Highways England

Climate Adaptation Risk Assessment Progress Update - 2016

November 2016

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Foreword

Highways England is the new company set up to operate and improve the nation's strategic road network. Comprising over 4,300 miles of motorways and major A-roads, the network is one of the country's most important infrastructure assets. A resilient and effective strategic road network is a vital part of a strong growing economy. It is our duty to keep it safe and operable by addressing risks posed by climate change. This Climate Change Adaptation Progress Update is our first such publication.

This report highlights to our stakeholders the work we have been doing to adapt, and the plans we have in place, to address the risks we identified through our risk assessment processes. By adapting the way we do things, we will ensure that we continue to deliver a resilient road network for our customers and meet our performance expectations.

The 2015-2020 roads period will be a time of significant investment in our roads. Through this investment, we will improve the condition of the network's assets and increase the network's ability to cope with change. Our assets are designed for a long service life using rigorous standards to produce infrastructure that lasts. The strategic road network is here to stay and it is our responsibility to make sure it will continue to serve our customer's needs both now and into the future.

1. Introduction

Highways England, formerly the Highways Agency, is the new government owned company set up from April 2015 to operate and improve the 4,300 miles of motorway and major A-roads that form the strategic road network. Our primary role is to deliver a better service for road users and to support a growing economy. We recognise that we all have an important part to play in minimising the causes and managing the risks associated with a changing climate. With this in mind, our report focuses on our climate resilience. That is, how we are changing the way we do things and the decisions we make to prepare for the potential effects of climate change.

As a government owned company, we operate under the direction and guidance of the Secretary of State for Transport described in the Highways England Licence[1] and the Department for Transport's Road Investment Strategy[2]. The licence sets out our duties and obligations and states that Highways England should:

"*Adapt its network to operate in a changing climate, including assessing, managing and mitigating the potential risks posed by climate change to the operation, maintenance and improvement of the network*"

Our delivery plan for 2015-2020[3] sets out in detail how we will deliver the strategic vision set out in the Road Investment Strategy, how we will measure our success, and how we will identify future goals and plans to keep improving our customers' and neighbours' experience of the network. The eight areas in which our performance will be measured are:

1. Making the network safer;
2. Improving user satisfaction;
3. Supporting the smooth flow of traffic;
4. Encouraging economic growth;
5. Delivering better environmental outcomes;
6. Helping cyclists, walkers, and other vulnerable users of the network;
7. Achieving real efficiency; and
8. Keeping the network in good condition.

To achieve our objectives in each of these areas, we need to understand how changes in the climate can impact our operations and the network, and then address our vulnerabilities to these risks where we can.

[1] Department for transport (2015) Highways England: Licence. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/431389/strategic-highways-licence.pdf
[2] Department for Transport (2015) Road Investment Strategy for the 2015/16-2019/20 Road Period. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408514/ris-for-2015-16-road-period-web-version.pdf
[3] Highways England (2015). Delivery Plan 2015-2020. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/424467/DSP2036-184_Highways_England_Delivery_Plan_FINAL_low_res_280415.pdf

2. Background

Our Climate Change Adaption Strategy

Highways England is committed to understanding and assessing the risks posed to the strategic road network from a changing climate, and taking appropriate management action to mitigate these risks. As the Highways Agency, we developed a climate change strategy and adaptation framework[4] which continues to guide Highways England's adaptation strategy today. The framework provides a consistent approach to assessing and understanding the risks posed to the strategic road network. Highways England's Adaptation Framework Model (see Figure 1) provides a seven stage process that identifies our activities, which will be affected by a changing climate, determines associated risks and opportunities, and identifies preferred options to address them.

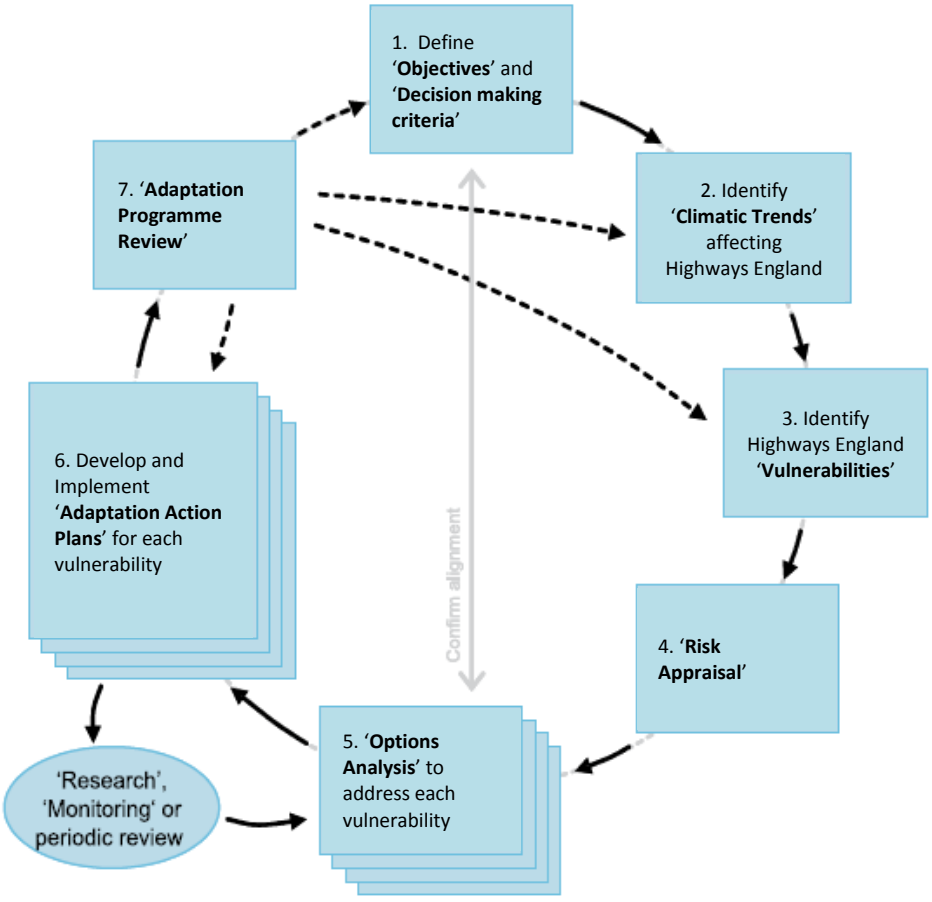


Figure 1: Climate Change Adaptation Framework Model

[4] Highways Agency. Climate Change Adaption Strategy and Framework. http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf

Climate Adaptation Risk Assessments

The Climate Change Act 2008 gives the Department for Environment Food and Rural Affairs (Defra) the power to request that certain organisations report on how they are adapting to climate change. These reports should include:

- The current and future predicted impacts of climate change on the organisation; and
- Proposals for adapting to climate change.

Organisations, primarily from the energy, transport and water sectors, including Highways England (then the Highways Agency), produced their first round reports between 2010 and 2011. The first round of reports provided a detailed assessment of the climate change risks identified by the reporting organisations, as well as the plans and activities that would be undertaken to prepare for these risks.

Progress Updates

The second round of reporting is being conducted on a voluntary basis and is intended to provide an update on the progress made by first round reporting authorities. New organisations have also been invited to provide full risk assessments. Highways England is voluntarily providing a progress update. This includes a summary of the 2011 risk assessment, an update on adaptation work achieved to date and our plans going forward:

- **Chapter 3-5**: A summary of the 2011 risk assessment;
- **Chapter 6**: A validation of the risk assessment scores;
- **Chapter 7-11**: A progress update on our adaptation journey; and
- **Chapter 12**: Our plans going forward.

This report is intended to fulfil both Highways England's on-going commitment to the adaptation reporting power, and provide our stakeholders, including our employees, supply chain and our customers, with an overview of the work we have achieved to prepare our organisation and the network for the future impacts of climate change.

3. Climate Change Trends and Hazards

The climatic changes likely to affect our business areas and activities over the next century are summarized in this chapter. We have considered the climate change projections and hazards, which have the potential to affect our business and users of the network. Reviewing climate projections forms stage 2 of our climate adaptation framework (Figure 1).

From first-hand experience, we know that some of our services are sensitive to current weather events. These services, plus others, are likely to become increasingly vulnerable as the climate changes in the future. We need to know what those changes are, in order to be able to prepare for them.

Weather Event Case Study: A303 at Deptford, Wiltshire. 2014

The A303 trunk road provides a key strategic route between the M3 near Basingstoke and the A30 near Honiton in Devon, which in turn links to the M5 at Exeter. As it passes through Wiltshire, the A303 is a mix of single and dual carriageway, with one of the dual carriageway sections located at the junction with the A36 at Deptford.

Following an extended period of heavy rainfall over December and into January 2014, large volumes of groundwater began to run off from adjacent agricultural land, on the edge of Salisbury Plain, onto lane 1 of the eastbound A303 just west of its junction with the A36. Due to the exceptionally high groundwater levels in the area, and the rate of flow onto the eastbound carriageway, the floodwater overwhelmed the road's drainage system. The eastbound carriageway was closed to traffic just after 7 a.m. on 9th January, including the eastbound entry slip road from the A36. Eastbound traffic was diverted into Salisbury and then back to the A303, which added some 12 miles to road user's journeys, although there was no significant queuing of traffic on the A303.

By early evening on 10th January Highways England had removed the central reservation barrier and established a contraflow on the westbound carriageway, allowing traffic to remain on the A303 and travel past the flooded area in both directions. Traffic remained unable to join the A303 eastbound from the A36 until 16th January. The contraflow remained in place until late on 21 January, when the groundwater flows had reduced sufficiently to allow the eastbound A303 to safely reopen, some 12 days after it had closed. During this time the contraflow enabled traffic to continue using the A303 without any appreciable delay in either direction.

Source: Transport Resilience Review, 2014.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf

The UK Climate Impacts Programme (UKCP09) provides the latest projections on the future climate of the UK. UKCP09 data informed the Highways Agency Climate Change Adaptation Strategy (2010) and our Climate Risk Assessment (2011) and remains the best available published information. As such, we continue to use UKCP09 projections to inform decision making today.

