents An increased risk of flooding impacts the performance of the network, including congestion and incidents (safety). Third party flooding There are risks associated with flooding of third party land from the HA network. Pollution With a reduction in mean precipitation, drainage dilution levels will be more concentrated due to receiving water courses carrying less water. Cross asset deterioration Flooding increases the rate of deterioration of other assets.	
Maintenance and management of existing assets	Geotechnics	Increased scour and erosion of earthworks	Increase in winter precipitation Increase in extreme precipitation	Flooding	There is a risk to the geotechnics asset of scour and erosion resulting from flood waters.	0.22
Maintenance and management of existing assets	Geotechnics	Stability of slopes, change in water levels/ pore pressure	Increase in extreme temperature Increase in winter precipitation	Flooding Change in ground water level	In the maintenance and management of existing geotechnical assets, the risks to the stability of slopes from flooding include: Increased erosion and instability at the base of embankments. The risks to slope stability from increased precipitation are linked to increased pore pressures/water levels which can give rise to a reduction in the factor of safety and a greater risk of instability.	0.11
Maintenance and management of existing assets	Geotechnics	Drainage ditches	Increase in winter precipitation Increase in extreme precipitation		Risk of volume of water exceeding the capacity of ditches.	0.22
Maintenance and management of existing assets	Geotechnics	Earthworks construction across existing landslip	Increase in winter precipitation Increase in extreme precipitation	Change in ground water level	This represents a very limited part of the asset. The risk here relates to a reduction in the factor of safety and higher probability of instability.	0.33
Maintenance and management of existing assets	Signs	Renewal and repair	Increase in mean temperature Increase in extreme temperature Increase in wind speed for worst gales		Minimal risks to the Highways Agency's signs during their design life.	0.10

Maintenance and management of existing assets	Restraint systems	Renewal	Increase in mean temperature Increase in winter precipitation		Prime risk is workforce safety. No other significant risks identified to the renewal of restraint systems as part of the maintenance and management of the existing asset.	0.20
Maintenance and management of existing assets	Restraint systems	Repair	Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	Prime risk is workforce safety. No other significant risks identified to the repair of restraint systems as part of the maintenance and management of the existing asset.	0.10
Maintenance and management of existing assets	Soft estate	Landscape	Increase in mean temperature Decrease in summer precipitation	Longer growing season Reduction in soil moisture	The risks involved here with existing soft estate make-up of species and landscape character is the potential for certain species to become unstable and potentially a safety risk if not managed properly. (i.e. Beech will become susceptible to drought conditions and become a safety issue as a result requiring removal along some parts of the SRN.) A removal of certain species may result in more exposure to the SRN.	0.22
Maintenance and management of existing assets	Soft estate	Ecology	Increase in mean temperature	Longer growing season Reduction in soil moisture	Change in climate may well have an impact on existing ecological habitats. Climate change may result in more migration of species both along our SRN and across it. Risk is more migration may result in more road deaths and potential safety related issues resulting in the requirement for more mitigation to compensate - greater costs. The same applies to cultural heritage and drainage issues.	0.22
Maintenance and management of existing assets	NMU facilities (Non Motorised User)	Off road	Increase in extreme temperature Increase in winter precipitation Increase in extreme precipitation	Flooding	Risk of NMUs experiencing flooding off-road	0.11
Managing network operation	Managed motorways	Technology	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	The main risk identified is accessibility to roadside cabinets (electrical). Our technology has been designed to withstand the weather related impacts for the duration of its service life, which, for technology will be around 15 years.	0.22

