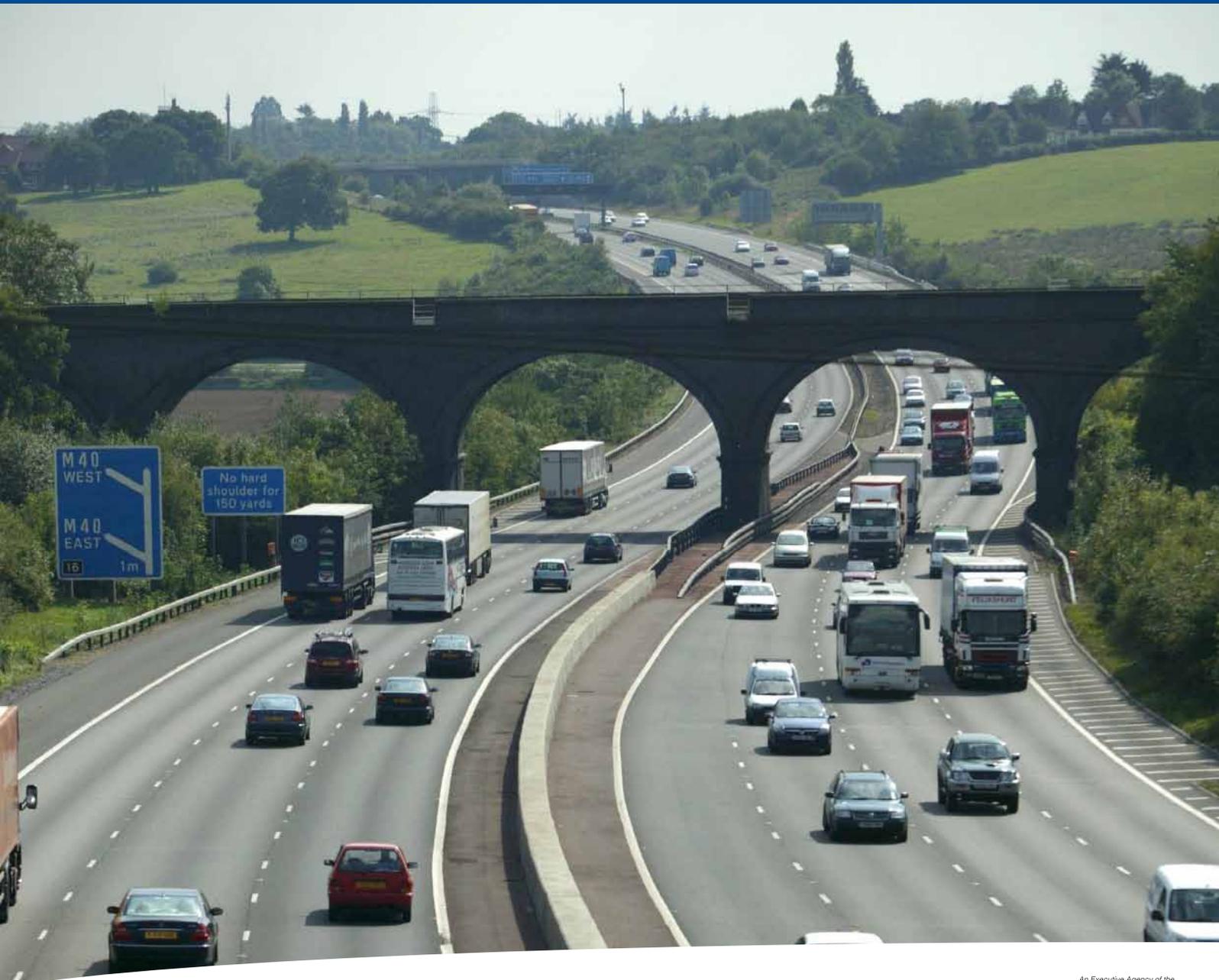


# Climate Change Adaptation Strategy and Framework



Climate Change Adaptation Strategy and Framework  
Revision B - issued November 2009

For more information:

Visit the Highways Agency website  
<http://www.highways.gov.uk/aboutus/24172.aspx>

Contact the Highways Agency Information Line  
(HAIL) on 08457 50 40 30

# Climate Change Adaptation Strategy: September 2009

## Highways Agency responsibilities:

The Highways Agency is responsible for the operation, maintenance, and improvement of England's strategic road network, which provides a vital service to industry, communities, and individuals. It is a key component of the country's overall transportation infrastructure, linking with local roads and other transportation modes, carrying a third of all traffic in England, and two thirds of all heavy freight traffic. As a result we must ensure that the network continues to function in the face of a changing climate.

## Highways Agency Action:

The Highways Agency's response to the challenge of climate change must involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (changing behaviour so that it is more appropriate to the expected future climate). This strategy is focused on adapting to climate change; we are developing a separate carbon management strategy and recognise these two areas are highly interdependent.

## Highways Agency Commitment:

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

## Desired outcomes:

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

## Key Drivers:

Global scientific consensus is that the world's climate is changing. Stern (2007)<sup>1</sup> highlights climate change as a serious and urgent issue and the need for action is widely acknowledged. Scientific evidence<sup>2</sup> indicates that the rapidly changing climate is predominantly a result of increases in greenhouse gases caused by human activities.

In recognition of this, Parliament passed the Climate Change Act<sup>3</sup> in November 2008, which amongst other things, places a requirement on Government to report at least every five years on the risks to the UK of climate change, and to publish a programme setting out how these impacts will be addressed. The Act also introduces powers for Government to require public bodies and statutory undertakers to carry out their own risk assessments and make plans to address those risks.

As an Executive Agency of a Government Department, the Highways Agency is not legally required to report. However, in recognition of the importance of the Highways Agency's infrastructure and the risks of climate change to our operations, we have volunteered to report to the Secretary of State for the Environment, Food and Rural Affairs, to provide public assurance of our progress on adaptation.

1 [http://www.hm-treasury.gov.uk/sternreview\\_index.htm](http://www.hm-treasury.gov.uk/sternreview_index.htm)

2 <http://www.ipcc.ch>

3 <http://www.defra.gov.uk/environment/climatechange/uk/legislation/index.htm>

### Predicted climate changes:

The key findings from the UK Climate Projections 09 (UKCP09)<sup>4</sup> are:

- All areas of the UK get warmer, and the warming is greater in summer than in winter
- There is little change in the amount of precipitation (rain, hail, snow etc) that falls annually, but it is likely that more of it will fall in the winter, with drier summers, for much of the UK
- Sea levels rise, and are greater in the south of the UK than the North

### Climate Change Challenges:

Many of the Highways Agency's activities are either directly affected or influenced by the climate. The Highways Agency needs to ensure it can continue to provide a robust strategic road network in a changing climate.

Decisions have to be taken in the face of a range of uncertainties. These exist in climate change predictions, for example as a result of the uncertainty in climate models and in future greenhouse gas emissions. There is also uncertainty in the way that changes in climate will affect the activities of the Agency, the performance of its assets and the expectations and behaviours of customers and stakeholders. This uncertainty should not inhibit decision-making, but does need to be understood and taken into account.

The UKCP09 adoption of probability analysis within the climate change predictions however, greatly assists risk consideration and decision-making.

### Climate Change Risks:

Table S1 provides examples of some of the high level climate change related risks that could impact upon the Highways Agency, and their associated consequences. The application of the HA Climate Change Adaptation Framework will allow us to identify specific risks, and determine the most appropriate management options.

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

Table S1 – Climate Related Risk

4 <http://ukcp09.defra.gov.uk>

### Business as usual:

The challenges of adapting to a changing climate cannot be considered in isolation. Climate change needs to be a routine consideration, factored into the Highways Agency's day to day decision making processes rather than a discrete risk to be managed independently. Although, many Highways Agency activities are affected by climate, few decisions can be made taking only climate considerations into account.

### Highways Agency Adaptation Framework:

The Highways Agency 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.

In order to facilitate this we have developed a climate change adaptation framework, which provides a consistent approach to assessing and understanding the risks posed to the strategic road network.

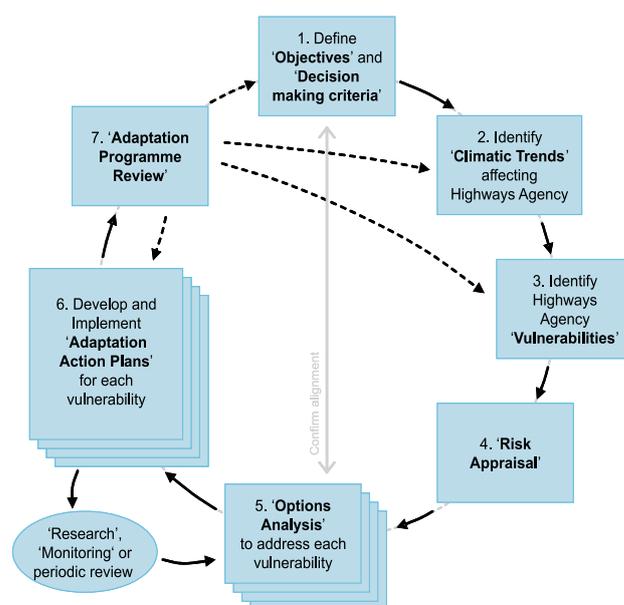
The development of the adaptation framework has built upon detailed review of work by the Highways Agency, and organisations, including UKCIP (UK Climate Change Impacts Programme), IPCC (InterGovernmental Panel on Climate Change), and the Stern review. It has been guided by consultation with a stakeholder group comprising members from the Highways Agency, DEFRA, Met Office, and other government departments and interested groups.

### Function of the framework:

The purpose of the adaptation framework is to enable the Highways Agency to systematically develop and implement its responses to the challenges of climate change in support of the delivery of its corporate objectives.

The adaptation framework provides a platform for decision makers to examine their individual business areas, including standards, specifications, maintenance, and the development and operation of the Highways Agency network. It provides the process to identify the activities which will be affected by a changing climate, determine associated risks (and opportunities), and identify preferred options to address and manage them.

### Highways Agency Adaptation Framework Model:



The Highways Agency's Adaptation Framework Model (HAAF) 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.

### **Vulnerability Identification:**

Over eighty Highways Agency activities, or vulnerabilities, have initially been identified which may be affected by climate change. A preliminary appraisal of the risks associated with these vulnerabilities has been undertaken which found that over 60% of them are expected to be materially affected by current predicted levels of climate change within their relevant asset life or activity time horizon. The risk appraisal has also enabled vulnerabilities to be prioritised for attention, based upon several criteria including their potential to disrupt the operation of the strategic road network.

The prioritisation provides a basis for establishing a forward programme of work to develop and implement adaptation action plans. Key areas for attention include internal business management processes, network resilience, investment appraisal, and various specific aspects of the design and maintenance of road pavement, structures and drainage.