There is a high degree of uncertainty related to climate projections; we therefore take a cautious approach by considering a high emissions scenarios. Headline projected climate changes suggests that England will experience the following trends up to 2080:

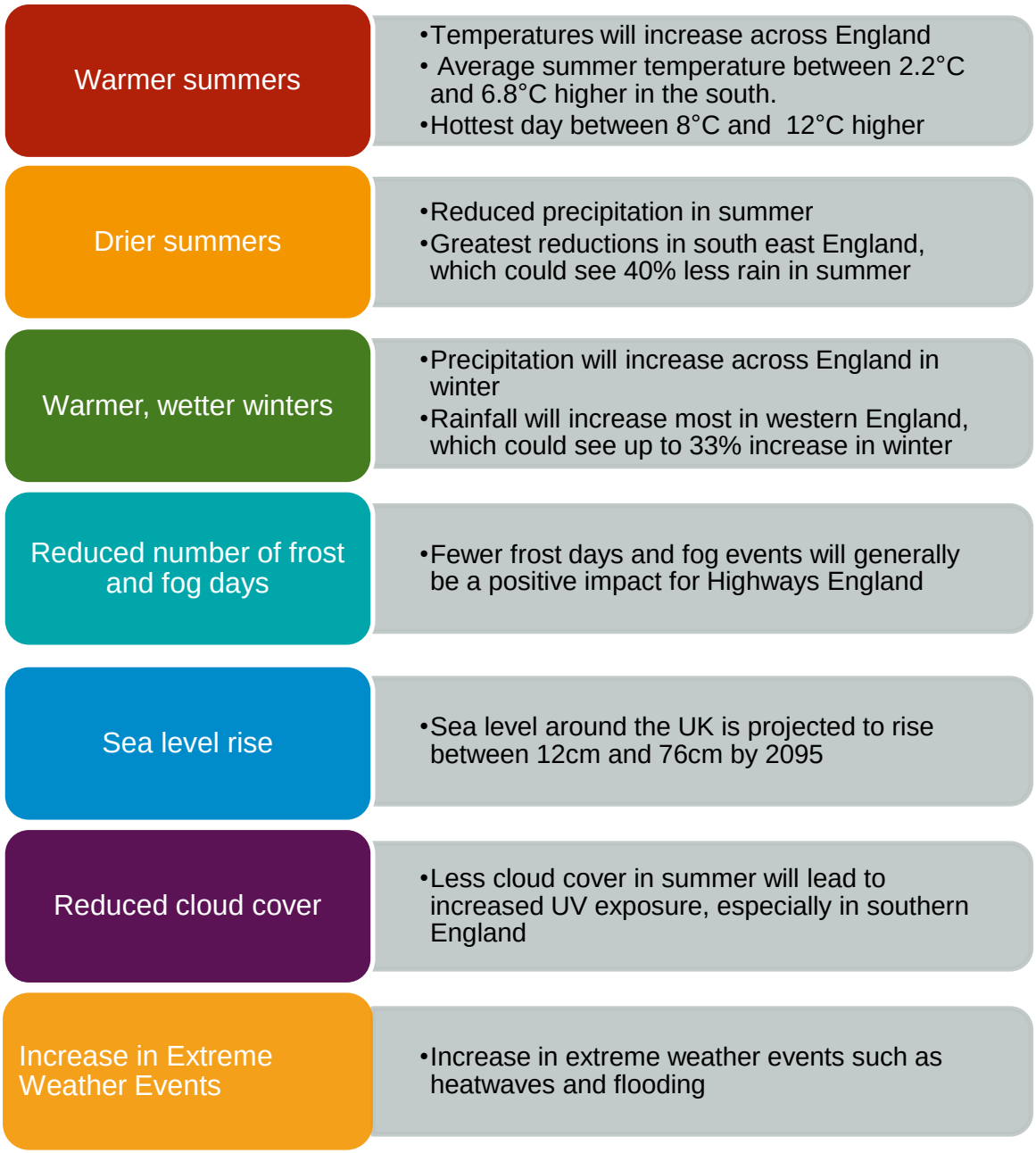


Figure 2: Headline Projected Climate Change Impacts from UKCP09

Using the UKCP09 projections, and research from the Conference of European Directors of Roads[5] (CEDR), we have highlighted climate change hazards with potential to impact our services and network users. We have categorised the hazards into primary climatic changes and secondary climatic change impacts, as shown in Table 1. Climate change hazards were used to identify Highways England vulnerabilities', which are listed in Appendix 1.

Table 1 Climate change hazards

Climate change hazards – Significance to Highways England		
Primary climatic changes	Secondary climatic change impacts	Importance for users
Increase in average temperature	Longer growing season Reduction in fog days in winter Reduction of icy days in winter	Low
Increase in maximum temperature	Extreme summer temperatures	High
Increase in winter rainfall	Flooding Increase in snowfall	High
Reduction in summer rainfall	Reduction in soil moisture	Low
More extreme rainfall events	Flooding	High
Increased wind speed for worst gales	Wind speed more frequently exceeding operational limits	High
Sea level rise	Higher Frequency of extreme storm surges	Low

Thresholds for Action

Key to optimising the value of UKCP09 is identifying operational or other thresholds that are important to Highways England. It is important to know when these thresholds might be reached in order to determine priorities and timescales for action. Examples might include (but are not limited to):

- Incidence of ground frost;
- Temperatures above which asphalt surfaces rut or stripping occurs; and
- The length of the frost-free season (allowing reduction in winter maintenance standby requirements).

Where the information we have is not currently sufficient to inform the threshold for action, our risk appraisal methodology and options appraisal process identifies the need for further monitoring or research. Subsequently, a programme of research and monitoring actions are underway. For example, we have commissioned a report on the economic impacts of flooding to increase our knowledge in this area.

[5] Conference of European Directors of Roads (2012).
http://www.cedr.fr/home/fileadmin/user_upload/Publications/2013/T16_Climate_change.pdf

4. Highways England's Vulnerabilities

Stage 3 of the Highways England adaptation framework (see Figure 1) is the identification of vulnerabilities. Vulnerabilities are the Highways England activities that could be affected by climate change. Whilst our assets are receptors of climatic events, it is the ways in which we design, maintain, operate and manage our assets that are defined as vulnerabilities. This distinction has been made to reflect that it is the way that Highways England works that needs to be adapted to meet the challenges of a changing climate, so we can continue to meet the needs of our customers and operate an effective and safe network.

Our list of vulnerabilities (see Appendix 1) presents the (primary) changes to the climate and the (secondary) associated impacts. Each vulnerability was considered, in turn, to identify if and how it will be affected by climate change and whether this will put our objectives, as set out in the Licence and Road Investment Strategy, at risk. Each vulnerability was then assigned into one of the following categories:

- Defining and managing network strategy and planning
- Design and construction of new and replacement assets
- Maintenance and management of existing assets
- Managing network operations
- Internal business management

The vulnerabilities were also assigned to the area of our organisation for which they are concerned with so that the appropriate technical experts could consider them. Table 2 shows the number of vulnerabilities we identified in each of our core business areas. These are the same as those presented in our 2011 risk assessment.

Table 2 - Vulnerabilities identified across each business area

Area	Number of Vulnerabilities Identified													
Drainage														
Geotechnics														
Pavements														
Structures														
Traffic Management														
'Other'														

Vulnerability Score (see Chapter 5)

High

Medium

Low

5. Risk Assessment Methodology

This report provides a progress update regarding the adaptation activities we have undertaken, following the completion of our 2011 risk assessment. It does not focus on the risk appraisal methodology itself, as we continue to use the same process. This chapter, therefore, provides a summary of our current risk appraisal process, stage 4 of the adaptation framework (see Figure 1).

Since 2011, transport industry literature on climate change adaptation, such as the Conference of European Directors of Roads RIMAROCC methodology[6], has helped to validate our approach to risk assessment and compare our identified risks with those of other European road operators. The objectives of our risk assessment methodology, stage 1 of our adaptation framework, are to:

- Provide a means of consistently scoring the vulnerabilities to form a ranking;
- Enable Highways England to determine where to focus efforts in adapting to climate change; and
- Provide a basis for future planning and prioritisation.

To make certain that we continue to meet our objectives, there are several ways in which we need to be able to prioritise risk. Prioritisation is based on a combination of the following and other factors:

- Risks that have the greatest potential effect on users;
- Risks expected to materialise first; and
- Risks with the greatest uncertainty for which further research would be beneficial.

The risk appraisal methodology sets out a series of steps to enable the above priorities to be considered. There are four primary criteria against which all vulnerabilities are appraised, as shown in Table 3. These risk categories are referred to throughout the appraisal process.

Table 3 Primary criteria for risk appraisal

Primary criteria	Definition
Uncertainty	Compound measure of current uncertainty in climate change predictions and the effects of climate change on the asset/activity.
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.
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.

[6] Conference of European Directors of Roads (2010). http://www.fehrl.org/index.php?m=32&mode=download&id_file=10736

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.

The process for appraising each vulnerability is shown in Figure 3.

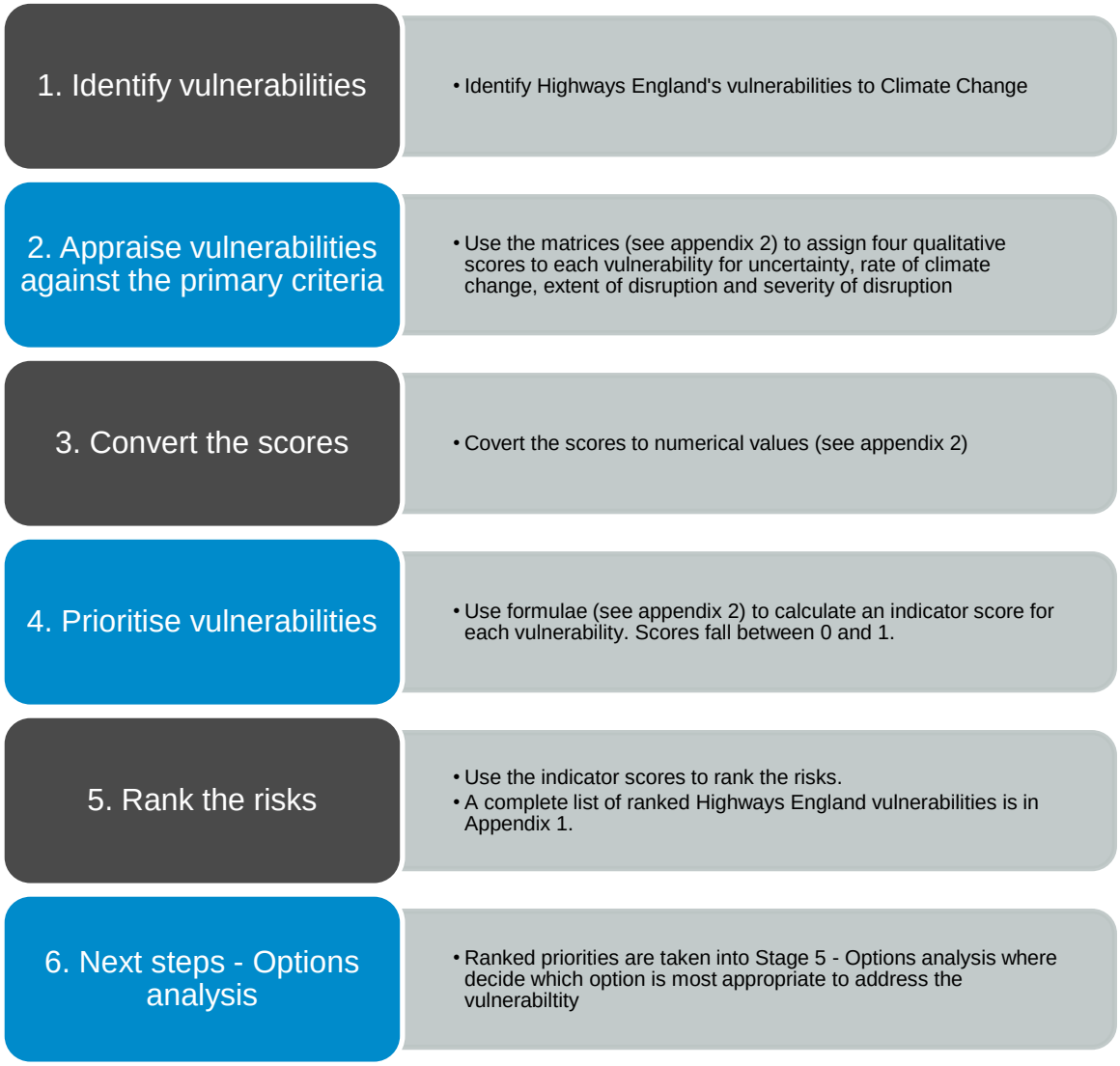


Figure 3 Highways England risk appraisal process (Stage 4 of the Highways England Adaptation Strategy Model)

An example of how we applied the risk assessment methodology to a vulnerability is included in Appendix 3. The output of the risk appraisal methodology is a fully ranked and prioritised list of vulnerabilities which were taken to stage 5 of our adaptation framework, Options Analysis.