Managing network operation	Managed motorways	Traffic Officers	Increase in extreme precipitation Increase in wind speed for worst gales	Flooding Frequency of extreme storm surges	Flooding could impact the Traffic Officer Service (TOS) in the following ways: • Ability of TOS to access the network and carry out duties. • The TOS is not meant to help motorists in conditions of severe flooding (not equipped with life preservers or specific training). These are dangerous conditions which are for the emergency services to respond to. There are however expectations placed upon on-road Traffic Officers (TOs) to operate in flooded areas. There is an increased risk to TOs of high sided vehicle blow-overs and flying debris, including loads detached from vehicles and third party structures blowing onto the network.	0.22
Managing network operation	Managed motorways	Regional Control Centres	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	An increase in mean and extreme temperatures would affect the energy consumption used within the RCCs for climate control (air conditioning). This directly impacts the facilities management costs for each of the Agency's 7 Regional Control Centres. There is a potential flooding risk to some RCCs. Site specific risk assessments would need to be conducted to determine the level of risk. Continuity procedures are in place whereby the work of an RCC could be undertaken by another RCC in the event of part/full closure. However, managed motorways operations are not transferable.	0.22
Managing network operation	Incident management	Breakdowns	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales		There is a risk of more incidents due to: • vehicles having broken down/ overheated • a higher frequency of vehicle fires • smoke drifting across carriageways from wildfires • HGV blow-overs • Flying debris Increased danger of secondary incidents if vehicles are blown into hard shoulder There is a risk to road users unable to exit the network if stuck in a queue (e.g. at a time of extreme temperature).	0.22