Specific recommendations for implementation include the initiation of a “quick-wins” programme leading to the early application of adaptation actions where these are straightforward, low-cost and their benefits are clear, such as amending design standards for long-life assets to address predicted climatic changes.

### **Strategy Ownership:**

The Senior Responsible Owner for the strategy is David Gingell, Director of the Network Planning and Performance Division in Network Services. The Board champion is Ginny Clarke, Board Director of Network Services.

Implementation of the strategy and technical assistance will be provided by the Sustainable Development and Climate Change team in Network Services.

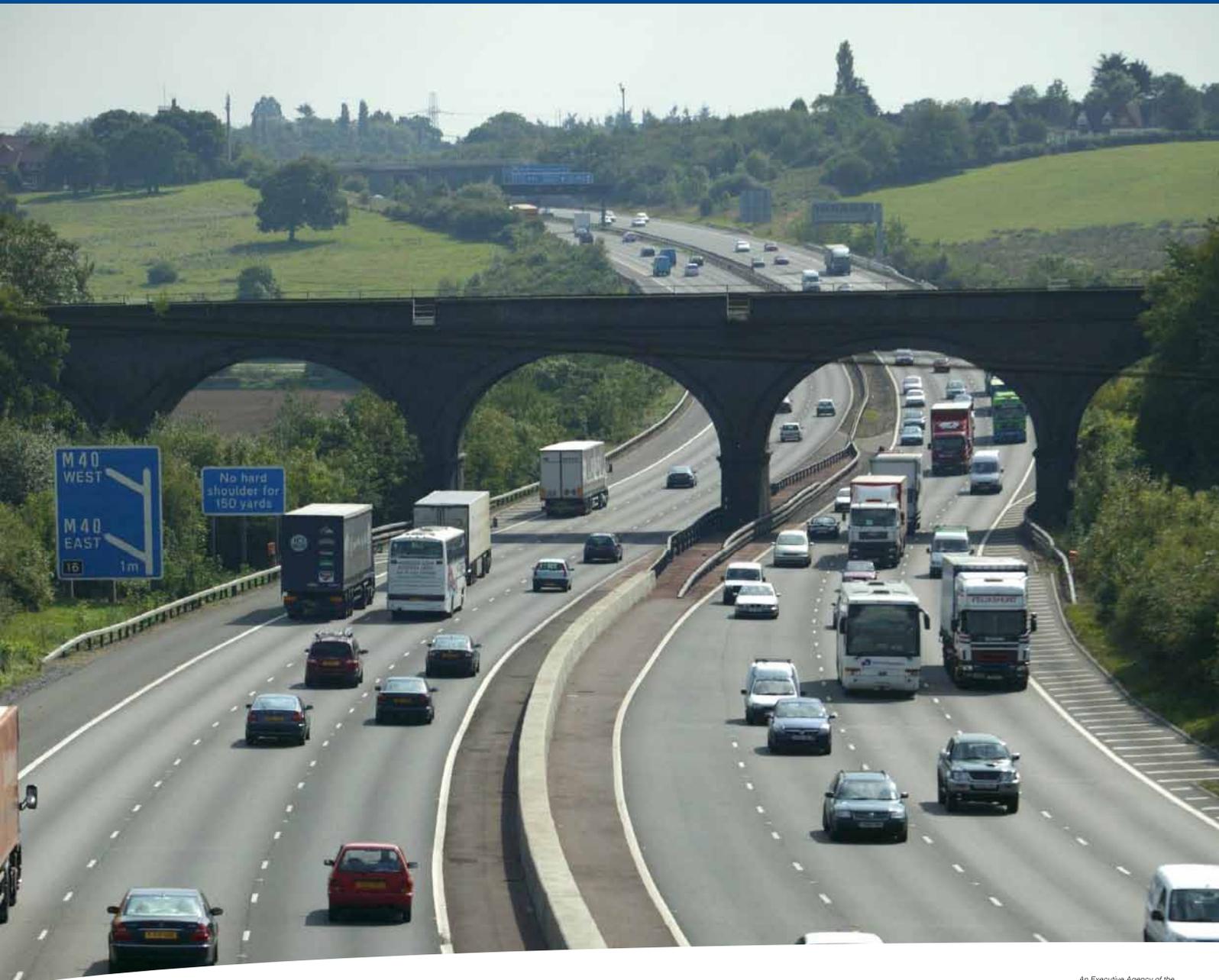
Email: [sustainability@highways.gsi.gov.uk](mailto:sustainability@highways.gsi.gov.uk)

Adaptation on the Highways Agency website: [Highways Agency - Climate Change Adaptation](#)

Climate Change & energy on the Defra website: [Defra, UK - Environmental Protection - Climate change and energy](#)

# Climate Change Adaptation Framework

## Volume 1



This document has been prepared for the Highways Agency by a team led by Parsons Brinckerhoff drawn from the following organisations:



## Executive summary

Global scientific consensus is that the world's climate is changing. Stern (2007) highlights climate change as a serious and urgent issue and the need for action is widely acknowledged. Scientific evidence indicates that the rapidly changing climate is predominantly a result of increases in greenhouse gases caused by human activities.

The Highways Agency's response to the challenge of climate change must involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (changing behaviour so that it is more appropriate to the expected future climate).

Many of the Highways Agency's activities are either directly affected or influenced by climate. The Highways Agency needs to ensure that it can continue to provide an effective strategic road network in the context of a changing climate.

This need has been recognised in the Highways Agency's first Sustainable Development Action Plan (2007), and has led to the development of this Climate Change Adaptation Strategy and associated Framework. This Framework provides a systematic process to identify activities that will be affected by a changing climate, determine associated risks, and identify preferred options to address and manage them.

In support of the adaptation Framework, the Highways Agency Adaptation Framework Model (HAAFAM) has been developed. It has been designed specifically to meet the needs of the Highways Agency and to address key aims of the adaptation provisions of the Climate Change Bill.

The HAAFAM:

- is aligned with the Highways Agency's corporate objectives;
- focuses on the activities of the Highways Agency, and how they need to adapt;
- identifies priorities for action;
- integrates, where possible, with current Highways Agency processes;
- establishes clear responsibilities;
- facilitates strategic oversight of progress and the management of residual risk; and,
- offers flexibility to accommodate changing demands and developments in climate science.

Although the HAAFAM has been the primary focus, work has extended beyond its development. Several of

its stages have been applied and are reported in this document. Furthermore, Volume 2 contains templates, tools and further supporting data. The objective of the HAAFAM has been defined and associated decision making criteria established. Climate change trends data has been gathered and summarised.

Over eighty Highways Agency activities, or vulnerabilities, have been identified that may be affected by climate change. A preliminary appraisal of the risks associated with these vulnerabilities has been undertaken which found that over 60% of them are expected to be materially affected by current predicted levels of climate change within the relevant asset life or activity time horizon. The risk appraisal has also enabled vulnerabilities to be prioritised for attention, based upon several criteria including their potential to disrupt the operation of the Highways Agency network.

The prioritisation provides a basis for establishing a forward programme of work to develop and implement adaptation action plans. Key areas for attention include internal business management processes, network resilience, investment appraisal, and various specific aspects of the design and maintenance of road pavement, structures and drainage.



## Contents

### Executive summary

### Terminology and abbreviations

## 1 Introduction

1.1 Background.....	1
1.2 The challenge of a changing climate.....	1
1.3 Purpose .....	2
1.4 Development approach.....	2
1.5 How to use this document.....	3

## 2 Overview of Highways Agency Adaptation Framework Model

2.1 Introduction.....	4
2.2 The seven stages of the HAAFMM.....	5
2.3 Stages of HAAFMM undertaken to date .....	8

## 3 Climate change trends

3.1 Observed and projected climate change .....	9
3.2 Primary climatic variables and secondary climatic impacts.....	9
3.3 Climate predictions .....	10
3.4 Climate analogues.....	10

## 4 Risks to the Highways Agency from climate change

4.1 Identification of vulnerabilities.....	11
4.2 Completion of the vulnerability schedule .....	12
4.3 Risk appraisal .....	12
4.4 Scoring approach .....	13
4.5 Prioritisation of vulnerabilities.....	15
4.6 Early adaptation.....	15
4.7 Results of risk appraisal .....	15

## 5 Options analysis and the development of adaptation action plans

5.1 Options Analysis Process .....	20
5.2 Detailed vulnerability definition .....	21
5.3 Options assessment .....	21
5.4 Development and implementation of adaptation action plans .....	28



## **6 Delivery of the adaptation programme**

<b>6.1 Programme management .....</b>	<b>29</b>
<b>6.2 Roles and responsibilities .....</b>	<b>29</b>

## **7 References**

### **Annexes**

<b>A1 Projected climate change in UK</b>	
<b>A2 Background to climate change predictions</b>	
<b>A3 Overview of UKCIP08 climate predictions</b>	
<b>B1 Vulnerability schedule</b>	
<b>B2 Guidance on risk appraisal</b>	
<b>B3 Risk appraisal templates</b>	
<b>B4 Vulnerability rankings</b>	
<b>B5 Detailed risk appraisal results</b>	
<b>C1 Detailed vulnerability definition template</b>	
<b>C2 Options assessment templates</b>	
<b>C3 Adaptation action plan template</b>	



## Terminology and abbreviations

### Terminology

Adaptation costs	Adaptation costs are the direct and indirect financial costs associated with the implementation of an adaptation option.
Consequence costs	Consequence costs are the direct and indirect financial costs associated with residual risks and actions necessary after an adaptation option has been implemented.
Climate	Climate in a narrow sense is defined as the average weather, or more rigorously, as its statistical description in terms of the mean and variability of surface variables such as temperature, precipitation and wind over a period of time. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2007).
Climate analogue	A climate analogue refers to a current climate in one location that is similar to the projected future climate in another location.
Climate change	Climate change is a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural processes or to persistent human induced changes in the composition of the atmosphere or in land use.
Hazard	A hazard is defined as something with the potential to cause risk events and therefore adverse consequences. In this Framework it refers to climatic changes that could cause events, incidents or impacts that threaten the ability of the Highways Agency to meet its corporate objectives.
Highways Agency Adaptation Framework Model	The Highways Agency Adaptation Framework Model (HAAFAM) is a systematic process to identify the activities of the Highways Agency that will be affected by a changing climate; determine associated risks and opportunities; and to identify preferred options to systematically address them.
Receptor	Receptor refers to the receiving body that may be affected by climatic events e.g. assets, structures, buildings and humans.
Risk	A risk is an event that is a possible but not certain outcome of a particular circumstance and is unwanted or has unwanted consequences. Risk is typically measured as a suitable combination (often the product) of a measure of likelihood and a measure of consequence.
Vulnerability	Vulnerability is defined as a Highways Agency activity that could be affected by climate change e.g. defining design specifications or maintaining assets.
Weather	Weather refers to the conditions in the atmosphere and the air around us at a particular moment, including temperature, rain, sun, snow, fog, clouds and wind.