6. Vulnerability Scores

Vulnerability Scores

This chapter provides a summary of the vulnerabilities identified through the 2011 risk assessment process, using the methodology described in Chapter 4.

Table 44 contains some of the most highly disruptive and time critical with high confidence vulnerabilities. Consideration of adaptation action planning becomes a priority when the threshold, a score of 0.44 or above, has been reached. These areas of our activities have been the focus for adaptation planning; however adaptation planning has not been limited to these. See Appendix 1 for the full table of vulnerabilities and adaptation actions.

Table 4: Highly disruptive and time critical vulnerabilities where there is a high confidence the risk will occur together with the target risk ambition following action.

Category	Area	Aspect	Climate Risk	Action	Target Risk
Design + construction of new + replacement assets + Maintenance and management of existing assets	Structures (including gantries)	Wind actions (loads) applied to	0.67	Monitor	Medium
		Design for increased scour risk	0.67	Do Minimum	Low
		Design of bearings and expansion joints	0.44	Do Minimum	Medium
	Pavements	Design of foundations	0.44	Development of future proof designs	Medium
		Skid Resistance	1.0	Update operating procedures	Low
		Existing Foundations	0.44	Monitor	Medium
		Existing Concrete	0.67	Update operating procedures	Low
	Drainage	Surface Water Drainage	0.44	Development of future proof designs	Medium
		Attenuation	0.44		Medium
		Outfalls	0.44		Medium

Validation of Vulnerability Scores

As part of our progress update, we have undertaken a validation check of the risk assessment scores from our 2011 risk assessment. This is to check whether the criteria they are based on, or our activities which are being assessed, should change in any significant way.

Our vulnerability scores are based on a discrete number of criteria, as described in Table 3 (see Chapter 5). The validation process highlighted that the key influence on the scoring of

these criteria is the accuracy of climate projections. As outlined in Chapter 3 of this report, the latest climate projections available are UKCP09. Given that the projections have not changed since the 2011 risk assessment, it is not considered necessary to revisit the risk scores based on the criteria which make up the scores.

The validation process did highlight however, that since the 2011 risk assessment was completed, a significant change has occurred to Highways England. We are now a government owned company rather than a government agency. This has resulted in changes to the structure of our organisation and the objectives we work towards; although it must be noted this has not changed the boundaries of our control and the areas for which we are responsible.

In light of our organisation's revised objectives, an internal review has been held to ensure the current list of vulnerabilities is appropriate to Highways England as an organisation and to check if any new vulnerabilities need to be added. The result of this review was that the current list of vulnerabilities is still considered sufficient and appropriate for Highways England.

7. Options Analysis

A Highways England technical specialist was assigned to each vulnerability, to identify potential adaptation options.

For each vulnerability, six adaptation options were considered using the broad themes outlined below. These are similar to the measures identified by the ROADAPT guidelines[7] as the 'building blocks of an adaptation strategy':

- Do minimum;
- Monitor;
- Update operating procedures;
- Development of future proof designs;
- Develop contingency plans; and
- Retro-fit solutions.

A systematic evaluation process was then applied to all options, to identify the most effective actions to address and minimise the risk to the vulnerability.

Appendix 1 provides the full list of climate change vulnerabilities identified in the 2011 Climate Change Risk Assessment and the corresponding adaptation actions chosen to address them. An explanation of the decision making process and an example of each of the adaptation options are provided below.

Do minimum

After completion of the options analysis process, a number of vulnerabilities were considered to already have sufficient measures in place that address this risk. It is often the case that the requirements placed on our construction and maintenance supply chain are already rigorous enough, and historical design practice has often been to err on the side of caution. Therefore, in instances where a 'do minimum' approach has been selected, the thresholds or tolerances involved are considered already suitable to cope with the current climate change projections.

Example from Geotechnics: An increased frequency of soils and sub soils drying out, followed by increases in extreme precipitation, could destabilise material and lead to erosion. This is not considered a significant risk in the design and construction of new and replacement Geotechnics assets, because erosion at present is limited to a few isolated areas. Existing specifications allow for the use of topsoil retention systems where deemed relevant and any risks are already addressed on a project specific basis.

[7] Conference of European Directors of Roads (2015). Road for today, adapted for tomorrow – Guidelines. http://www.cedr.fr/home/fileadmin/user_upload/en/Thematic_Domains/Strat_plan_3_2013-2017/TD1_Innovation/I1_Research/TGR_TPM/Transnational_calls/CEDR_Call_2012/CEDR%20Call%202012%20Climate%20Change/ROADAPT/ROADAPT_integrating_main_guidelines.pdf

Monitor

Monitoring was considered the most appropriate option for vulnerabilities where we do not yet have sufficient data to inform other actions. By monitoring the situation we will increase our understanding of the vulnerability and the opportunities that exist to address it.

Example from Pavements: During extended periods of hot, sunny conditions, asphalt can become susceptible to permanent deformation affecting profile. In the case of hot rolled asphalt surface course (not used at present on the trunk roads) with added pre-coated chippings, this may affect texture depth. The thin surfacing materials in the current standard are considered adequate to meet the impact of climate change as they are not susceptible to the projected increases in temperature. However, to ensure robustness of the standards on surfacing materials, we research how these materials are performing on the network by monitoring the performance of thin surfacing. A small group of experts visit various sites to examine their relative performance, including the climate change impact on the material's behaviour. The main purpose of this research is to ascertain the factors and thresholds involved which cause the sudden failure of thin surfacing.

Update operating procedures

Updating operating procedures involves changing the way we do things to take account of the impacts of climate change.

Example from Pavements: Prolonged periods of dry weather, followed by rainfall, will lead to a reduction in skid resistance due to oil and detritus build-up on the carriageway. Conversely, prolonged periods of wet weather will lead to a reduction in skid resistance due to the wet surface reducing adhesion between tyres and the surfacing. Higher average summer temperatures may also adversely affect skid resistance as measurements for resistance on asphalt surfacing are lower at higher temperatures. A review into the current skid policy to ensure that it is fit for purpose taking into account predicted climate change has been conducted and a new skid policy for maintenance assessments was published in 2015[8].

Development of future proof designs

New and improved assets on the network are designed according to technical standards and specifications which are followed by our construction and maintenance contractors. Future proofing these designs involves providing additional capacity or functionality. These updated requirements could apply to all 'designs', e.g. designs for new structures or new roads, as well as the designs for maintenance, renewal and improvement works when these are implemented within the normal cycle for such activities. Typically it will be appropriate to adopt a precautionary approach in future-proofing designs, so that the asset/activity will perform satisfactorily throughout its life in the event of climatic changes.

[8] Highways England (2015). Design Manual for Roads and Bridges HD 28 Volume 7, Section 3, Part 1. http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol7/section3/hd2815.pdf

Example from Drainage: Updates are currently being undertaken to the Design Manual for Roads and Bridges (DMRB) guidance to ensure that all new drainage assets are provided on a consistent basis, using updated critical design storm guidance, to assure serviceability and minimise the risk. Provision of clear, unambiguous assessment & design guidance in DMRB Volume 11, Section 3, Part 10 (HD45)[9] and DMRB Volume 4, Section 2, Part 1 (HA106)[10] will ensure consistency of design approach for new and improved assets, providing robust design parameters to accommodate climate change parameters. Implementation of formal guidance will improve network resilience in the event of extreme events. Guidance on the run off from adjacent land is already included in HA106, which allows for run off from external catchments.

Develop contingency plans

Development of contingency plans involves the pre-planned response for when/if climate change risks are realised so that their immediate effects can be managed. This option is applied where nothing can reasonably be done to mitigate an identified risk, during the period until other measures are put in place, or where there is a residual risk, despite adaptation actions being employed.

Contingency plans have not been considered necessary at this stage for any of the vulnerabilities identified. We will, however, continue to monitor our vulnerabilities and update contingency plans where they are considered necessary and appropriate.

Retro-fit solutions

A retro-fit solution is proactively applying modifications to existing assets/activities outside of the 'normal' cycle for renewal/replacement. For example, replacing/fitting additional equipment or components or providing additional provision/capacity to existing assets before its renewal/replacement becomes critical. Retrofitting could potentially be applied everywhere on the network, or just at high risk sites. Work could start now, or only once climate change effects meet certain threshold criteria. Where the criteria for such a threshold it not yet fully understood monitoring is necessary.

Through the options analysis process, we have not yet identified a situation where retro-fitting has been considered the most appropriate option available. Highways England has a programme of regular renewal and improvement schemes in place; therefore retro-fitting is un-likely in many cases to be the most cost effective option of adaptation.

[9] Highways England (2015). Design Manual for Roads and Bridges HD45 Volume 11, Section 3, Part 10. http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol11/section3/hd4509.pdf

[10] Highways England (2004). Design Manual for Roads and Bridges HA106 Volume 4, Section 2, Part 1. http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol4/section2/ha10604.pdf

8. Adaptation Plans

The outcome of the options analysis process was the creation of adaption plans. These draw together the preferred options that would be taken forward from the categories set out in Chapter 7. Each adaptation plan takes the form of a database of actions which is monitored to ensure committed actions are achieved by targeted completion dates.

We have embedded a culture of climate change adaptation planning across Highways England, by giving ownership of the adaptation plans to the areas of our operations at risk from climate change. Figure 4 shows the topics these plans currently cover; the relative size of each circle represents the number of adaptation actions we are currently undertaking related to each topic area:

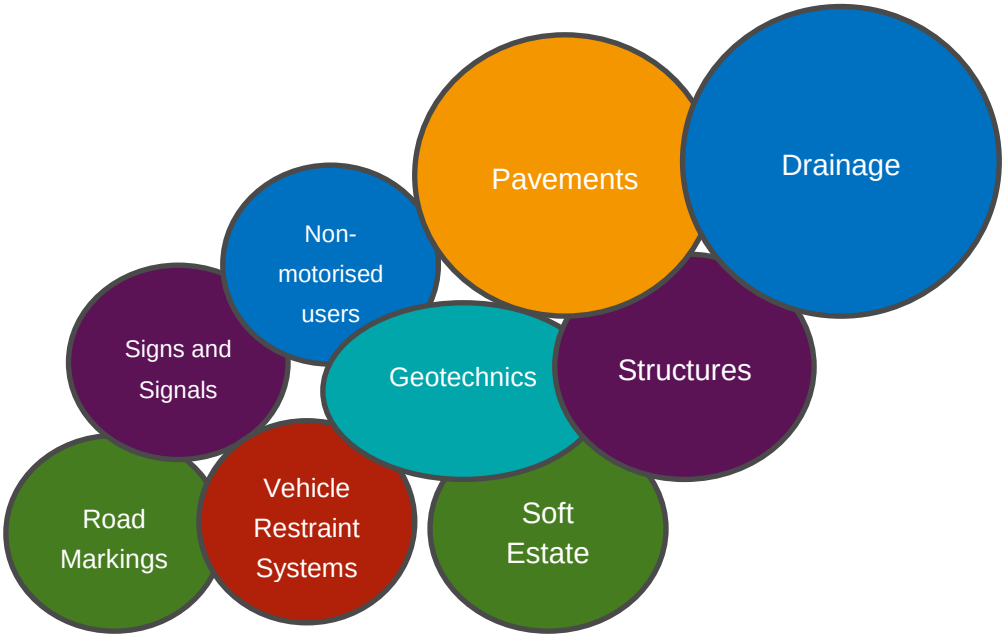


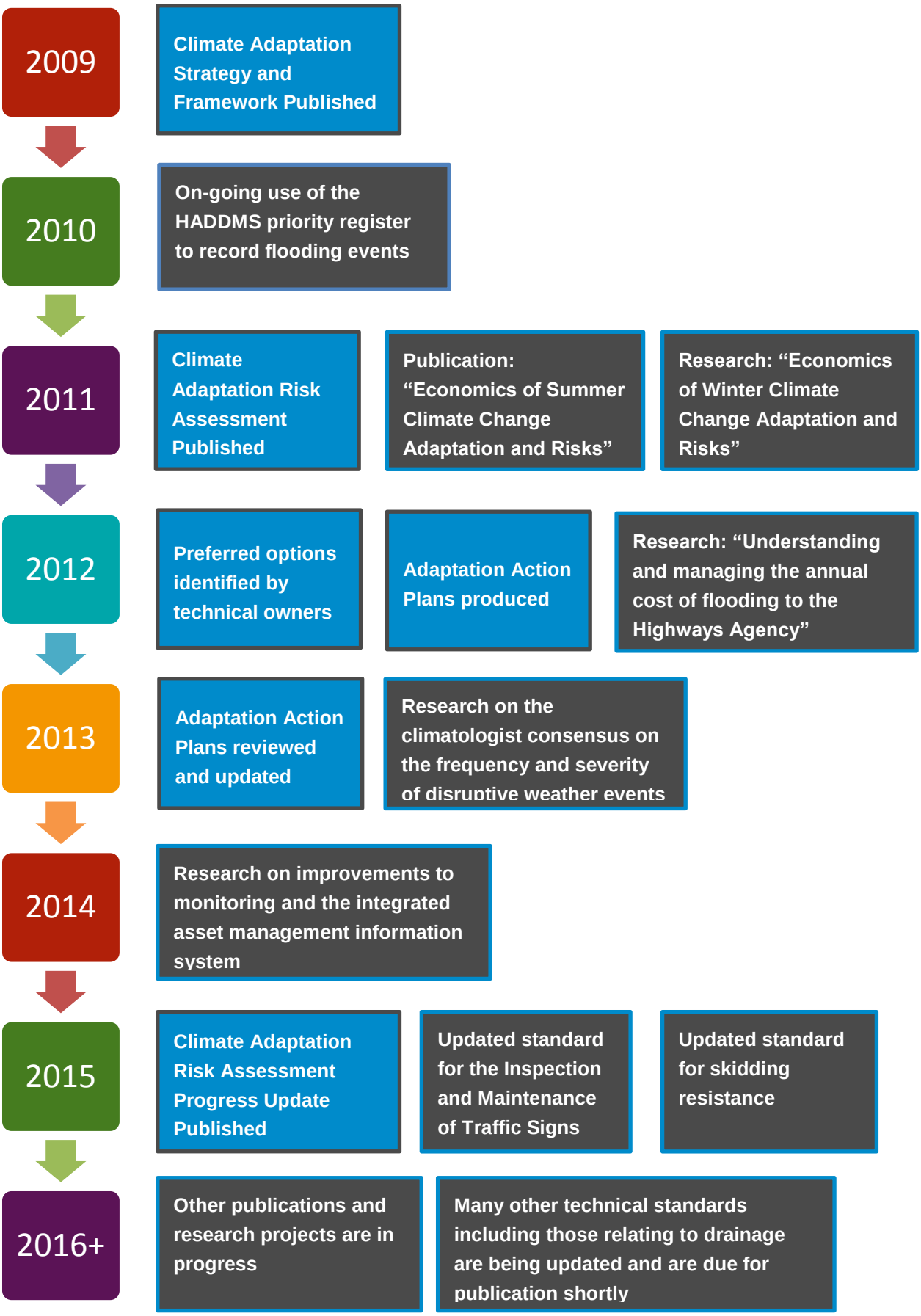
Figure 4 – Adaptation Plan Areas

For some risks it was decided that doing the minimum is appropriate because the rigorous design standards or procedures we have are already sufficient to cope with the predicted impacts of climate change. For example following a review, the standards for Vehicle Restraint Systems were considered to be sufficient to cope with the risks posed by climate change and thus a do minimum approach was agreed. In other cases it has been considered necessary to take action to ensure we are prepared. For example, updating the DMRB or the Manual of Contract Documents for Highway Works (MCHW) to ensure new designs and projects are prepared for the future climate.

We will continue to monitor all our vulnerabilities to ensure the option for adaptation that we have chosen remains the most suitable, and that the network remains resilient.

Since publishing our climate risk assessment in 2011, we have made significant progress towards ensuring our strategic road network is resilient to climate change. A timeline of our actions is provided in Chapter 9.

9. Adaptation Timeline



10. Interdependencies

Stakeholder Engagement

To effectively manage the wider uncertainties and opportunities that climate change presents, Highways England is committed to maximising value from stakeholder engagement. We have close links with a large number of stakeholders, including owners of other UK infrastructure systems.

Some of our other key relationships include freight organisations, local authorities, technology and innovation partners, sustainability and environmental bodies and motorway service operators. The launch of Highways England has presented an opportunity to strengthen relationships with these existing stakeholders and to work with new ones. Engagement with our stakeholders and neighbours provides us with an opportunity to work together to increase our reliance to climate change and share examples of good practice. To formalise our agreed understanding with our stakeholders we have a number of longstanding Memorandums of Understanding's, for example with Natural England, the Freight Transport Association and the Environment Agency. These Memorandums of Understanding ensure that we have common objectives and provide a resilient and safe network. We also continue to seek to deepen our relationships with our supply chain to deliver outcomes more effectively.

Environment Fund Partnership Projects

Highways England is delivering a designated Environment Fund that will be used to improve environmental outcomes in a number of areas including flood risk, landscape, carbon, cultural heritage, noise and biodiversity. This will include funding for partnership projects; these are projects where we work with our stakeholders to identify where joint action and funding will be the most effective method to achieve the desired environmental outcome. For example where flooding is an issue on part of the network it may also be an issue for adjoining land owners; by working together we are much more likely to be able to deliver a solution that increases ours and our stakeholder's resilience, both now and into the future.

European Road partnerships

Contributions have been made to the CEDR research and technical group programmes. Information has been shared among the member road authorities to support the CEDR report on Adaptation to Climate Change published in 2012[11]. Risks relating to climate change have been shared and received, along with proposed adaptation planning and examples of good practice. We also continue to learn from our European counterparts through their contributions to CEDR publications, most recently the 'Roads for today, adapted for

[11] Conference of European Directors of Roads (2012). Adaptation to Climate Change. http://www.cedr.fr/home/fileadmin/user_upload/Publications/2013/T16_Climate_change.pdf

tomorrow – guidelines'[12]. This report sets out methods and approaches for the climate risk assessment of roads, from which we can make comparisons and align our own risk assessment process where beneficial.

National Transport and Infrastructure Systems

The strategic road network is made up of over 4,300 miles of motorways and major A-roads in England. It makes up just 3% of the total roads in England, yet carries nearly a third of all road traffic and two-thirds of large goods vehicle traffic. The economic and strategic value that the network provides makes it one of the most important infrastructure assets in the UK. The importance of adapting the network for future climate change is therefore of paramount importance to the UK. However, the network, and its resilience cannot be viewed in isolation due the numerous interdependencies that exist between the strategic road network and the wider transport and infrastructure systems.

The risks that climate change poses to infrastructure assets could include, at its worst, severance of infrastructure links and potentially prohibit the safe use of infrastructure. This could necessitate changes in how people use infrastructure and ultimately lead to the need to switch transport mode, alter energy use or limit their use of communications. Highways England needs to understand how impacts on all infrastructure assets, not just the strategic road network, could affect its users and their safety.

Use of the network is facilitated by access from local roads managed by Local Highways Authorities. Furthermore, our customers often travel along motorways and trunk roads to reach the next part of their journey; for example to reach train stations, sea ports or airports. It is therefore important that Highways England and other transport operators are aware of the wider resilience of the transport system and how the implications of climate change for one part of the system can have wider implications. For example a decrease in capacity in one transport mode may result in users choosing an alternative transport method. We must work together with the Department for Transport (DfT), infrastructure owners and transport operators to consider climate change adaptation from the strategic to the local level. In light of this, we have signed a Memorandum of Understanding's with Transport for Greater Manchester to ensure a strategic approach to the management of highways across the city region.

The safe operation of the network involves the use of communication systems to monitor conditions and inform road users. It also involves the use of energy to operate technology assets such as lighting and variable message signs. The continued resilience of the road network is therefore intrinsically linked to the resilience of energy and communications infrastructure. We therefore continue to consider the wider resilience of our operations where possible. For example in the event a control centre in one area being unable to operate, another control centre will temporarily be able to cover both areas.

[12] Conference of European Directors of Roads (2015). Road for today, adapted for tomorrow – Guidelines. http://www.cedr.fr/home/fileadmin/user_upload/en/Thematic_Domains/Strat_plan_3_2013-2017/TD1_Innovation/I1_Research/TGR_TPM/Transnational_calls/CEDR_Call_2012/CEDR%20Call%202012%20Climate%20Change/ROADAPT/ROADAPT_integrating_main_guidelines.pdf

11. Reviews

This chapter looks at published reports on resilience and adaptation progress in the transport sector. We intend here to demonstrate how we have taken on board the advice and guidance of such literature to further improve our adaptation programme.

Managing climate risks to well-being and the economy – Adaptation Sub-Committee (ASC) Progress Report

The Adaptation Sub-Committee's Progress Report 2014 is part of a series of reports to assess how England is preparing for the risks and opportunities of climate change and shows how the National Adaptation Programme prepared under the Climate Change Act is being implemented. The report looks at the resilience of national infrastructure including the strategic road network. There are three broad areas where improvement was advised. Below is a brief overview of this advice and a summary of the work that is underway or actions that have been achieved which address these concerns.

1) **Detailed actions plans had not been published**.
   Detailed action plans are in place within the relevant business areas. These plans are internal technical documents that record the risk score, options appraisal process and the targeted adaptation option. Appendix 1 of this report provides an overview of the work on-going with regard to each vulnerability.

2) **No Publically available information on resilience spending plans**
   As part of the first roads period there will be significant investment to address resilience with a specific focus on flooding and pollution through measures to attenuate and improve flood resilience on the strategic road network. This investment is part of a £300m designated environment fund. We published plans for this fund in our Delivery Plan[13] which noted the following areas of focus:

- Improving resilience to flooding and reducing flood risk to communities adjacent to the network. Activity will focus on addressing all identified high priority flood risk locations recorded in our Drainage Data Management System;
- Improving water quality through better environmental protection and specifically improving surface and groundwater quality by addressing priority locations of known pollution;
- Reviewing opportunities for specific measures to contribute to a coherent and resilient ecological network; and
- Working with our stakeholders to identify opportunities for delivering wider environmental benefits in partnership with other land-owners, and communities.