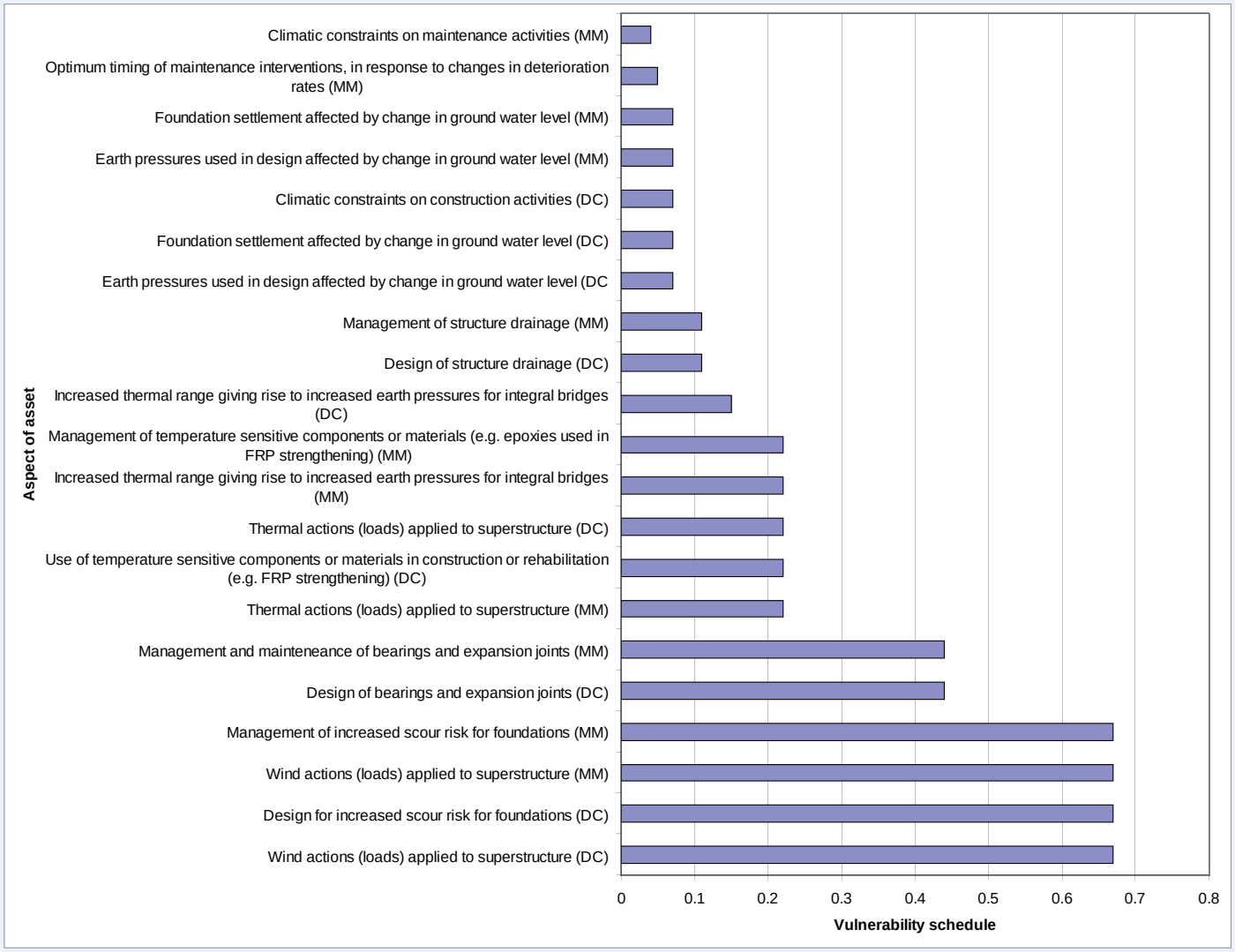
Managing network operation	Incident management	Road user incidents / accidents	Increase in winter precipitation Decrease in summer precipitation Increase in extreme precipitation Increase in wind speed for worst gales		Increased risk of more incidents caused by ice: • Specific risk posed by skidding vehicles to those working on the network • Risk of traction-related incidents Other causes of incidents: • Spray • Aquaplaning • Losing control on standing water • Overturned vehicles	0.07
Managing network operation	Incident management	Third party incidents	Increase in extreme precipitation Increase in wind speed for worst gales	Flooding Frequency of extreme storm surges	Increased risk to those working on network.	0.22
Managing network operation	Restricting network use	High winds	Increase in wind speed for worst gales		High winds will require the HA to close structures / roads to high sided vehicles and motorcycles more frequently. There is a risk in the absence of a structured method for restricting access to vulnerable vehicles as opposed to fully closing a stretch of the network.	0.10
Managing network operation	Restricting network use	Flooding	Increase in extreme precipitation Increase in wind speed for worst gales	Flooding Frequency of extreme storm surges	There may be a need to open up diversion routes if parts of the HA network become flooded. There is a risk of Local Authority routes becoming gridlocked if parts of strategic network are closed – a reputational risk for the HA if seen to be the "cause". (The majority of HA roads are at a higher elevation than local roads which means that if HA roads suffer fluvial flooding, it is likely that the adjacent local authority roads will also be flooded.)	0.44
Managing network operation	Education	Motorised users	Increase in mean temperature Increase in winter precipitation Reduction in snowfall	Reduction in icy days in winter	Education aims to transfer decision making responsibilities to the road user. The HA communicate travel information and advice throughout the year but especially at times of adverse winter conditions. There is a risk that road users will not heed advice given.	0.33
Managing network operation	Education	Non-motorised uers	Increase in mean temperature Increase in winter precipitation Reduction in snowfall	Reduction in icy days in winter	Risk of NMUs failing to change behaviour as a result of education.	0.33