### Abbreviations

CO <sub>2</sub>	Carbon dioxide
CSR	Comprehensive spending review
DfT	Department for Transport
IPCC	Intergovernmental Panel on Climate Change
HAAFAM	Highways Agency Adaptation Framework Model
PAR	Project appraisal report
UKCIP	UK Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change



# 1 Introduction

This Chapter provides an introduction to the Highways Agency's Climate Change Adaptation Framework. It explains the background to its development and its purpose. In support of this Framework, the Highways Agency's Adaptation Framework Model is introduced, which provides a framework for systematically managing the impacts of climate change.

## 1.1 Background

The Highways Agency is an executive agency of the Department for Transport (DfT) and is responsible for operating, maintaining and improving the strategic road network in England on behalf of the Secretary of State for Transport.

The Highways Agency's network includes over 7500 km of roads ranging from motorways carrying up to 200,000 vehicles per day to single carriageway trunk roads carrying fewer than 10,000 vehicles per day.

The network provides a vital service to commerce, industry, communities and individuals. It is a key component of the country's overall transportation infrastructure, linking with local roads and other transportation modes, and carries a third of all road traffic in England and two thirds of all heavy freight traffic.

The network is valued at over £87 billion. It incorporates an extensive asset base including bridges, earthworks, tunnels, and the technology that supports the network's effective operation.

## 1.2 The challenge of a changing climate

Global scientific consensus is that the world's climate is changing. In their Fourth Assessment Report (2007a) the Intergovernmental Panel on Climate Change (IPCC) state:

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and sea temperatures, widespread melting of snow and ice, and rising global average sea level".

Stern (2007) highlights that, "climate change is a serious and urgent issue". The need for action is widely acknowledged. Scientific evidence indicates that the rapidly changing climate is predominantly a result of increases in greenhouse gases caused by human activities. Achieving reductions in emissions will play a key role in mitigating the scale of climate change in the future. However, as Stern explains:

"Adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed".

The Highways Agency's response to the challenge of climate change must therefore involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (changing behaviour so that it is more appropriate to the expected future climate).

Many of the Highways Agency's activities are either directly affected or influenced by climate. The Highways Agency needs to ensure that it can continue to provide an effective strategic road network in the context of a changing climate. This need has been recognised in the Highways Agency's first Sustainable Development Action Plan (2007), which identified the requirement to develop a Climate Change Adaptation Strategy and associated Framework.

Climatic changes represent a hazard to the Highways Agency. They represent a challenge to one of the basic tenets on which many of the Highways Agency's activities are founded, that historic climate records provide a good indication of future climate. The risks which flow from this hazard present a complex challenge, affected by uncertainty, the nature of climatic events, and the need to integrate adaptation actions with the Highways Agency's wider operations.

Uncertainty stems from a number of sources. It exists in climate change predictions, for example as a result of the uncertainty in climate models and in future greenhouse gas emissions. There is also uncertainty in the way that changes in climate will affect the activities of the Highways Agency, the performance of its assets and the expectations and behaviours of customers and stakeholders. This uncertainty should not inhibit decision making, but does need to be understood and taken into account.

The nature of climatic events adds further to the complexity of decision-making. In devising adaptation strategies for vulnerabilities that are affected by extreme weather events, it is important to recognise

that extreme events have always occurred, albeit infrequently, and will continue to do so in the future. Our weather is a complex system subject to continuous fluctuations. As such, adaptation strategies cannot wholly eliminate the risk arising from extreme weather conditions, but can aim to bring risks in line with acceptable levels. To achieve this, it will be necessary to account for trends in the probability of extreme events.

The challenges of adapting to a changing climate cannot be considered in isolation. Climate change needs to be a routine consideration, factored into the Highways Agency's day-to-day decision making processes rather than a discrete risk to be managed independently. Although, many Highways Agency activities are affected by climate, few decisions can be made taking only climate considerations into account.

For example, an important task for the Highways Agency is determining the optimum strategies for maintaining its assets. Possible effects of climate change will be an increase in the demands placed on existing assets, such as their ability to perform under higher temperature and greater rainfall intensity, and also an increase in their rate of deterioration. Climate change may therefore affect the optimum maintenance strategy, as illustrated in Figure 1.1, but the optimum strategy will still depend on many other factors.

### 1.3 Purpose

The purpose of the Adaptation Framework is to enable the Highways Agency to systematically develop and implement its responses to the challenges of climate change in support of the delivery of its corporate objectives.

The Adaptation Framework provides a platform for decision makers to examine their individual business areas, including standards, specifications, maintenance, and the development and operation of the Highway Agency network. It provides a systematic process to identify the activities that will be affected by a changing climate, determine associated risks (and opportunities), and identify preferred options to address and manage them.

To serve this purpose, the Highways Agency Adaptation Framework Model (HAAFMM) has been developed. The HAAFMM is described in Chapter 2. It has been designed specifically to meet the needs of the Highways Agency and to address key aims of the adaptation provisions of the Climate Change Act. Its

development has been underpinned by the following requirements.

- The HAAFMM is aligned with the Highways Agency's responsibilities and corporate objectives.
- It focuses on the activities of the Highways Agency, and how they need to change in response to a changing climate.
- It identifies priority areas for action.
- It integrates, where possible, with the ways in which the Highways Agency fulfils its current responsibilities.
- It establishes clear responsibilities for developing and implementing adaptation actions in specific areas of activity, and also facilitates strategic oversight of progress and residual risk.
- It offers flexibility to enable the adaptation process to evolve to accommodate changing demands placed on the Highways Agency, developments in climate science and the results of research and/or monitoring.

The HAAFMM comprises seven stages. Importantly, it also recognises that cyclical and tiered management processes are necessary to manage the risks of climate change most effectively. Furthermore, as described in Chapter 6, the HAAFMM introduces one new key role holder in the Highways Agency, the Climate Change Adaptation Programme Manager.

### 1.4 Development approach

The development of the Adaptation Framework has built upon a detailed review of previous work by the Highways Agency and organisations including UKCIP, IPCC, and the Stern Review (2007). It has been guided by consultation with a stakeholder group comprising members from the Highways Agency, other government departments and interested groups.

The Framework has been developed in close collaboration with the Highways Agency by a consortium of companies led by Parsons Brinckerhoff and including Gifford, Met Office, Risk Solutions and WSP. The Contract for its development was let to the PB-WSP joint venture under the Highways Agency's National Framework for Research and Development.

Whilst the HAAFMM has been a focus for the development of this Adaptation Framework, work has extended beyond establishing the overall management processes set out in the HAAFMM. Several stages of the model have been applied and are reported in this

document. In Volume 2 there are templates, tools and further supporting data.

## 1.5 How to use this document

The Adaptation Framework is presented in three volumes.

- **Volume One** introduces the challenges of managing the risks associated with climate change. It describes the HAAFM and key results from the application of its early stages. It defines responsibilities and describes processes, and makes recommendations for priority adaptation areas. Decision makers and those who will have responsibilities for implementing parts of the HAAFM should be knowledgeable of its content. As a minimum, decision makers should have a clear understanding of Chapter 2. Those with responsibilities for implementing parts of the HAAFM will require a more detailed understanding.
- **Volume Two** is presented in a series of annexes. These annexes provide supporting information for the application of the HAAFM, including more detailed descriptions of the methodologies to be

employed and associated tools. It also contains results from the application of early stages of the HAAFM. These resources are provided to assist those with responsibilities for implementing parts of the HAAFM.

- **Volume Three** will be published later and addresses geographical risk. It presents data on locations along the Highways Agency's network where weather-related incidents have occurred, in particular, those related to flooding and high-winds. It provides data to assist those responsible for undertaking options analysis and developing adaptation action plans for associated vulnerabilities.

Roles and responsibilities are described in the relevant section of this document and are summarised in Chapter 6. For clarity key responsibilities for each stage of the HAAFM are presented in tables that have been shaded in green and are contained in Section 2.2. Chapter 6 contains an overall summary table that also highlights the parts of the Framework that role-holders need to be familiar with.

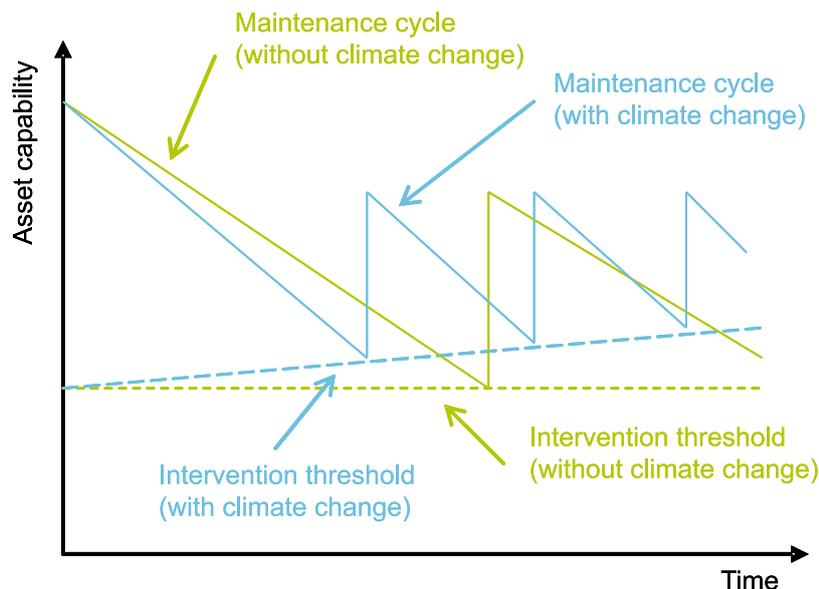


Figure 1.1: Representation of influence of climate change on maintenance cycles

## 2 Overview of Highways Agency Adaptation Framework Model

This Chapter provides an overview of the Highways Agency’s Adaptation Framework Model (HAAFM). Each of the seven stages of the model is described and specific responsibilities for their implementation are summarised. Greater detail on the application of these stages is contained in later chapters of this document.

### 2.1 Introduction

The Highways Agency Adaptation Framework Model (HAAFM) is illustrated in Figure 2.1. It has been developed building upon published literature, previous work by the Highways Agency and an analysis of the Highways Agency’s specific needs.

The HAAFM provides a systematic process to:

- identify the activities of the Highways Agency that will be affected by a changing climate;

- determine associated risks and opportunities; and
- identify preferred options to systematically address them.

Preferred options will be implemented through adaptation action plans, designed to embed changes within Highways Agency Standards, Specifications and other operating procedures. Together, these action plans will form an overall adaptation programme to safeguard the provision of an effective strategic road network in a changing climate.