[13] Highways England Delivery Plan 2015-2020.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/424467/DSP2036-184_Highways_England_Delivery_Plan_FINAL_low_res_280415.pdf

3) **Progress with implementing resilience measures is not reported for the strategic road network**
This report is intended to report our progress with implementing resilience measures for the strategic road network.

Transport Resilience Review – Department for Transport (DfT)

The DfT's Transport Resilience Review[14], published in 2014 in response to extreme weather experience during the winter of 2013/2014, provided an independent review of the UK's transport network's ability to cope with extreme weather, a key impact of climate change. The report notes that the majority of the strategic road network was designed and constructed to modern engineering standards, and therefore has a good level of physical resilience to extreme weather compared to other transport infrastructure assets.

The Transport Resilience Review does, however, provide us with specific recommendations to increase our resilience. These included recommendations for Highways England to:

"*Consult with the Freight Transport Association, Road Haulage Association and other affected groups in developing proposals to restrict vulnerable vehicles from using exposed sections of the strategic road network"* and *"Work with the Met Office to agree how best to utilise the improving granularity of wind forecasts to give the best possible wind forecast information to lorry fleet operators".*

We are reviewing the effectiveness of trials to identify whether the Commercial Vehicle Incident Prevention Programme could deliver improved management of High Sided Vehicles during high winds.

"Conduct a flooding risk assessment exercise using the newly updated Environment Agency flood risk maps and other data to identify potential flood risk locations on the strategic road network, to supplement its log of actual flooding events" and *"Complete its drainage asset inventory".*

We are producing a new Flood Risk Strategy. In addition to this, we are also increasing our drainage asset inventory and condition data coverage to better understand the condition of drainage assets on the strategic road network.

*"*Review the range and wording of messages displayed on variable message signs" and *"Continue to improve and refine the content of its website*."

We included the objective "To understand the overall information provision that is given to road users about the weather ranging from roadside infrastructure to the winter driving campaign" in our Severe Weather Programme for 2015/16.

[14] Department for Transport (DfT) 2014. Transport Resilience Review. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf

12. Conclusions and Next Steps

Overall, it has been considered that the risks and vulnerabilities set out in our 2011 Climate Change Risk Assessment remain unchanged. Our climate change adaptation review process has highlighted that many of the vulnerabilities identified during the first round report are already being addressed through our current programmes, improvements and planning activities. The review has also, in some cases, identified where this is not the case and has resulted in us undertaking further action to correct this. There are a number of next steps we will now take to continue our efforts to adapt to climate change, as outlined below.

Communication

We are producing a communications plan which will help to continue embedding adaptation in all areas of the organisation and communicate this to those that work with us. We will communicate the work we have done, the work we are continuing to do and encourage future adaptation planning to take place where necessary. The communication plan will also identify how all our staff are able to contribute to this process, by continually questioning and reviewing the way in which we do things.

Monitoring the Risks

To make sure our vulnerabilities are prioritised accurately, we will continue to monitor any changes in climate projections and update our risk scores accordingly.

Continue to Adapt

In many cases, climate change adaptation is inherently considered as part of our current standards, practices and procedures to ensure the resilience of the network. In addition to this, we have a number of specific adaptation actions that are on-going and will be delivered in the near future, as well as longer term research and monitoring which will inform future adaptation. We will continue to maintain and improve a resilient network that continues to serve its customer's needs both now and into the future.

Appendix 1

List of Vulnerabilities and Our Adaptation Progress

The table within this appendix captures the following information:

- **Activity category**
  The broad function of the business that is considered.

- **Area**
  The particular asset type such as pavements, drainage, structures or geotechnics.

- **Aspect**
  The specific business activity within the business area.

- **Primary climatic change**
  The actual change in climate that could impact on the aspect.

- **Secondary climatic change**
  The effects brought about by the primary climatic change.

- **Highways England risks**
  A description of risks to Highways England from climate change.

- **Vulnerability score**
  A score of between 0 and 1 (based on vulnerabilities which are highly disruptive, time critical with high confidence).

- **The adaptation option**
  The chosen option for adapting to climate change (Do minimum, Monitor, Update operating procedures, Development of future proof designs, Develop contingency plans or Retro-fit solutions).
  The reference to the specific Highways England's internal Adaptation actions plans is included in blue.

- **The progress of the adaptation option**
  The level of progress that has been made in adapting this aspect to climate change:
  - Not applicable: Adaptation options have not yet been considered necessary
  - In progress: Adaptation option is underway and due for completion soon
  - On-going: Adaptation option is an on-going process
  - Completed: Adaptation option has been achieved

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 designing/maintained drainage network to remove sub-surface moisture.	0.44	**Development of Future Proof Designs** Interim advice note on pavement foundations will be updated and incorporated into HD25. DC01 Design of foundations	In progress
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 to manage this specific risk and used on parts of the current network. There is a cost to procuring materials that withstand higher temperatures. Business management costs are involved in changing materials specification and defining changes to construction practices.	0.44	**Monitor** Gather feedback from surfacing contractors through liaison with the mineral products association (MPA), and monitor performance of thin surfacing on the network. Pavements DC02 Laying new asphalt materials Pavements MM03 Existing asphalt	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
					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.		**Update Operating Procedures** Update HD32/HD38 to ensure that requirements for joint sealants are included in new forms of contract. Pavements MM04 Existing concrete.	In progress
Design and construction of new and replacement assets	Pavements	Construction - laying surface dressing, microsurfacing, HMB 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	**Monitor** Gather feedback from surfacing contractors through liaison with the mineral products association (MPA) Pavements DC02 Laying new asphalt materials	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 be present significant risks over this period.	0.22	**Monitor** The potential impact of temperature changes on structures is considered low as the extreme temperatures do not greatly exceeding the existing design guidance. Therefore adaptation action is to continue to monitor. Structures DCMM01 Thermal actions applied to superstructure	On going
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	**Monitor** The potential impact of wind actions on structures is considered low as the extreme temperatures do not greatly exceeding the existing design guidance. Therefore adaptation action is to continue to monitor. Structures DCMM02 Wind actions applied to superstructure	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Design guidance already allows for temperature changes and the range is considered generous. Review in 25 years. Structures DCMM03 Increased thermal range giving rise to increased earth pressures for integral bridges	N/A
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	**Do Minimum** Existing design guidance already takes this into account. Structures DCMM04 Earth pressures used in design affected by change in ground water level	N/A
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	**Do Minimum** New designs are already conservative and there is no evidence for existing structures being affected. Structures DCMM05 Foundation settlement affected by change in ground water level	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Existing processes for inspection of bridges should be adequate to detect problems and monitoring, flood emergency plans or retrofitting would be implemented on specific structures based on these assessments. Current guidance has been reviewed and no updated are required. Structures DCMM06 Increased scour risk for foundations	N/A
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	**Do Minimum** Structures drain into the network drainage. Network drainage is covered by its own action plans. Structures DCMM07 Structure drainage	N/A
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	**Development of Future Proof Designs** Update design requirements, including technical standards and specifications to provide additional capacity/ functionality. Structures DCMM08 Use of temperature sensitive components or materials in construction or rehabilitation (e.g. FRP strengthening)	In Progress

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Existing review procedures of design standards are adequate for a do minimum approach. Structures DCMM09 Bearings and expansion joints	N/A
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	**Monitor** The Specification for Highway Works already prescribes how certain construction activities (for example concreting) should be carried out in, for example, high or low temperatures. Climate change impacts will be monitored and updates to operating procedures and contingency plans produced when necessary. Structures DCMM10 Climatic constraints on construction activities Structures DCMM11 Optimum timing of maintenance interventions in response to changes in deterioration rates	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 England drainage assets, the risks 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 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.	0.44	**Development of Future Proof Designs** There are various updates on-going to guidance and standard documents that will ensure the design and construction of future drainage assets takes account of climate change consistently and adequately. Drainage DC07 Capacity of drainage system Drainage DC08 Increased flooding from adjacent land	In progress

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Erosion at present is limited to the granular deposits across the network in a few isolated areas. Existing documentation already allows for erosion control to be put in place where felt to be appropriate. Geotechnics DC03 Erosion	N/A
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	**Do Minimum** Current design practice is to adopt a conservative approach with respect to long-term groundwater levels, taking into account any potential climate change impacts. Geotechnics DC04 Stability of earthworks	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Current practice and documentation already allows for variations to compaction processes during construction. Geotechnics DC05 Earthworks stability and compaction	N/A
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 for the coming years.	0.22	**Do Minimum** The number of potential sites around the network is very small and the existing geotechnical processes as set out in HD22 are sufficiently robust to identify existing landslides so that the appropriate design measures can be adopted taking into account any climate change aspects. Geotechnics DC06 Earthworks construction across existing landslip	N/A
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.	0.1	**Development of Future Proof Designs** Technical Directive TD 25/01 has been replaced by a new standard TD25/15. Other DC09 Signs and Signals - Stability	Complete

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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.	0.1	**Do Minimum** The impact of Climate Change on the technology asset will require greater consideration in its specification and design, as well as the increasing demands on its use to support operational measures in times of crisis. This will be considered in the future due to the short design life of technology. Other DCMM12 Technology	N/A
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 specification of road markings.	0.15	**Development of Future Proof Designs** Identify to industry what performance classes we will specify over the next 5 years to align production with demand. Look to revise existing standards to enable adoption of new materials or alternative sources by the end of 2020. Other DC11 Road markings Design / specification	In Progress