Managing network operation	Education	Worker safety	Increase in mean temperature Increase in extreme temperature Increase in winter precipitation		The risk here is a lack of appreciation of skid risk/out of control vehicle danger for those working on the hard shoulder and wider network.	0.22
Managing network operation	Education	Highways Agency staff	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	The risk to HA staff is the ability to conduct 'business critical' activities, although contingency plans are in place.	0.22
Defining and managing network strategy and planning	Development control	Development control			Risk that development on any given site could exacerbate local risks. To be determined on a case by case basis.	0.05
Defining and managing network strategy and planning	Demand management	Demand forecasting			No significant risks identified.	0.33
Defining and managing network strategy and planning	Demand management	Influencing travel behaviour	Increase in mean temperature Increase in winter precipitation Decrease in summer precipitation Increase in extreme precipitation		The Agency communicates to road users through a number of channels. We already provide advice to drivers on travelling in extreme weather conditions and work closely with partners to manage demand of the network through a range of initiatives aimed at influencing travel behaviour.	0.11
Defining and managing network strategy and planning	Land management	Estate assets	Increase in mean temperature Increase in extreme temperature Decrease in summer precipitation		Risks from the effects of climate change impacting the aquisition, management and disposal of property.	0.22
Defining and managing network strategy and planning	Strategic resilience	Critical geographic importance	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	There is a risk that flooding of the strategic road network would compromise its strategic resilience.	0.67

Defining and managing network strategy and planning	Network resilience	Impact from third parties	Increase in winter precipitation Increase in extreme precipitation	Change in ground water level	A risk that actions of third parties could impact the Highways Agency's asset e.g. extreme precipitation could exceed drainage capacity from adjacent land and cause flooding impact to the HA.	0.67
Defining and managing network strategy and planning	Network resilience	Demand and operation (rail systems fail)	Increase in extreme temperature Increase in winter precipitation Increase in extreme precipitation		Risk of cascade failure whereby the failure of one asset / infrastructure type e.g. rail would change the demand for the highways infrastructure – leading to a negative impact on the reliability and safety of journeys.	0.67
Defining and managing network strategy and planning	Investment appraisal	Identifying best ways of investing resources/ investment appraisal			Risk to investment appraisal if climate projections are not considered.	1.00
Defining and managing network strategy and planning	Budgeting (spending reviews)	Budgeting (spending reviews)			Risk of insufficient funding to support climate change adaptation.	0.67
Defining and managing network strategy and planning	Network performance	Monitoring and standards	Increase in extreme precipitation Increase in wind speed for worst gales	Flooding Frequency of extreme storm surges	For existing (especially older) assets, there is a risk that existing standards will not tolerate the future climatic conditions.	0.11