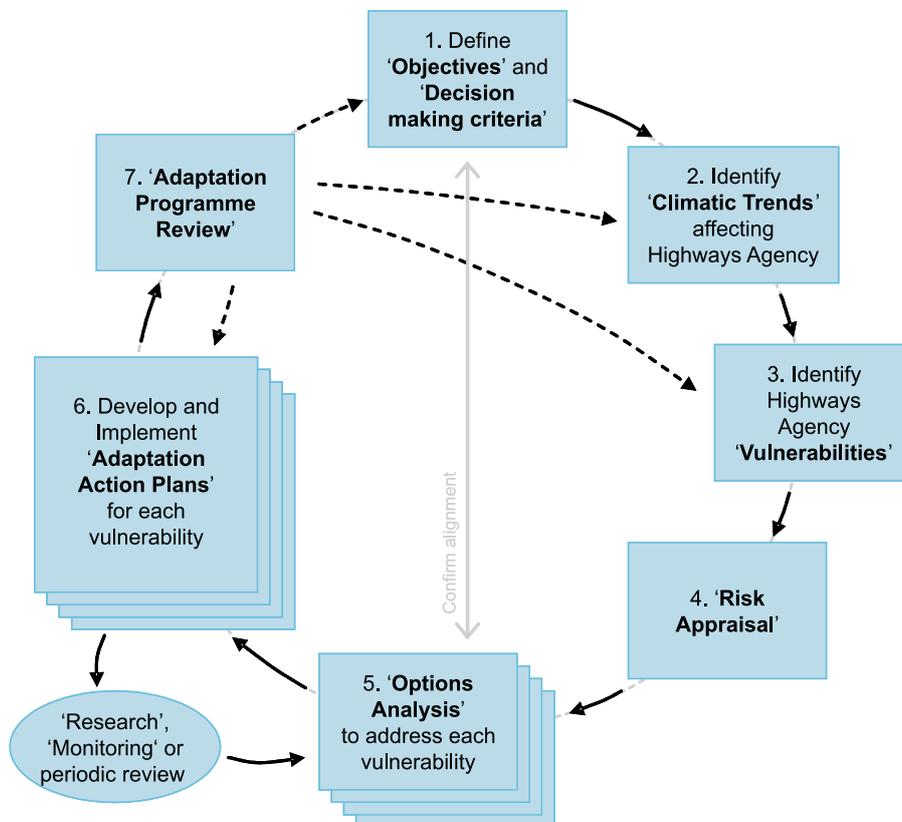


Figure 2.1: Highways Agency Adaptation Framework Model

The HAAFM has been developed to offer flexibility to enable the adaptation process to evolve to accommodate changing demands placed on the Highways Agency, for example as a result of modifications to its corporate objectives, DfT requirements, customer needs and expectations, and scientific advances.

An overview of the seven stages of the HAAFM is given in Section 2.2, with greater detail contained in later chapters. Several of the early stages of the HAAFM have already been implemented. Progress to date is described in Section 2.3.

## 2.2 The seven stages of the HAAFM

### Stage 1: Define Objectives and Decision-making Criteria

The first stage of the HAAFM requires the objective of the HAAFM itself to be defined. This objective is defined as follows, and serves to align the HAAFM with the Highways Agency's corporate objectives.

#### Adaptation Framework Model Objective

To enable the Highways Agency to systematically develop and implement its responses to the challenges of climate change in support of the delivery of its corporate objectives.

Climate change will affect different Highways Agency activities in different ways. Many of the impacts will be adverse, but some will be positive, such as a possible reduction in winter maintenance activities. The term "challenges" in the objective statement is therefore used to refer both to the need to manage adverse impacts and to capitalise on positive impacts.

A set of decision-making criteria also needs to be defined to secure suitable outcomes in response to the HAAFM objective. A common framework of decision-making criteria will provide consistency of approach across the broad range of Highways Agency activities affected by climate change. The decision-making criteria are used in determining preferred options in Stage 5 of the HAAFM.

The decision-making criteria for the selection of preferred adaptation actions are defined as follows.

#### Criteria for the Selection of Preferred Adaptation Actions

Preferred adaptation options shall accord with the Highways Agency's sustainability requirements and provide the optimum balance between minimum whole-life-cost, certainty of outcome and residual risk.

The Highways Agency employs several different investment appraisal methods across its different business areas (e.g. PAR). It is not therefore appropriate to align the decision making criteria with just one of these approaches. However, the relevant approach is used to inform the optimum balance between sustainability, cost, uncertainty and risk.

#### Stage 1: Definition of Objectives and Decision-making Criteria

Role	Responsibilities	Timing
Highways Agency Board	Endorsement and periodic review.	In response to changes to Highways Agency objectives or every 3 years to align with CSR.

### Stage 2: Identify climate trends that affect the Highways Agency

Stage 2 of the HAAFM identifies the climatic changes likely to affect the business areas and activities of the Highways Agency (i.e. potential climate change hazards). They have been categorised as 'primary' climatic changes and 'secondary' climatic change impacts, as described in Chapter 3. These climatic changes form the starting point to identify Highways Agency vulnerabilities in Stage 3 of the HAAFM.

#### Stage 2: Identification of Climate Trends

Role	Responsibilities	Timing
Climate Change Programme Manager	Review; integration into programme; dissemination.	In responses to advances in climate science, literature, policy and legislation.

### Stage 3: Identify Highways Agency vulnerabilities

In Stage 3 of the HAAFM, Highways Agency activities that could be affected by climatic changes are identified. These activities or activity areas are termed vulnerabilities. They may be affected positively or negatively by climatic change. The adaptation Framework focuses on vulnerabilities because they represent the ways in which the Highways Agency works that may need to change in the future.

To facilitate the process of identifying vulnerabilities, a **vulnerability schedule** has been produced. The vulnerability schedule is presented in the form of a matrix. It lists Highways Agency activities that could be

affected by projected climatic changes (i.e. Highways Agency vulnerabilities). It establishes their relationship to climate change hazards and to associated risks to the Highways Agency corporate objectives.

Stage 3: Identification of Highways Agency vulnerabilities		
Role	Responsibilities	Timing
Climate Change Programme Manager	Initiate re-examination of vulnerabilities; review of findings; maintenance of vulnerability schedule.	In response to changes from Stages 1 or 2, or every 3 years to align with CSR.
Divisional Director (or as delegated)	Allocation of resources; review and endorsement of findings.	
Technical and operational specialists	Undertake vulnerability identification; reporting	

## Stage 4: Risk appraisal

Stage 4 of the HAAFM utilises risk appraisal to categorise the nature of the risk associated with each of the vulnerabilities identified in Stage 3. It provides a means of 'scoring' the climate change induced risks so that vulnerabilities can be ranked, enabling the Highways Agency to determine where to focus its efforts in adapting to climate change, and as a basis for future planning and prioritisation.

The primary criteria used to assess vulnerabilities are:

- uncertainty;
- rate of climate change;
- extent of disruption; and,
- severity of disruption.

Using these primary criteria, and compound criteria formed through combining them, vulnerabilities are ranked against prioritisation indicators.

Stage 4: Risk appraisal		
Role	Responsibilities	Timing
Climate Change Programme Manager	Initiate risk appraisal; review of findings; ranking and prioritisation	Following implementation of Stage 3.
Divisional Director (or as delegated)	Allocation of resources; review and endorsement of findings.	
Technical and operational specialists	Undertake risk appraisal.	

## Stage 5: Options analysis to address vulnerabilities

Stage 5 of the HAAFM identifies and assesses the options available to the Highways Agency to respond to the risks associated with each of the vulnerabilities identified in Stage 3, enabling a preferred option to be identified.

Options will need to be considered for each vulnerability, and it will be important that these are aligned wherever possible with existing Highways Agency practices, for example by embedding changes within existing documentation.

Options for the treatment of risks include:

- future-proofing of designs;
- retro-fit solutions;
- developing contingency plans;
- updating operating procedures;
- monitoring; and,
- research.

Once identified, each of the potential 'options' undergoes a comparative assessment against a 'do-minimum' scenario. This assessment may vary in complexity depending upon the nature of the risk and the level of investment necessary to manage it. The assessment provides a robust basis on which to select the preferred option to take forward to Stage 6.

Stage 5: Options Analysis		
Role	Responsibilities	Timing
Climate Change Programme Manager (CCPM)	Liaison with DD to agree programme / vulnerabilities to be considered; review of findings; provide recommendations to DD regarding endorsement.	Annual programme agreed between CCPM and DD.
Divisional Director (DD) (or as delegated)	Liaison with CCPM to agree programme / vulnerabilities to be considered; allocation of resources; review and endorsement of findings.	Annual programme agreed between CCPM and DD.
Technical and operational specialists	Undertake options analysis.	

## Stage 6: Develop and implement Adaptation Action Plans

In Stage 6 of the HAAF, the preferred option is developed into a detailed adaptation action plan, which is then implemented and subject to a process of ongoing review and management.

Wherever possible, the adaptation action plans will define the steps necessary to modify existing Highways Agency Standards, Specifications and other operating procedures, rather than lead to the development of new requirements. In some cases, they may determine that no immediate action is necessary, but instead define a trigger for future review. Alternatively, they may lead to the initiation of research or monitoring, following which, reappraisal of options (Stage 5) may be appropriate, as indicated by the feedback loop in Figure 2.1.

## Stage 7: Adaptation programme review

Key information from the adaptation action plans will be drawn together into an overall adaptation programme in Stage 7 of the HAAF. This will provide transparency, support coordination and facilitate the ongoing review of progress. It will provide the basis for the annual Climate Change Adaptation Progress Review Report, to be presented to the Highways Agency Board.

Stage 6: Development and implementation of Adaptation Action Plans		
Role	Responsibilities	Timing
Climate Change Programme Manager (CCPM)	Liaison with DD to agree programme; review of findings; recommendations to DD regarding endorsement.	Annual programme agreed between CCPM and DD.
Divisional Director (DD) (or as delegated)	Liaison with CCPM to agree programme; allocation of resources; review and endorsement of findings; monitoring outcome of submission of related schemes to investment appraisal processes (e.g. Project Appraisal Report (PAR)).	Annual programme agreed between CCPM and DD.
Technical and operational specialists	Development of adaptation action plan; implementation responsibilities as defined in plan.	Implementation actions undertaken as defined in adaptation action plan.

Four feedback loops are identified from Stage 7 of the HAAF. These feed back to:

**Stage 6**, illustrating the ongoing review of progress of each of the adaptation action plans;

**Stage 3**, illustrating the periodic need to ensure any new areas of vulnerability are identified;

**Stage 2**, illustrating the need to reassess the climatic trends affecting the Highways Agency in the light of new scientific understanding and / or published literature;

**Stage 1**, illustrating the need to revisit the HAAF objective and decision-making criteria in the light of changes to Highways Agency corporate objectives or DfT requirements.