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Monitor** Monitor relevant guidance and research involving various species and habitat types as well as their management requirements. Other DC12 Soft estate - capital investment, landscape.	On going
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 our soft estate acting as habitat corridors. Climate change may result in more migration of species both along our 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	**Monitor** Monitor relevant guidance and research involving various species and habitat types as well as their management requirements. Other DC13 Soft estate - capital investment, ecology	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 NMU facilities.	0.11	**Do Minimum** Highways England does not provide shelter areas. Any shelter areas on the SRN are owned by local councils. Highways England is however upgrading certain areas around bus shelters in order to comply with equality legislation. Other DC14 Shelter provision	N/A
Design and construction of new and replacement assets	NMU facilities (Non Motorised User)	Underpass	Increase in winter precipitation Increase in extreme precipitation		No significant risks identified that relate to underpasses in the design and construction of new and replacement NMU facilities.	0.22	**Do Minimum** There is no need to change NMU policy/standards because drainage standards are being updated and will take into account NMU facilities. Other DC15 Underpass provision	N/A
Design and construction of new and replacement assets	NMU facilities (Non Motorised User)	Drainage design	Increase in winter precipitation Increase in extreme precipitation		No significant risks have been identified that relate to drainage design, in the design and construction of new and replacement NMU facilities.	0.11	**Do Minimum** Cycle paths include drainage, often in the form of filter drains. Highways England will continue to advise supply chain on maintenance. Other DC16 Drainage design Drainage DC07 Capacity of drainage system	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Update Operating Procedures** Review the current skid policy to ensure that it is fit for purpose taking into account predicted climate change. Publish new skid policy (HD28/15). Pavements MM01 Skid resistance	Complete
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 pavements above to heave and subside.	0.44	**Monitor** Develop tools to monitor foundation condition, i.e. traffic speed deflectometer network level surveys. Traffic speed deflectometer needs further research to enable different pavement layers to be assessed. Pavements MM002 Foundations	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Update Operating Procedures** Update HD32/HD38 to ensure that requirements for joint sealants are included in new forms of contract. Pavements MM04 Existing concrete.	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Monitor** Gather feedback from surfacing contractors through liaison with the mineral products association (MPA), and monitor performance of thin surfacing on the network. The thin surfacing materials in the current standard are generally adequate to meet the impact of climate change as they are not susceptible to higher temperatures. To ensure robustness of the standards on surfacing materials research is ongoing into how these materials are performing on the network. Pavements MM03 Existing asphalt	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Monitor** Gather feedback from surfacing contractors through liaison with the mineral products association (MPA), and monitor performance of thin surfacing on the network. The thin surfacing materials in the current standard are generally adequate to meet the impact of climate change as they are not susceptible to higher temperatures. To ensure robustness of the standards on surfacing materials research is ongoing into how these materials are performing on the network. Pavements MM03 Existing asphalt	On going
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	**Monitor** The potential impact of temperature changes on structures is considered low as the extreme temperatures do not greatly exceeding the existing design guidance. Therefore adaptation action is to continue to monitor. Structures DCMM01 Thermal actions applied to superstructure	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Monitor** The potential impact of wind actions on structures is considered low as the extreme temperatures do not greatly exceeding the existing design guidance. Therefore adaptation action is to continue to monitor. Structures DCMM02 Wind actions applied to superstructure	On going
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	**Do Minimum** Design guidance already allows for temperature changes and the range is quite generous. Review in 25 years. Structures DCMM03 Increased thermal range giving rise to increased earth pressures for integral bridges	N/A
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	**Do Minimum** Existing design guidance already takes this into account. Structures DCMM04 Earth pressures used in design affected by change in ground water level	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** New designs are already conservative and there is no evidence for existing structures being affected. Structures DCMM05 Foundation settlement affected by change in ground water level	N/A
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	**Do Minimum** Existing processes for inspection of bridges should be adequate to detect problems and monitoring, flood emergency plans or retrofitting would be implemented on specific structures based on these assessments. Current guidance has been reviewed and no updated are required. Structures DCMM06 Increased scour risk for foundations	N/A
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	**Do Minimum** Structures drain into the network drainage. Network drainage is covered by its own action plans. Structures DCMM07 Structure drainage	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Development of Future Proof Designs** Update design requirements, including technical standards and specifications to provide additional capacity/ functionality. Structures DCMM08 Use of temperature sensitive components or materials in construction or rehabilitation (e.g. FRP strengthening)	In Progress
Design and construction of new and replacement assets	Structures (including gantries)	Management and maintenance 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	**Do Minimum** Existing review procedures of design standards are adequate for a do minimum approach. Structures DCMM09 Bearings and expansion joints	N/A
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	**Monitor** The Specification for Highway Works already prescribes how certain construction activitie s (for example concreting) should be carried out in, for example, high or low temperatures. Climate change impacts will be monitored and updates to operating procedures and contingency plans produced when necessary. Structures DCMM10 Climatic constraints on construction activities	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** There is no obvious risk as a result of temperature changes that impact either the safety or serviceability of the network. A reduction in the use of de-icing salts will be beneficial and slow down rates of deterioration. Structures DCMM11 Optimum timing of maintenance interventions in response to changes in deterioration rates	N/A
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 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 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.	0.44	**Monitor**: Highways England have continued to use the Highways England Drainage Data Management System (HADDMS) to record flooding events and inform the prioritisation of drainage assets to be upgraded to cope with existing and future flooding Drainage MM08 Capacity of drainage system Drainage MM09 Increased flooding from adjacent land Drainage MM10 Flooding of third parties from HE drainage	On going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Erosion of existing earthworks is insignificant at present with only a few isolated examples. Any potential increase due to increased precipitation is likely to be limited and will be identified during the regular earthworks inspections linked to work being undertaken with respect to flooding hotspots on the network. Geotechnics MM05 Increased scour and erosion of earthworks	N/A
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	**Do Minimum** Slope stability is well understood. Existing regular inspections are sufficient. Geotechnics MM06 Stability of slopes, change in water levels/ pore pressure	N/A
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	This aspect is considered as part of drainage. Drainage MM08 Capacity of drainage system	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Do Minimum** Such locations are rare on the network. Each Managing Agent should assess the specific situation as part of their regular HADGMS inspection and risk assessment. It is very difficult to predict the effect of increased precipitation and, more importantly, identify the need for pro-active measures to address any perceived risk. Geotechnics MM07 Earthworks construction across existing landslip	N/A
Maintenance and management of existing assets	Signs and signals	Renewal and repair	Increase in mean temperature Increase in extreme temperature Increase in wind speed for worst gales		Minimal risks to the Highways England's signs during their design life.	0.1	**Development of Future Proof Designs** Technical Directive TD 25/01 has been replaced by a new standard TD25/15. Other MM11 Signs - renewal and repair	Complete
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.	0.2	**Do Minimum** Existing review process of design guidelines is sufficient and is reviewed every 5 years. Other MM12 Vehicle restraint systems - renewal	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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.	0.1	**Do Minimum** VRS does not cause incidents, it mitigates injuries. Actions to be taken in regards to other DMRB standards to prevent vehicles leaving the carriageway. Other MM13 Vehicle restraint systems – repair	N/A
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 and noise which will need to be mitigated against. (i.e. greater exposure to noise could result in more complaints and the risk for the need of greater number of environmental barriers to compensate for this increase.)	0.22	**Monitor** Monitor relevant guidance and research involving various species and habitat types as well as their management requirements. Other MM14 Soft estate - capital investment, landscape	On-going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 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. The same applies to cultural heritage and drainage issues.	0.22	**Monitor** Monitor relevant guidance and research involving various species and habitat types as well as their management requirements. Other MM15 Soft estate - capital investment, ecology	On-going
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	**Do Minimum** Any off road cycle paths or facilities are provided with filter drains. Other MM16 Off road	N/A
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, dependent on asset type will be between 15-50 years.	0.22	**Do Minimum** Highways England is aware of the need to adapt to climate change and suggests this will be considered in the future due to the short design life of technology. Other DCMM12 Technology	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	**Monitor** Monitor impact of changes in rain, snow and wind speeds. If required, update operating procedures. Traffic management MNO1 Traffic Officers	On-going

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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 Highways England's seven Regional Control Centres. There is a risk that lanes used for hard shoulder running (HSR) are more vulnerable to flooding effecting functionality of managed motorways. 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	**Do Minimum** Current regional control centre leases end in 2019/20, flooding and climate change impacts will be considered when looking to extend leases. Traffic management MNO2 Regional Control Centres	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
Managing network operation	Incident management	Breakdowns	Increase in mean temperature Increase in extreme temperature 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	**Monitor** Monitor impact of changes in rain, snow and wind speeds. This information will be used to assess if an increase in resources/equipment is required. Traffic management MNO3 Breakdowns	On-going
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	**Do Minimum** Highways England will continue to put road safety at the top of the agenda and set targets to reduce the number of people killed or seriously injured on the network. Traffic management MNO4 Road user incidents / accidents Traffic management MNO5 Third party incidents	N/A
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		

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
Managing network operation	Restricting network use	High winds	Increase in wind speed for worst gales		High winds will require us 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.	0.1	**Update Operating Procedures** The Severn Crossing already has a filtering process. Similar procedures are being considered for the Dartford crossing and other locations where required. Traffic management MNO6 High winds	On-going
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 network become flooded. There is a risk of Local Authority routes gridlock if parts of strategic network are closed – a reputational risk for Highways England if we are seen to be the “cause”. The majority of our roads are at a higher elevation than local roads which means that if SRN roads are flooded, it is likely that the adjacent local authority roads will also be flooded.	0.44	Adaptation considered by design, construction and maintenance vulnerabilities relating to drainage. Traffic management MNO7 Flooding	N/A
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. Highways England communicates 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	**Do Minimum** Continue to inform network users as appropriate. Traffic management MNO8 Motorised users	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
Managing network operation	Education	Non-motorised users	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	**Do Minimum** Continue to inform network users as appropriate. Traffic management MNO9 Non-motorised users	N/A
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	**Development of future proof designs** Review uniform and equipment used by traffic officers and workers on road. Update if required. Traffic management MN10 Worker safety	On-going
Managing network operation	Education	Highways England staff	Increase in extreme temperature Increase in extreme precipitation Increase in wind speed for worst gales	Flooding	The risk to Highways England is the ability of staff to conduct 'business critical' activities.	0.22	**Do Minimum** Contingency plans are in place. Traffic management MN11 Highways England staff	N/A
Defining and managing network strategy and planning	Development control	Development control			Risk that development on any given site could exacerbate local risks.	0.05	**Do Minimum** To be determined on a case by case basis through EIA and other processes.	N/A
Defining and managing network strategy and planning	Demand management	Demand forecasting			No significant risks identified	0.33	N/A	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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		Highways England 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	Not carried forward at this stage.	N/A
Defining and managing network strategy and planning	Land management	Soft estate	Increase in mean temperature Increase in extreme temperature Decrease in summer precipitation		Local variation of risks in the level and type of landscape and ecology strategies required.	0.22	Not carried forward at this stage.	N/A
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	N/A Adaptation considered by design, construction and maintenance vulnerabilities relating to drainage.	N/A
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 England's asset e.g. extreme precipitation could exceed drainage capacity from adjacent land and cause flooding impact to the network.	0.67	N/A Adaptation considered by design, construction and maintenance vulnerabilities relating to drainage.	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
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	Not carried forward at this stage.	N/A
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	Not carried forward at this stage.	N/A
Defining and managing network strategy and planning	Budgeting (spending reviews)	Budgeting (spending reviews)			No risks associated directly with spending reviews	0.67	N/A	N/A
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	N/A Adaptation considered in specific areas such as pavements or structures.	N/A
Internal business management	Facilities management	Facility energy	Increase in mean temperature	Reduction in icy days in winter	For Highways England's 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 8 offices, the National Traffic Information Service, 7 Regional Control Centres and 35 outstations.	0.11	Not carried forward at this stage.	N/A

Activity category	Area	Aspect	Primary climatic changes	Secondary impacts of climate change	Highways England risks resulting from identified climatic changes	Score	Adaptation action	Progress of action
Internal business management	Staff costs	Staff numbers			No significant risks identified to staff numbers as a consequence of climate change with Civil Service and Highways England business continuity in place.	0.67	N/A	N/A
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 England estate is at risk of flooding.	0.11	N/A Adaptation considered by design, construction and maintenance vulnerabilities relating to drainage.	N/A

Appendix 2

Risk Appraisal Matrices and Prioritisation Formulae

This appendix comprises the matrices and formulae required to calculate the scores for each vulnerability appraisal.

1. **Uncertainty** - 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 using the table below:

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

2. **Rate of Change** - The time horizon for climate change effects to become material is determined using predicted climate change trends. The asset life/activity time horizon sub-indicator reflects the duration of the consequences of decisions concerning the vulnerability.

		Asset life / activity time horizon	
		Short-term (< 30 years)	Longer-term (> 30 years)
Time horizon for climate change effects to become material	Short-term (up to 2020)	H	H
	Mid-to-longer term (between 2020 and 2080)	M	H
	Longer-term (beyond 2080)	L	M

3. **Extent of Disruption** - In determining the extent of disruption it is important to take account of the spatial variation of the relevant climatic event. A risk event associated with extreme temperatures for example may have localised events but these may well occur at several places on the network at the same time thereby increasing the extent of disruption.