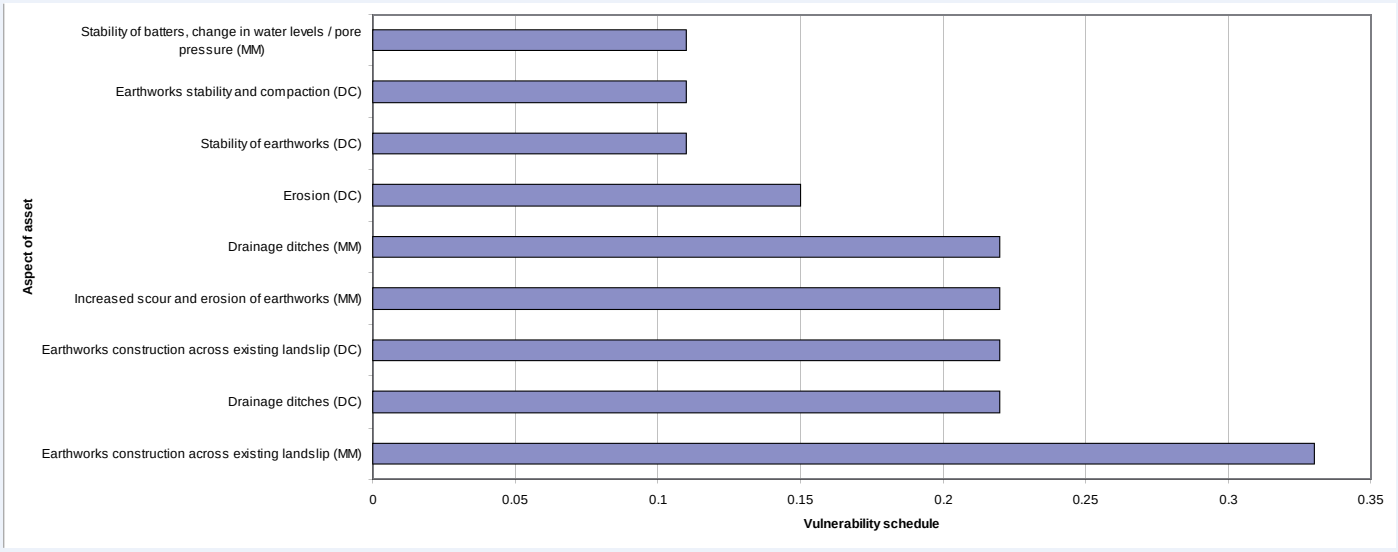
Annex B: Vulnerability graphs

Figure B.1 – Vulnerability ranking of the structures asset



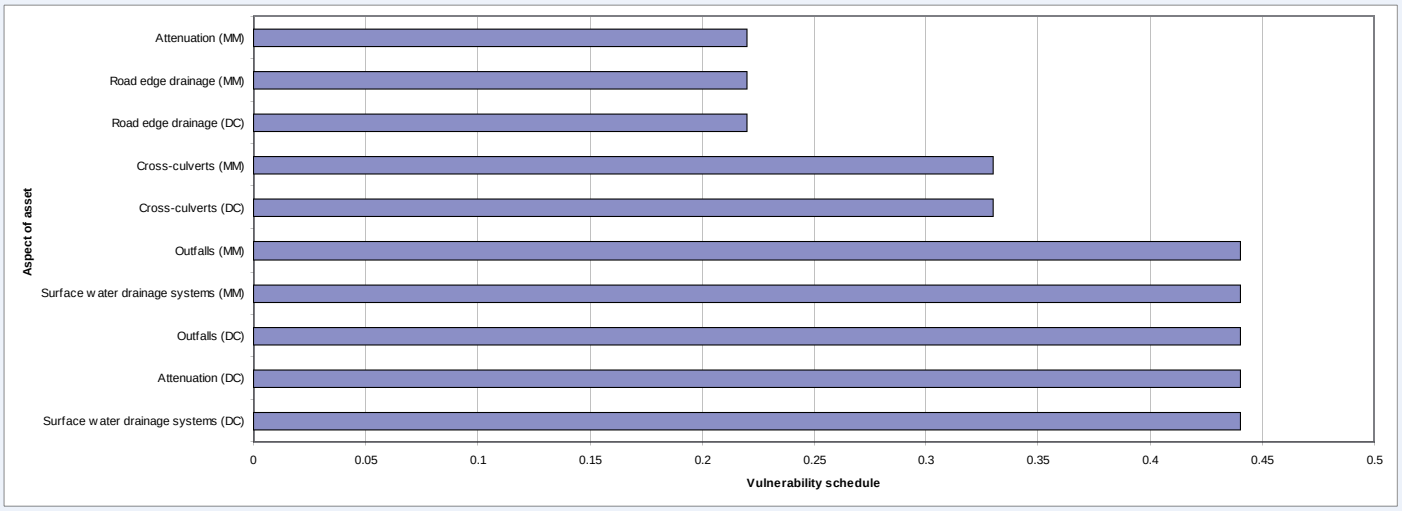
Priority risks include the design for increased scour risk for foundations, management of increased scour risk for foundations and wind actions (loads) applied to superstructure. (MM = maintenance and management of existing asset. DC = design and construction of new and replacement asset).

Figure B.2 – Vulnerability ranking of the geotechnics asset:



Priority risk is earthworks construction across existing landslip. (MM = maintenance and management of existing asset. DC = design and construction of new and replacement asset).

Figure B.3 – Vulnerability ranking of the drainage asset:



Priority risks include surface water drainage systems, attenuation and outfalls.
(MM = maintenance and management of existing asset. DC = design and construction of new and replacement asset).

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