Stage 7: Adaptation programme review		
Role	Responsibilities	Timing
Highways Agency Board	Receive and endorse Climate Change Adaptation Progress Review Report; implementation of associated agreed recommendation.	Annual
Climate Change Programme Manager	Implementation and oversight; presentation of Climate Change Adaptation Progress Review Report.	Ongoing. Report submitted annually.

## 2.3 Stages of HAAFM undertaken to date

As explained in Chapter 1, whilst the focus to date has been the development of the HAAFM and the supporting tools for its implementation, several stages of the model have been applied and are reported in this document. These are summarised in Table 2.1.

Stage of HAAFM	Application to date	Percentage complete	Document reference
<b>Stage 1:</b> Define the Objectives and Decision-making Criteria	HAAFM objective and decision making criteria established.	100%	See Section 2.2.
<b>Stage 2:</b> Identify Climate Trends that affect the Highways Agency	Trends have been summarised based on currently available data.	100%, to be updated with UKCP09	See Chapter 3 and Annex A1
<b>Stage 3:</b> Identify Highways Agency Vulnerabilities	vulnerability schedule has been prepared.	100% (first application)	See Section 4.2 and Annex B1
<b>Stage 4:</b> Risk Appraisal	Risk appraisal has been undertaken for the vulnerabilities in the risk schedule. Ranking tables have been produced.	100% (first application)	See Section 4.7 and Annexes B3 and B4
<b>Stage 5:</b> Options Analysis	Example options analyses have been undertaken.	6%	See Annex C5
<b>Stage 6:</b> Develop and Implement Adaptation Action Plans	Example action plans have been developed.	6%	See Annex C6
<b>Stage 7:</b> Adaptation Programme Review	To be implemented.		

Table 2.1: Stages of the HAAFM applied to date

### 3 Climate change trends

This Chapter addresses Stage 2 of the HAAFM. It provides a summary of how the climate is predicted to change over this century, based on the current state of knowledge. It explains the background to these predictions and the current level of confidence in them. The usefulness of these predictions to the Highways Agency is explained, along with the potential benefits of climate analogue studies.

#### 3.1 Observed and projected climate change

The UK climate is changing. Nine of the ten warmest years in the historic record have occurred in the last decade (up to 2007). The 12-month period ending in April 2007 was the warmest period on record with July 2006 the warmest since observations began. The UK is probably warmer now than it has been at any time in the last thousand years. This trend within the UK is consistent with the wider picture of a general world-wide warming noted by the IPCC, whose 4th Assessment Report (IPCC (2007a)) concludes that warming of the climate system is unequivocal.

Long term changes in climate have been observed at continental, regional, and ocean basin scales as well as in the UK, and include changes in temperature, patterns of rainfall, of winds, and extreme weather. The IPCC also concluded that man is very likely responsible for most of the warming observed since the mid 20th century.

Significant changes that have been observed in the UK climate include:

- warming of the central England temperature by about 1°C since the 1970s;
- an increase in the relative importance of heavy precipitation events in winter;
- an increase in the number of severe windstorms to levels last seen in the 1920s;
- sea levels around the UK have risen by about 1mm/yr in the 20th century, and by more than this since the 1990s; and
- a new all-time maximum temperature for the UK of 38.5°C, set at Faversham, Kent on 10th August 2003.

In broad terms, climate models suggest that we should expect to see a continuation of the changes that have been observed in the UK, albeit at an increased rate.

#### 3.2 Climate predictions

At present, the best available published information on climate predictions is contained in the

Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (2007a) and more recently, the UK Climate Projections 2009 (UKCP09), published in July 2009. This information has been drawn upon in developing the tables presented in Annex A1.

UKCP09 provides the latest projections on the future climate of the UK providing significant advances on the previously available scenarios in UKCIP02. UKCP09 uses a cutting edge peer-reviewed methodology to give a measure of the uncertainty in the range of possible outcomes. The projected changes provided by UKCP09 depend on the emissions scenario, the region of the UK and how far in the future is of interest. Further background on how these climate change projections are made, confidence levels and uncertainties is given in Annex A2.

The additional information available in the UKCP09 projections has great implications for the use and scope of the resulting projections. The main developments for UKCP09 relate to:

- advances in the methodology for expressing (downscaling) climate model projections in a form that is useful for local impacts modelling;
- a more rigorous framework for dealing with uncertainties which will help with risk-based decision-making; and
- advances in climate science and computing capability that allow the inclusion of more processes and higher resolution.

Headline projected changes for the 2080s for a medium emissions scenario include:

- all areas of the UK warming, more so in summer than winter. Changes in Summer mean temperatures are greatest in South East between 2.2°C and 6.8°C by the 2080s;
- increases in the number of days with high temperatures are found throughout the UK particularly in the South East;
- increases in the mean minimum temperature during winter of between 0.6°C and 5.9°C depending on location in the UK.

- reductions in the number of frost days are found, the greatest change being where the frost days are most frequent;
- an increase in the amount of precipitation in winter on the Western side of the UK;
- increased winter rainfall, rising sea levels and more frequent storm surges may increase flood risk;
- reduction in the precipitation in summer, especially in south east England which could see 40% less rain in summer;
- a reduction in the frequency of fog events;
- a reduction in the mean cloud amount in summer leading to more UV radiation exposure particularly in southern parts of the UK;
- sea level rise around the UK is projected to be between 12 and 76cm for the period 1990 to 2095.

Changes are likely to exceed current natural variability. Consequently, services that are demonstrably sensitive to current weather events are likely to become increasingly vulnerable in the future. UKCP09 projections will provide the Highways Agency with the tools to undertake quantitative options analysis (Stage 5 of the HAAFMM). The HAAFMM has been developed to take advantage of this new resource and further advancements in climate science that may occur in the future.

### 3.3 Primary climatic variables and secondary climatic impacts

To ascertain more specifically how future changes in climate could affect the Highways Agency, lists of primary climatic variables and secondary climatic impacts have been established. These lists are presented in Table 3.1 and Table 3.2. A full description of how these climatic variables are predicted to change is given in Annex A1, together with details of the current level of confidence in the predictions. Although not specifically covered in UKCP09, change in soil moisture (secondary impact) has been included in Table 3.2 due to the significant implications it may have on Highways Agency assets including foundations and embankments.

Primary climatic changes
Increase in average temperature
Increase in maximum temperature
Increase in winter rainfall
Reduction in summer rainfall
More extreme rainfall events
Increased wind speed for worst gales
Sea level rise

Table 3.1: Primary climatic changes

Secondary climatic change impacts
Longer growing season
Reduction in soil moisture
Change in groundwater level
Flooding
Reduction in fog days in winter <sup>1</sup>
Reduction of icy days in winter <sup>1</sup>
Frequency of extreme storm surges

Table 3.2: Secondary climatic change Impacts

### 3.4 Climate analogues

A climate analogue is a current climate that is similar to the projected future climate of a given location (for example, in terms of temperature and rainfall). Climate analogues are an intuitive way to place climate change projections in context and convey an immediate impression of their degree of significance, and the amount of adaptation that might be needed. To date, only one climate analogue study for the London area, by Hallegatte et al (2007), has appeared in the published literature. This suggests that the climate in London at the end of the century might be like that of Nantes according to one model, or Lisbon according to another. In this study, the climate variables compared were monthly temperature, and annual and monthly precipitation. Other climate characteristics such as wind strength or atmospheric humidity have not been assessed and therefore cannot be assumed to be analogous. If it is assumed that Nantes and Lisbon are well adapted to their current climates, then by studying their current road networks and the way it is managed, it is possible to gain an insight into the possible adaptation measures that could be required in the south of the UK. Further analogue studies could be a very useful tool in highlighting how climate change could affect specific aspects of the Highways Agency's network and operations.

<sup>1</sup> The increase in fog-free and ice-free days in winter will generally be a positive impact for the Highways Agency.

## 4 Risks to the Highways Agency from climate change

This Chapter is concerned with Stages 3 and 4 in the HAAFM. It explains the methodology used to identify the Highways Agency activities that could be affected by climate change, termed vulnerabilities, and the vulnerability schedule that has been developed to enable them to be presented in a consistent framework. The methodology for the preliminary prioritisation of these vulnerabilities is also presented, together with the results of applying it to the vulnerabilities identified to date.

### 4.1 Identification of vulnerabilities

Stage 3 of the HAAFM established the need to identify Highways Agency vulnerabilities. Within the HAAFM, vulnerabilities are defined as Highways Agency activities that could be affected by climate change. Thus, whilst the Highways Agency’s assets are receptors of climatic events, it is, for example, the way in which these assets are designed, maintained and operated that are defined as vulnerabilities.

This definition of vulnerabilities has been used to reflect the fact that it is the way the Highways Agency works that needs to be adapted to meet the challenges of a changing climate. This emphasis on vulnerabilities also enables responsibilities for identifying, analysing and managing the risks associated with specific vulnerabilities to be assigned effectively to technical and operational staff who specialise in the relevant field of activity.

To stimulate the identification of vulnerabilities and enable them to be catalogued in a consistent manner, a vulnerability schedule has been developed which maps Highways Agency activities to associated climate change hazards and also to risks to the delivery of the

Highways Agency’s corporate objectives. The format of the vulnerability schedule is illustrated in Figure 4.1.

The first step in completing the vulnerability schedule is to identify the climate change hazards that may impact on the vulnerability being considered. Climate change hazards have been categorised as either primary climatic changes or secondary climatic impacts (see Section 3.2). The second step is to consider how such impacts could affect the delivery of the Highways Agency’s corporate objectives. To assist in identifying these risks, a series of high-level climate-related risks to the corporate objectives have been defined, and are summarised in Table 4.1. Risks to the Highways Agency are recorded in the vulnerability schedule with reference to these high-level risks.

Within the vulnerability schedule, vulnerabilities have been divided into the categories in Table 4.2, and are further sub-divided into activity-areas for clarity.

		Highways Agency corporate objectives	
		Primary climatic changes	Secondary climatic impacts
		High-level climate-related risks to corporate objectives	
Vulnerabilities (Highways Agency activities)			
		Hazards	Risks

Figure 4.1: Vulnerability schedule

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

Table 4.1: Risks to Highways Agency corporate objectives

Vulnerability schedule activity 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

Table 4.2: Categorisation of vulnerability schedule activity

## 4.2 Completion of the vulnerability schedule

Drawing upon previous studies undertaken by the Highways Agency and consultation with specialists, the vulnerability schedule has been completed. As acknowledged in the HAAFM, it will be necessary to revisit the vulnerability schedule again in the future to confirm its completeness and identify any further vulnerabilities that need to be considered.

The completed vulnerability schedule is presented in Annex B1. It contains over eighty separate entries spanning all facets of Highways Agency work.

## 4.3 Risk appraisal

The vulnerability schedule provides a catalogue of risks to the Highways Agency. Stage 4 of the HAAFM establishes the need to undertake a preliminary appraisal of these risks.