Score	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

4. **Severity of Disruption** - For vulnerabilities that are sensitive to extreme events, such as flooding, 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 England's control.

	Criterion: Severity of Disruption
High	Disruption time > 1 week
Medium	Disruption time 1 day-1 week
Low	Disruption time <1 day

5. **Scoring Conversion** - The above High, Medium and Low scores must be converted into numerical scorres using the conversion table below, before moving onto the final table to calculate the final vulnerability scores.

H/M/L Score	Numerical Score
H	3
M	2
L	1

6. **Formulae to prioritise vulnerabilities** - The purpose of the prioritisation of vulnerabilities is to inform timescales for action and provide 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 here. There are several reasons why a vulnerability could be a priority for action. Thus, rather than developing a single league table of vulnerabilities, a series of tables that reflect different reasons for action are established.

Prioritisation criteria	Indicator score
Time-criticality	[Rate of climate change] divided by 3
High extent	[Extent of disruption] divided by 3
High disruption duration	[Severity of disruption] divided by 3
Potential research need (asset or activity)	[Uncertainty level - effects of climate change on asset/activity*] divided by 3
Highly disruptive, time-critical with high confidence	[Rate of climate change] x [Extent of disruption] x [Severity of disruption] x (4 - [Uncertainty]) divided by 81

* Use Section 2.2 of vulnerabilities appraisal form. This will provide a score of high, medium or low. Use the scoring conversion matrix to determine a score of 3, 2 or 1.

Appendix 3

Example of a Completed Risk Appraisal

Appendix 3 uses vulnerability DC01 'Design and construction of new and replacement assets' to demonstrate how the risk appraisal methodology was applied. The methodology process is summarised by figure 1; we will describe the considerations made for each of these stages to appraise DC01

Figure 1 Methodology Flow Diagram

1. Complete the vulnerability schedule

Step 1 Complete the vulnerability schedule

Follow Stage 3 of the Highways England Climate Change Adaptation Model to complete the vulnerability schedule, as shown in Table 1.

Table 1 Example vulnerability

Ref	Vulnerability activity category	Area	Aspect
DC01	Design and construction of new and replacement assets	Highway alignment	Improved drainage

2. Appraise the primary criteria

Step 2 Appraise the vulnerability against the primary criteria

The Vulnerabilities Assessment Form (VAF) and matrices (see Appendix 2) were used to appraise the primary criteria. The VAF provides a series of dropdown menus from which the most appropriate responses were selected. The primary criteria are;

- Uncertainty;
- Rate of change;
- Extent of disruption (network / users affected); and
- Severity of disruption.

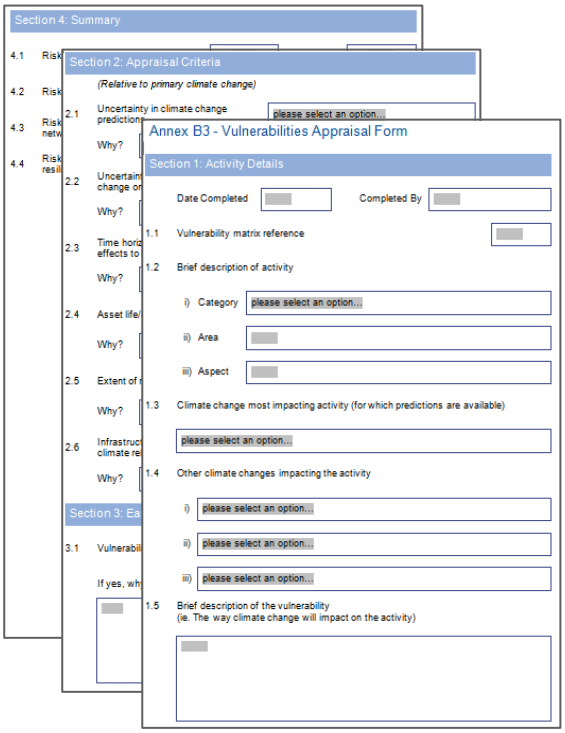


Figure 2 Vulnerability Appraisal Form

Firstly, a high level description of DC01 was entered into the VAF. The climatic changes that will impact DC01 were then selected.

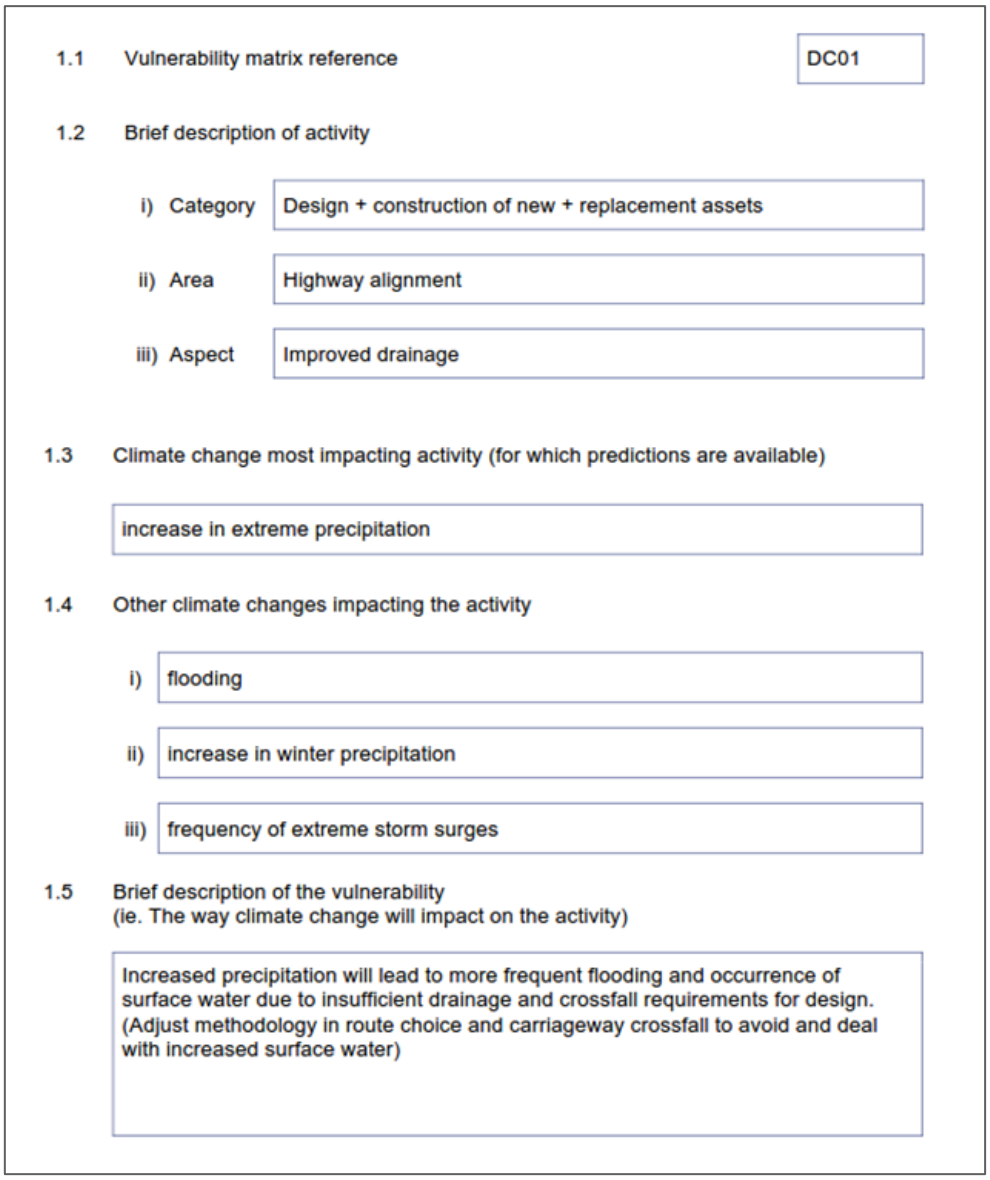


Figure 3 Vulnerability Description and Impacting Climate Changes

Uncertainty

The Highways England 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:

- The confidence of climate change predictions; and
- The climate change impact on the asset/activity.

Using the climate trends identified in Stage 2, the uncertainty matrix and expert opinion, it was determined that the uncertainty of effects of climate change on DC01 is **Low**. This qualitative score was entered in the tool.

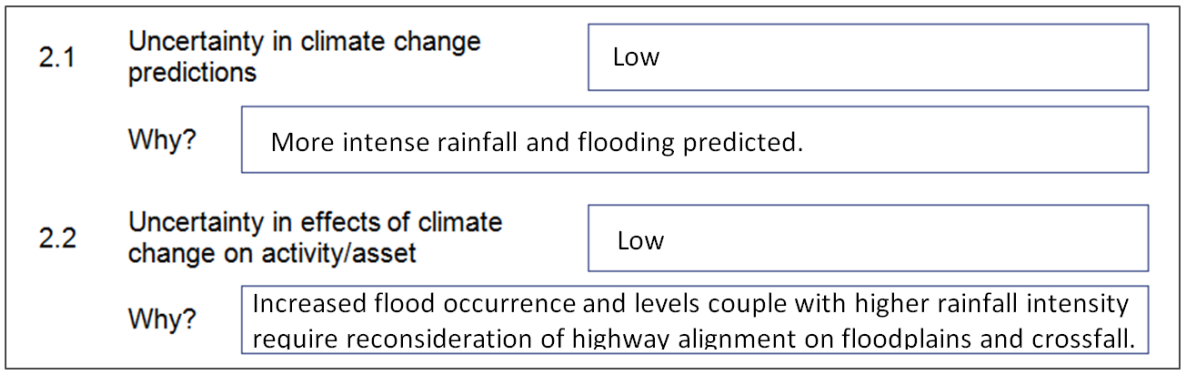


Figure 4 Uncertainty

Rate of climate change

The rate of change matrix was used to determine two qualitative scores for DC01. Within the rate of change matrix, there are two sub-indicators:

1. The time horizon for climate change effects to become material.

This is determined using predicted climate change trends and the likely timescale these trends are expected to impact on the vulnerability. That is, it reflects the likely time period within which something different needs to be done. For DC01 it was determined that the time horizon for climate change to become material was **short term**.

2. The asset life/activity time horizon.

This is assessed against two broad categories; Short-term (defined as less than 30 years) and Longer-term (defined as greater than 30 years). It reflects the duration of the consequences of decisions concerning the vulnerability. For example, decisions about the design criteria for new 'structures' typically have consequences that remain throughout the design life of the asset, 120 years, and would be assessed as longer-term. For DC01, the asset life/activity time horizon was determined as **longer term**. The qualitative scores were entered in the tool.