The objective of the risk appraisal process is to provide a means of 'scoring' the vulnerabilities to form hierarchies or rankings, and to enable the Highways Agency to determine where to focus its efforts in adapting to climate change. Essentially, it provides a basis for future planning and prioritisation.

The identification of priorities for the Highways Agency is not however entirely straightforward. For example, it may be appropriate to prioritise action on the risks that have greatest potential effect on travellers; or those expected to materialise first; or those with greatest uncertainty for which further research would therefore be particularly beneficial; or some combination of these and other factors. For this reason, the risk appraisal methodology uses multiple criteria. Separately and in combination, these criteria inform priorities for action.

The risk appraisal methodology has been developed to focus on the risks arising from climatic changes and

does not consider risks associated directly with possible adaptation actions. This distinction is necessary because adaptation-related factors are dependent upon the particular adaptation action being considered and cannot therefore be established at this stage. It is for this reason that costs of adaptation are not considered directly in the risk appraisal.

The four primary criteria used in the risk appraisal are uncertainty, rate of climate change, extent of disruption and severity of disruption. They are defined in Table 4.3.

Primary criteria for risk appraisal	
<b>Uncertainty</b>	- compound measure of current uncertainty in climate change predictions and the effects of climate change on the asset/activity.
<b>Rate of climate change</b>	- 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.
<b>Extent of disruption</b>	- 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.
<b>Severity of disruption</b>	- measure of the recovery time in the event of a climate-related event e.g. flood, or landslide. 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.

Table 4.3: Primary criteria for risk appraisal

## 4.4 Scoring approach

For each vulnerability, a High/Medium/Low score is assigned against each of the four primary risk appraisal criteria. This is achieved using sub-indicators and reference tables. Scoring is undertaken based on expert opinion, and necessarily involves some judgement.

### Uncertainty

Scores for **uncertainty** are determined from a review of climate change trends information (see Chapter 3 and Annex A1) 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 Table 4.4.

		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

Table 4.4: Uncertainty matrix

For some climate predictions, the level of uncertainty varies for predictions stretching further into the future. In these cases, the uncertainty level entered into the uncertainty matrix should be that which most closely relates to the asset life/activity time horizon from the 'rate of climate change' criterion (see below).

### Rate of Climate Change Criterion

Scores for rate of climate change reflect two factors:

- time horizon for climate change effects to become material; and,
- asset life/activity time horizon.

The **time horizon for climate change effects to become material** is determined using predicted climate change trends (see Chapter 3 and Annex A1) and considering the timescale over which such changes are expected to impact on the vulnerability. It reflects the time period within which it is expected that it will be necessary to do something differently, for any of the following reasons:

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

The time horizon sub-indicator is assessed as either short-term (defined as the period up to 2020), mid-to-long term (defined as the period between 2020 and 2080) or longer term (defined as the period beyond 2080).

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

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

The overall **rate of climate change** score is determined using Table 4.5.

		Asset life / activity time horizon	
		Short term <30 years	Long 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

Table 4.5: Rate of climate change matrix

## Extent of disruption

Scores for the **extent of disruption** are defined in Table 4.6.

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

Table 4.6: Extent of disruption matrix

Scores for the extent of disruption are defined in Table 4.6. In determining the extent of disruption it is important to take account of the spatial variation of the relevant climatic event. If the vulnerability is sensitive to an extreme event, the event may be relatively localised, as could be the case for extreme rainfall, or may be highly correlated over a large area, as may be the case for extreme temperatures. Thus, a risk event associated with extreme temperatures may well occur at several places on the network at the same time thereby increasing the extent of disruption.

## Severity of disruption

Scores for the severity of disruption are defined in Table 4.7. 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 Agency control. Responsive actions following extreme events can be particularly disruptive because their timing cannot be controlled.

In the cases of vulnerabilities that give rise to managed interventions, such as maintenance actions, the severity of disruption is a measure of how much disruption would arise if current practices are retained. For managed interventions, the degree of disruption can typically be controlled to a degree that is not possible for responsive actions following extreme climatic events.

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

Table 4.7: Severity of disruption matrix

The High/Medium/Low scores assigned to the primary criteria, and sub-indicators where necessary, are converted to numerical scores using Table 4.8.

Qualitative Score	Numerical Score
High	3
Medium	2
Low	1

Table 4.8: Scoring conversion

## 4.5 Prioritisation of 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.

The tables are generated using the prioritisation criteria given in Table 4.9. An indicator, or score, is determined for each of the prioritisation criteria using the formulae in Table 4.9. All these formulae give a score between 0 and 1.

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

Table 4.9: Prioritisation criteria and associated indicators

## 4.6 Early adaptation

Even if a vulnerability receives a low risk-ranking based on the risk appraisal scoring, it may still be sensible to undertake early adaptation for reasons associated with the nature of the likely adaptation strategy, rather than due to the nature of the climate change risk itself. For example, if early action is straightforward and potentially highly cost-effective.

In support of the prioritisation process, vulnerabilities are flagged in the risk appraisal process as **early adaptation action advisable**, if any of the following criteria are met:

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

Vulnerabilities are identified as early adaptation action advisable if some action is required or advisable within 5 years. Action may refer to the initiation of more detailed analysis or the implementation of specific interventions.

## 4.7 Results of risk appraisal

A risk appraisal has been undertaken of the vulnerabilities identified in the vulnerability schedule (see Section 4.2). The appraisal was undertaken by specialists using the risk appraisal template included

in Annex B3. On the basis of the results of the risk appraisal, the prioritisation indicators in Table 4.9 were calculated and rankings established.

Complete rankings against each of the prioritisation indicators are included in Annex B4. A summary of the vulnerabilities identified as a high priority is presented here. Copies of the completed risk appraisals are included in Annex B5 and provide full descriptions of the vulnerabilities. The vulnerabilities listed in Tables 4.10 to 4.13 may be understood most readily with reference to their full descriptions included in Annex B5.

Vulnerabilities for which early adaptation was identified as advisable have been highlighted in blue in the ranking tables in Annex B4 and Tables 4.10 to 4.13. A complete list of these vulnerabilities is also included separately in Annex B4.

## Time-criticality

Vulnerabilities identified as time critical are expected to be materially affected by current predicted levels of climate change within the asset life or activity time horizon. The risk appraisal identified over 60% of vulnerabilities as being time critical. Because of the large number of vulnerabilities, they are not listed here.

## High extent

Vulnerabilities identified as high extent affect over 80% of the network or users, or a highly strategic route. The high extent vulnerabilities identified in the risk appraisal, with a score of 1, are summarised in Table 4.10.

Because of their impact across the whole network several vulnerabilities associated with strategy and business management have been identified as having high extent. Similarly, vulnerabilities concerned with education have been identified as a result of their broad

Category	Area	Aspect	Ref
Internal business management	Staff Costs	Staff numbers	BM02
Design and construction of new or replacement assets	Pavements	Design of foundations	DC02
	Structures (including gantries)	Wind actions (loads) applied to superstructure	DC06
	Drainage	Cross-culverts	DC16
Maintenance and management of existing assets	Pavements	Skid Resistance	MM01
		Foundations	MM02
		Integrity of materials	MM03
	Structures (including gantries)	Wind actions (loads) applied to superstructure	MM07
Drainage	Cross-culverts	MM18	
Managing network operation	Education	Motorised Users	NO09
		Non-motorised users	NO10
		Highways Agency Staff	NO12
Defining and managing network strategy, planning	Demand management	Demand forecasting	NS02
	Land management	Soft estate	NS04
	Strategic resilience	Critical geographic importance	NS05
		Network resilience	Impact from 3rd parties
	Investment Appraisal	Demand and operation (rail systems fail)	NS07
		Identifying best ways of investing resources/ investment appraisal	NS08
	Budgeting (spending reviews)	Budgeting (spending reviews)	NS09

Table 4.10: Vulnerabilities with high extent

impact. Other vulnerabilities identified as having high extent generally relate to assets that are widespread across the network or relate to assets that serve strategic routes, such as major crossings, which can be particularly sensitive to high winds.

## High disruption duration

Vulnerabilities identified as having high disruption duration are expected to affect users for over one week. The high disruption duration vulnerabilities identified in the risk appraisal, with a score of 1, are summarised in Table 4.11.

The majority of the high disruption duration vulnerabilities are associated with failures of assets that will take a significant period of time to remedy. Several vulnerabilities associated with strategy and business management have also been identified because of their potential to broadly affect the network over an extended period. These strategy and business management vulnerabilities are primarily concerned with the need for the Highways Agency to have the staff and financial

resources necessary to delivery the adaptation programme.

## Potential research need

Vulnerabilities identified as having high research need are those where there is currently a high degree of uncertainty associated with the effect of climate change on the relevant asset or activity. Research needs associated with climate change prediction have not been identified specifically at this stage, as they will be best assessed once a clearer understanding of UKCP09 is obtained. Vulnerabilities with a high research need, corresponding to a score of 1, are summarised in Table 4.12.

Key areas of uncertainty include the overall financial and staff resource requirement for delivering the adaptation programme, the long term effects of climate change on the deterioration rate of assets and the timing of their maintenance or renewal.

Category	Area	Aspect	Ref
Internal business management	Staff Costs	Staff numbers	BM02
Design and construction of new or replacement assets	Pavements	Design of foundations	DC02
		Materials specification and construction details	DC03
	Structures (including gantries)	Wind actions (loads) applied to superstructure	DC06
		Design for increased scour risk for foundations	DC10
Maintenance and management of existing assets	Pavements	Skid Resistance	MM01
		Foundations	MM02
		Integrity of materials	MM03
		Maintenance	MM04
	Structures (including gantries)	Wind actions (loads) applied to superstructure	MM07
		Management of increased scour risk for foundations	MM11
	Geotechnics	Earthworks construction across existing landslip	MM25
Defining and managing network strategy, planning	Investment Appraisal	Identifying best ways of investing resources/ investment appraisal	NS08
	Budgeting (spending reviews)	Budgeting (spending reviews)	NS09

Table 4.11: Vulnerabilities with high disruption duration

Category	Area	Aspect	Ref
Internal business management	Staff Costs	Staff numbers	BM02
Design and construction of new or replacement assets	Soft estate	Capital investment ecology	DC29
Maintenance and management of existing assets	Structures (including gantries)	Optimum timing of maintenance interventions, in responses to changes in deterioration rates	MM16
	Signs	Renewal and repair	MM26
	Restraint systems	Renewal	MM27
Defining and managing network strategy, planning	Development Control	Development Control	NS01
	Land management	Soft estate	NS04
	Budgeting (spending reviews)	Budgeting (spending reviews)	NS09

Table 4.12: Vulnerabilities identified as having potential research need

### Highly disruptive, time critical with high confidence

Vulnerabilities identified as highly disruptive and time-critical with high confidence have both high extent and high disruption duration. In addition, they are identified as time-critical with a high confidence.

Table 4.13 summarises the vulnerabilities that have an associated indicator score (see Table 4.4) greater than 0.4. The indicator scores are included in the table. Vulnerabilities are grouped first by category and area and then ranked by indicator score.

### Next steps

The vulnerabilities in Tables 4.10 to 4.13 are priorities for action, particularly those in Table 4.13. These tables therefore provide a basis for identifying the vulnerabilities to be considered first in undertaking Stage 5 of the HAAF.

Category	Area	Aspect	Score	Ref
Internal business management	Staff Costs	Staff numbers	0.67	BM02
Design and construction of new or replacement assets	Pavements	Materials specification and construction details	0.44	DC03
		Design of foundations	0.44	DC02
	Structures (including gantries)	Wind actions (loads) applied to superstructure	0.67	DC06
		Design for increased scour risk for foundations	0.67	DC10
		Design of bearings and expansion joints	0.44	DC13
	Drainage	Surface Water Drainage Systems	0.44	DC15
		Attenuation	0.44	DC18
		Outfalls	0.44	DC19
Maintenance and management of existing assets	Pavements	Skid Resistance	1.00	MM01
		Integrity of materials	0.67	MM03
		Foundations	0.44	MM02
		Maintenance	0.44	MM04
	Structures (including gantries)	Wind actions (loads) applied to superstructure	0.67	MM07
		Management of increased scour risk for foundations	0.67	MM11
		Management and maintenance of bearings and expansion joints	0.44	MM14
	Drainage	Surface Water Drainage Systems	0.44	MM17
		Outfalls	0.44	MM21
Managing network operation	Restricting network use	Flooding	0.44	NO08
Defining and managing network strategy, planning	Investment Appraisal	Identifying best ways of investing resources/investment appraisal	1.00	NS08
	Strategic resilience	Critical geographic importance	0.67	NS05
	Network resilience	Impact from 3rd parties	0.67	NS06
	Network resilience	Demand and operation (rail systems fail)	0.67	NS07
	Budgeting (spending reviews)	Budgeting (spending reviews)	0.67	NS09

Table 4.13: Vulnerabilities identified as highly disruptive, time critical with high confidence

## 5 Options analysis and the development of adaptation action plans

This Chapter is concerned with Stages 5 and 6 of the HAAFM. It explains the methodology used to identify and compare options to manage the risks associated with the Highways Agency’s vulnerabilities. This methodology provides a tiered approach enabling the assessment of options to be kept as simple as is required for the preferred option to become clear. Guidance on the identification of preferred options is provided. Once selected, the preferred option is translated into an adaptation action plan. Model contents for adaptation actions plans are given.

### 5.1 Options Analysis Process

The purpose of the options analysis process is to enable a preferred option for the management of risk associated with each of the Highways Agency’s vulnerabilities to be established. The process should generally be applied separately to each of the vulnerabilities identified in Stage 3 and prioritised in Stage 4 of the HAAFM, unless a common adaptation action can be used to address several vulnerabilities.

In many cases, the selection of a preferred option will be readily apparent, but in other cases detailed analysis will be necessary and justified, particularly in support

of significant investment decisions. For this reason the options analysis process incorporates the possibility of using increasingly refined methods of options assessment where the identification of the preferred option is clouded by uncertainty or risk.

The options analysis process and its link to the development of adaptation action plans are illustrated in Figure 5.1. It commences with a re-examination of the vulnerability, building upon the work undertaken in Stages 3 and 4 of the HAAFM. An initial options assessment is then undertaken. If, as a result of this initial assessment, the preferred option is clear then it is developed into an adaptation action plan as Stage 6

of the HAAFM. If the preferred option is not clear, the options assessment is refined.

As indicated in Figure 5.1, in some cases the preferred option will be to undertake some further research or monitoring, after which it will be appropriate to re-assess options for adaptation utilising the findings of this work. Similarly, the adaptation action plan may identify the need for a periodic review of the adaptation option being pursued.

The work done in undertaking the options analysis is recorded in an options analysis report.

Within the options analysis process, options assessment enables the costs and consequences of different options to be understood and compared. The effect of climate on the Highways Agency network and operations can be quite complex. Options assessment requires a simplified model of this overall

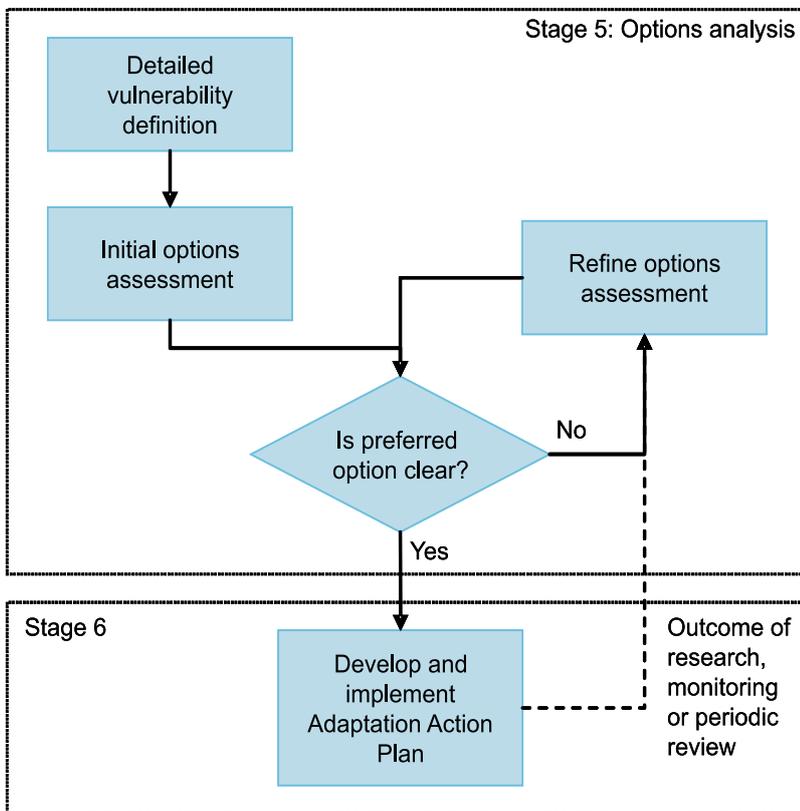


Figure 5.1: Options analysis and adaptation action plan development process

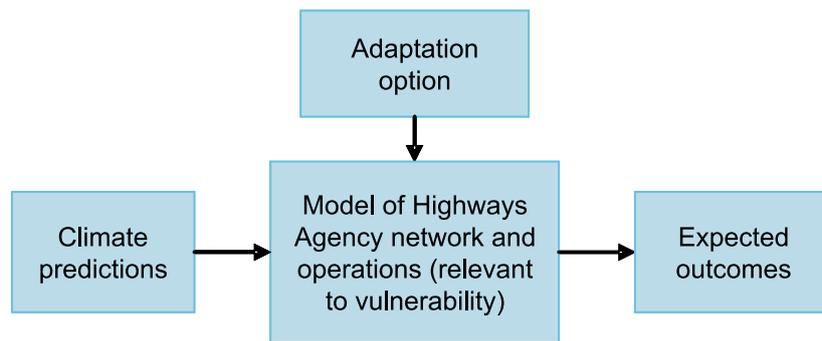


Figure 5.2: Representation of the system used for options assessment

system to be established which retains its essential features with sufficient accuracy for the comparison of options to be valid. The elements of this simplified model are illustrated in Figure 5.2. The key challenge in undertaking the initial options assessment, and its subsequent refinement if required, is retaining as much simplicity as possible in this model whilst incorporating sufficient detail for the preferred option to be clear.

The identification of the preferred option is informed through determining the minimum whole-life-cost option taking account of the direct and indirect costs of adaptation and of the consequences of climate related incidents. The likelihood and severity of climate related incidents will be dependent on the adaptation option being considered. Thus an investment in adaptation actions will typically lead to a benefit through reducing the likelihood and severity of climate related incidents, and therefore reducing the corresponding direct and indirect consequence costs.

It is not, however, appropriate for whole-life-cost to be used as the sole indicator of the preferred option. The sustainability of adaptation options also needs to be taken into account, as does the level of uncertainty and the potential risks associated with each adaptation option. Furthermore, the sensitivity of expected outcomes to any assumptions, predictions and simplifications needs to be considered together with any interfaces issues and any issues stemming from the investment decision-making framework used in the field relevant to the vulnerability. For these reasons, the selection of the preferred option necessitates the balancing of several criteria and requires judgement.

In summary, options analysis is concerned with developing a more thorough understanding of the vulnerability itself, determining feasible options to manage the associated risks, estimating the costs, benefits and consequences of each of these feasible options, and carefully selecting a preferred sustainable

option. The process is underpinned by four key principles:

- adaptation options considered should be network level strategies, but may define criteria for local implementation or works;
- the preferred option must align with the Highways Agency's sustainability requirements, and provide a balance between cost, uncertainty and risk;
- the simplest possible approach should be used to identify the preferred option;
- if the identification of the preferred option is confounded by uncertainty or risk, either the options assessment process should be refined or an interim option adopted incorporating research and/or monitoring, the findings of which can later be used in the re-examination of adaptation options.

## 5.2 Detailed vulnerability definition

The first step in the options analysis process is to refine the definition of the vulnerability and clearly catalogue all of the associated risks. This activity builds upon the work undertaken in Stages 3 and 4 of the HAAFM, in particular the risk appraisal results included in Annex B5. A proforma for undertaking the detailed vulnerability definition is included in Annex C1. Information to be included in the detailed vulnerability definition is summarised in Table 5.1.

## 5.3 Options assessment

The process for undertaking options assessment comprises four stages as shown in Figure 5.3. The process commences with the identification of feasible options. This is followed by the determination of their expected outcomes. Costs and benefits are then established and finally a preferred option is identified, if one is clear.