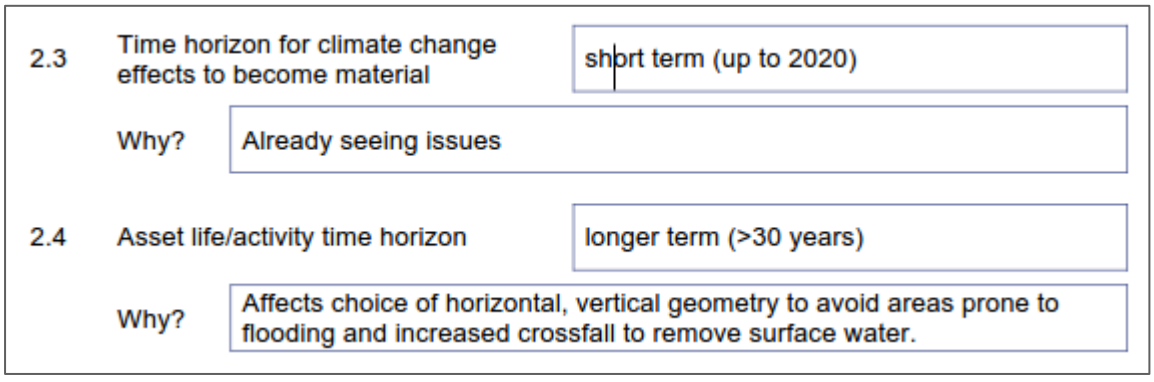


Figure 5 Rate of Climate Change

Extent of disruption

Next the extent of disruption matrix was used to determine a score for DC01. When determining the extent of disruption it is important to take account of the spatial variation of the relevant climatic hazard. Some vulnerabilities may be sensitive to relatively localised hazards such as extreme rainfall.

Alternatively, the vulnerability may be highly correlated over a large area, as may be the case for extreme temperatures. Therefore, 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.

For DC01, it was determined that <20% of network/users are likely to be affected by flooding. The qualitative score was entered into the VAF.

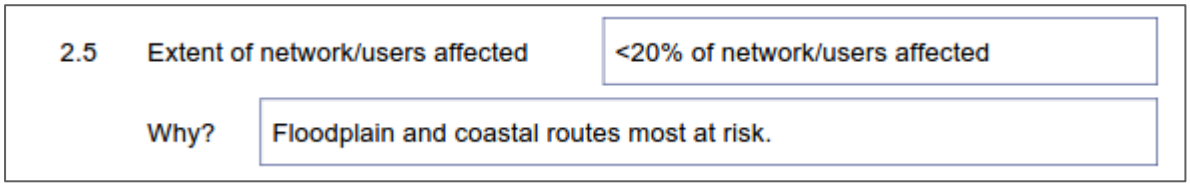


Figure 6 Extent of disruption

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 England 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.

Using the severity of disruption matrix, DC01 was assessed to take between 1 day and 1 week for any disruption to be removed from the network. The qualitative score was entered into the VAF.

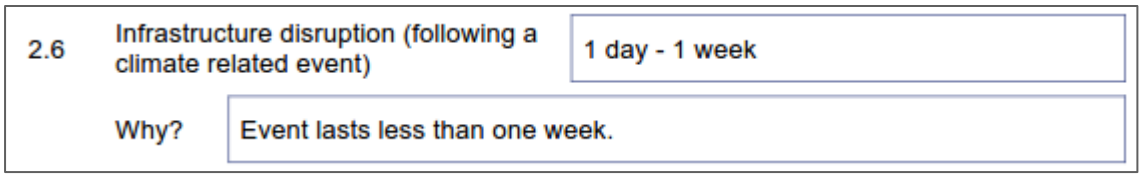


Figure 7 Severity of Disruption

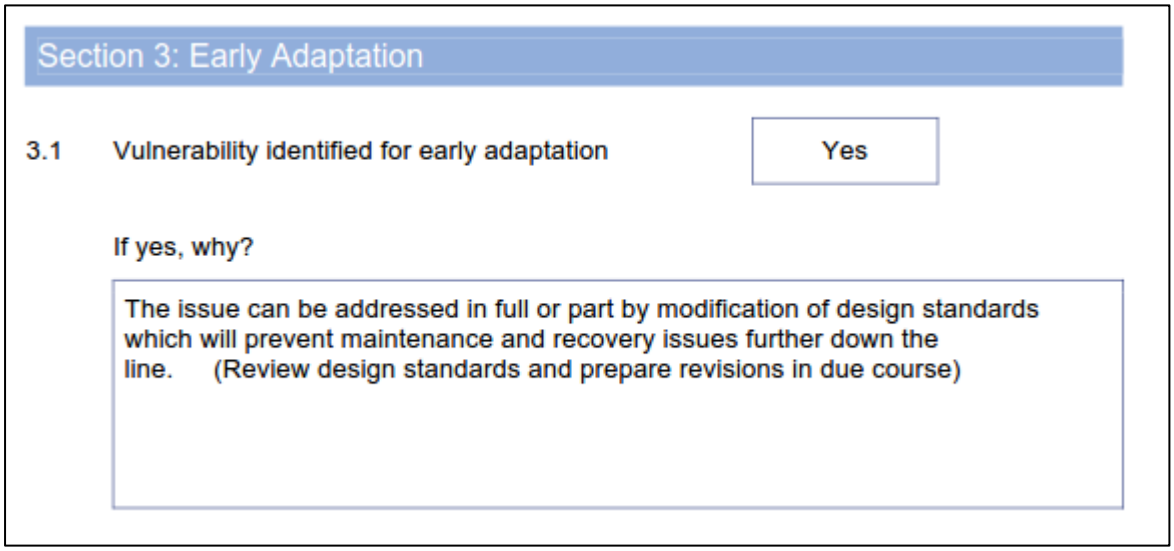
Early adaptation

Even if a vulnerability receives a low risk-ranking based on the vulnerability scoring, it may still be sensible to undertake early adaptation. Vulnerabilities are flagged as early adaptation advisable if any of the following criteria are met:

1) long lead-time needed to plan adaptation (e.g. to enable research or required changes to policy/standards to be introduced);
2) significant planning/smoothing will 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,

3) adaptation is concerned with a long-life, expensive asset where it is suspected that there will be clear benefit derived from future-proofing new designs now (e.g. because marginal cost implications to future-proof now, but very expensive to address retrospectively).

It was determined that it was advisable for DC01 to be flagged as 'early adaptation advisable', and this was recorded in the VAF.



Section 3: Early Adaptation

3.1	Vulnerability identified for early adaptation	Yes

If yes, why?

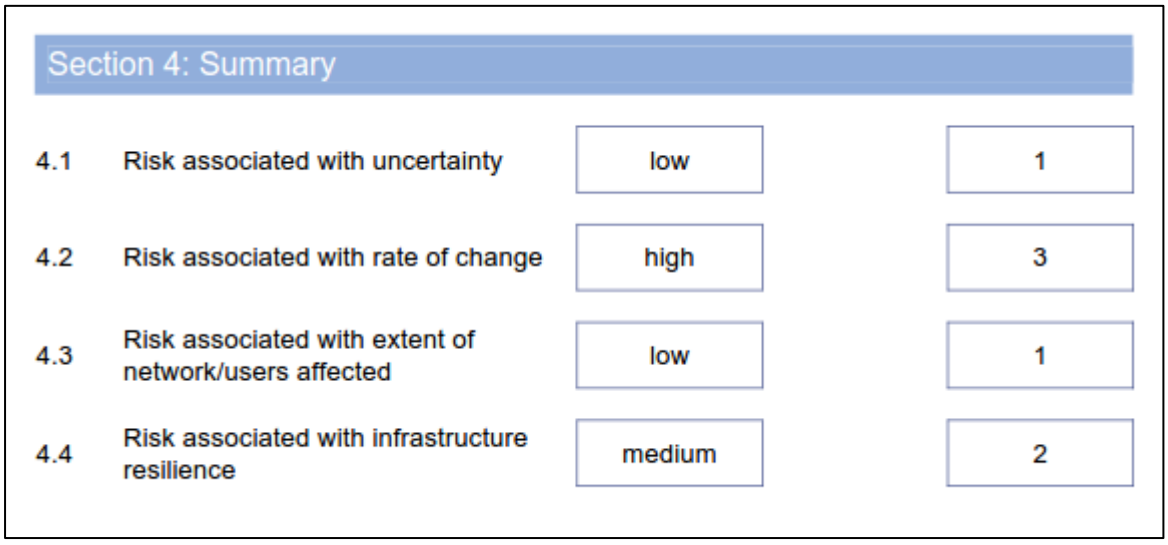
The issue can be addressed in full or part by modification of design standards which will prevent maintenance and recovery issues further down the line. (Review design standards and prepare revisions in due course)

Figure 8 Early Adaption Identification

3. Convert the scores

Step 3 Convert the scores

The VAF automatically converts the qualitative risk appraisal scores into numerical scores using the scoring conversion matrix (see Appendix 2). For vulnerability DC01, the scores are as follows.



Section 4: Summary

4.1	Risk associated with uncertainty	low	1
4.2	Risk associated with rate of change	high	3
4.3	Risk associated with extent of network/users affected	low	1
4.4	Risk associated with infrastructure resilience	medium	2

Figure 9 Scoring Conversion

4. Prioritise vulnerabilities

Step 4 Prioritise the vulnerabilities

The purpose of the prioritisation of vulnerabilities is to inform timescales for action and provide priority areas in devising adaptation strategies. There are several reasons why a vulnerability could be a priority for action. Five league tables, therefore, have been developed to reflect the different reasons for prioritising action.

To generate the league tables, a set of formulae is applied to each of the prioritisation criteria's numerical scores as produced in the VAF. This provides a new set of scores known as 'indicator scores', and each has a value between 0 and 1. The calculations for DC01 are illustrated below:

Table 2 Formulae for Vulnerability Prioritisation

Prioritisation criteria	Indicator score formulae	Indicator score formulae for DC01	Indicator score for DC01
Time-criticality	[Rate of climate change] divided by 3	3 divided by 3	1
High extent	[Extent of disruption] divided by 3	1 divided by 3	0.33
High disruption duration	[Severity of disruption] divided by 3	2 divided by 3	0.67
Potential research	[Uncertainty level of the effects of climate change on asset/activity*] divided by 3	1 divided by 3	0.33
Highly disruptive, time-critical with high confidence	[Rate of climate change] x [Extent of disruption] x [Severity of disruption] x (4 – [Uncertainty]) divided by 81	3 x 1 x 2 x(4-1) / 81	0.22

* Use Section 2.2 of vulnerabilities appraisal form. This will provide a score of high, medium or low. Use the scoring conversion matrix to determine a score of 3, 2 or 1.

5. Rank the risks

Step 5 Rank the risks

When the indicator scores have been calculated, they are placed into five league tables; one for each of the prioritisation criteria. Any vulnerability that is identified as 'early adaptation action advisable' is highlighted within the league tables.

Below is an excerpt from the time-critical league table. DC01 had an indicator score of 1.00 and was also highlighted as early adaptation advisable.

B4-1: Time-critical — Early adaption action advisable

Ref	Category	Area	Aspect	Score
BM01	Internal business management	Facilities management	facility energy	1.00
BM02	Internal business management	Staff Costs	Staff numbers	1.00
BM03	Defining + managing network strategy + planning	Property management	Property management	1.00
DC01	Design + construction of new + replacement assets	Highway alignment	Improved drainage	1.00
DC05	Design + construction of new + replacement assets	Structures (including gantries)	Thermal actions (loads) applied to superstructure	1.00
DC06	Design + construction of new + replacement assets	Structures (including gantries)	Wind actions (loads) applied to superstructure	1.00
DC09	Design + construction of new + replacement assets	Structures (including gantries)	Foundation settlement affected by change in groundwater level	1.00

6. Next step - Options analysis

Step 6 Next steps – Options analysis

The vulnerabilities identified as priorities for action are taken forward into Stage 5 of the Highways England Adaptation Strategy Model – Options analysis.