Section	Content to include:
Activity	<ul style="list-style-type: none"> <li>Activity category, area and aspect</li> </ul>
Climate change	<ul style="list-style-type: none"> <li>Climatic changes that will affect the activity.</li> <li>Current knowledge of the relevant climate change predictions and the associated levels of uncertainty.</li> <li>Spatial characteristics of the climate change i.e. whether it is likely to be highly localised, or widespread, or any geographical areas that are known to be more or less likely to be affected.</li> </ul>
Impact of climate change	<ul style="list-style-type: none"> <li>Expected physical impact of climate change on the identified asset/activity and what this is expected to lead to.</li> <li>Level of uncertainty of the physical impact of climate change on the asset /activity.</li> <li>Descriptions of what would be expected to happen in the event of climate change if current practices/procedures are maintained.</li> </ul>
Adaptation urgency	<ul style="list-style-type: none"> <li>Timescale within which the identified impacts of climate change are expected to materialise, relative to the asset life/activity time horizon.</li> </ul>
Extent	<ul style="list-style-type: none"> <li>Extent of the Highways Agency network expected to be affected by the vulnerability.</li> <li>How localised impacts are expected to be, and whether they will be spatially correlated.</li> <li>Strategic routes expected to be affected. Potential impacts on users.</li> </ul>
Risks	<ul style="list-style-type: none"> <li>Risks to Highways Agency corporate objectives based upon the high-level risks summarised in Table 4.1.</li> </ul>
Interfaces	<ul style="list-style-type: none"> <li>Other Highways Agency activities that may be affected by possible adaptation options and opportunities for coordinated actions.</li> </ul>
Investment framework	<ul style="list-style-type: none"> <li>Current basis of decision making for investment options in the field relevant to the vulnerability.</li> <li>Time horizon for investment decisions (i.e. the period used as the basis for comparing the costs of options).</li> </ul>

Table 5.1: Contents of detailed vulnerability definition

The degree of sophistication employed in the options assessment is flexible. In many cases, the preferred option will emerge on the basis of an initial simple assessment, avoiding any unnecessary investment

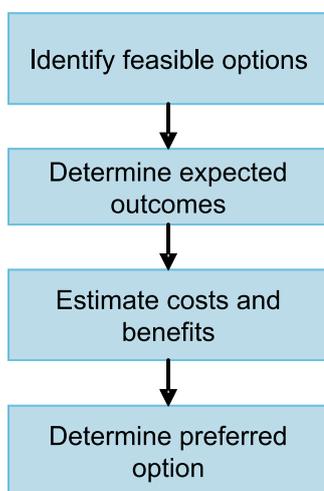


Figure 5.3: Stages in the options assessment of feasible options

of effort, but in some cases it may be necessary to undertake several iterations with increasing levels of refinement before the preferred option becomes clear.

### Identification of feasible options

Feasible options are established based on expert opinion. Each option should be a network-level strategy to manage the risks associated with the vulnerability. It may, however, define adaptation actions that are implemented locally, possibly with intervention criteria based on local conditions. Options may be based on commencing action once a threshold of climate change is reached or it may be considered appropriate to commence a national programme now in order to address vulnerable sites before the expected effects of climate change are realised.

In establishing feasible options, the generic options given in Table 5.2 should be considered. Not all of these options will be relevant to all vulnerabilities, and the list is not necessarily exhaustive. A do-minimum option should, however, always be considered. In many cases, suitable options for consideration will incorporate

Generic Option	Examples
Do minimum	Minimum actions necessary to maintain a safe and serviceable network. May include: developing contingency plans, monitoring changes and, for assets, doing patch-and-mend repairs/like-for-like replacements, as required.
Future-proof designs	Updating design requirements, including technical standards and specifications, to provide additional capacity/functionality. These updated requirements could apply to all 'designs' e.g. designs for new structures or new roads, as well as to 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 towards the extreme predictions.
Retro-fit solutions	Proactively applying modifications to existing assets/activities outside of the 'normal' cycle for renewal/replacement. For example, proactively replacing/fitting additional equipment or components or providing additional provision/capacity to existing assets. This option could 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.
Develop contingency plans	Development of a pre-planned response for when/if climate change risks are realised so that their immediate effects can be managed. This option could apply 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. It should be included as standard within the 'do minimum' option.
Update operating procedures	Updating operating procedures to take account of the impacts of climate change. For example, updating the procedure for working in high temperatures.
Research	The main purpose of research is to reduce uncertainty, where this presents a barrier to determining preferred adaptation options with a reasonable level of confidence. It could be done to provide better understanding of the likelihood and consequences of a risk for the network. Alternatively, it could be done to help determine or refine appropriate adaptation options.
Monitor	Monitoring of the rate of climate change and/or the subsequent effects on a particular asset/activity to increase confidence in the appropriate adaptation option, or to determine the appropriate point at which to implement some pre-determined action. An important part of this option would be to identify indicators of change and threshold 'triggers' for action.

*Table 5.2: Generic adaptation options*

elements of several of these generic options. For example, it may be appropriate to combine monitoring with contingency planning or to future proof designs as a precautionary step whilst initiating research to establish alternative cost-effective and sustainable solutions. The key requirement is for experts to consider carefully the sustainable options they consider have the potential to offer the minimum whole-life-cost, minimum risk and greatest certainty of outcome.

In developing feasible options, experts should consider climate analogues to review the approaches used currently in locations that experience a similar climate to that predicted for UK (see Section 3.4).

Tools for recording feasible options are included in Annex C2. These establish a record of the reasons why any of the generic options are not considered feasible. For the feasible options they record the following details:

- a description of the option, including criteria for interventions/actions;
- a summary of the expected work required to implement the option;
- expected timing/programme for implementation;
- any requirements for consultant support.

The proposed timing/programme for adaptation options should take account of relevant Highways Agency

processes for implementing the work involved, such as updating standards, identifying local projects, obtaining funding and aligning activities within other works programmes.

## Determining expected outcomes

The next stage in the options assessment is to determine the expected outcomes of each of the feasible options. In addition, the sensitivity of the expected outcomes to the accuracy of assumptions, predictions and modelling simplifications needs to be recorded together with risks and uncertainties associated with each of the options. It is particularly important to identify whether an option could lead to a level of safety on the network below that currently considered acceptable, or any other conflict with current Highways Agency requirements.

As illustrated in Figure 5.2, a simplified model of the Highways Agency's network and operations relevant to the vulnerability needs to be established that can enable the expected outcomes arising from different climate predictions and adaptation options to be understood.

Initially, expected outcomes should be determined based on expert opinion, international evidence and readily available data, with the primary objective being to establish the most likely outcome of implementing each of the options (i.e. what the expert expects think will happen). Where it proves necessary to refine the options assessment, both in establishing the expected outcomes and understanding their sensitivity to assumptions and predictions, the following approaches may be useful:

- using more refined climate prediction data (such as the full UKCP09 predictions);
- refining the model of the Highways Agency's network and operations relevant to the vulnerability (see Figure 5.2);
- considering expected worst-case and best-case climate scenarios to provide an indication of the potential spread of outcomes;
- using 'Monte Carlo' simulation or other probabilistic analysis tools.

The nature of the expected outcomes, and their sensitivity to climate predictions, will be dependent on the vulnerability being considered. The risks associated with some vulnerabilities are influenced by

trends in average climatic conditions whilst others are related to the occurrence of extreme events.

For those affected by average trends, expected outcomes may be reasonably predictable, for example as a series of discrete actions such as planned maintenance interventions or renewals at predicted intervals. These interventions may need to be more frequent in the future if assets deteriorate more rapidly under new climatic conditions.

In contrast, expected outcomes for vulnerabilities that are sensitive to extreme events are often more difficult to quantify. By their nature, extreme events are not expected to occur very often. Furthermore, designs typically include additional explicit factors of safety and may also include implicit conservatism. As a result, in the case of vulnerabilities sensitive to extreme weather events, the expected, or most likely, outcome may well be that no climate related risks will manifest themselves even with a changing climate. This does not mean, however, that adaptation is not necessary.

The effect of climate change can be to increase the likelihood of a weather related event occurring. The role of adaptation in such cases is to manage the risk so it is maintained at acceptable levels. In such cases, it is likely to be most straightforward to treat the expected outcome of an option as a reduction in the likelihood and/or severity of an extreme weather-related event.

For example, adopting this approach, if the current annual probability of a weather-related incident, such as damage to a structure necessitating repair, was estimated as, say, 0.01 (corresponding to a return period of 100 years based on the historic climate) the expected outcome of an adaptation option would be expressed as a change in this annual probability that would vary with time as the climate changes. Such an approach enables the benefits of adaptation to be taken into account in estimating costs and benefits without recourse to more sophisticated probabilistic methods.

In summary, one of two approaches will typically be appropriate for defining expected outcomes, either a series of discrete (consequential) actions at predicted intervals, or as a reduction in the likelihood and/or severity of a weather-related incident or event.

## Estimating financial costs and benefits

The next stage in the options assessment is to estimate the financial costs and benefits associated with each of

	Adaptation costs	Consequence costs
Highways Agency resource costs	<p>Highways Agency time to define and implement adaptation measures, including:</p> <ul style="list-style-type: none"> <li>• develop detailed specification of work required for adaptation</li> <li>• procure consultant support</li> <li>• manage stakeholder consultation</li> <li>• publish updated standards/specifications, new requirements/guidance for adaptation</li> <li>• provide training/technical support</li> <li>• manage/monitor implementation of new procedures/requirements</li> </ul>	<p>Highways Agency time associated with residual weather-related risks, including:</p> <ul style="list-style-type: none"> <li>• Area Team time dealing with incidents as and when they occur</li> <li>• Traffic Officer time dealing with incidents on the network</li> <li>• Area Team/specialist time dealing with any associated PQs, etc.</li> <li>• Area Team time to procure/manage any physical repairs</li> <li>• time spent on working groups to investigate and determine the Highways Agency's response to an incident</li> <li>• time to support any legal cases/compensation claims arising from incidents</li> <li>• time to update any standards, specifications or internal processes as a result of incidents</li> </ul>
Professional costs	<p>Professional time to develop and implement adaptation measures including:</p> <ul style="list-style-type: none"> <li>• design and manage construction of adaptation measures</li> <li>• develop operating procedures for new equipment</li> <li>• any additional inspection or monitoring required for new/modified equipment or other assets</li> <li>• any training required for operatives to install/operate/maintain new or modified equipment or other assets</li> <li>• consultant support to the development of new procedures/requirements</li> <li>• research costs</li> </ul>	<p>Professional time to manage incidents associated with residual weather-related risks, including:</p> <ul style="list-style-type: none"> <li>• incident management</li> <li>• design and delivery of any temporary repairs</li> <li>• design and delivery of any longer-term repairs</li> </ul>
Works costs	<p>Costs of any works associated with adaptation option (additional to 'business as usual' costs)</p>	<p>Works costs associated with any repairs or other works to restore network functionality in the event of incidents related to residual weather-related risks</p>
Indirect costs	<p>Any disruption and casualty costs associated with the construction/operation/maintenance of adaptation measures (additional to 'business as usual' costs)</p>	<p>Disruption and casualty costs associated with any incidents related to residual weather-related risks</p>

*Table 5.3: Examples of adaptation and consequence costs*

the options. This is done based on the expected work required to implement the options, termed adaptation costs, and the costs associated with their expected outcomes, termed consequence costs. Generally, the benefit of investing in adaptation is a resulting reduction in consequence costs. Costs are broken down into:

- Highways Agency resource costs;
- professional costs;
- works costs; and,
- other indirect costs.

Examples of costs falling into each of these categories are included in Table 5.3. In preparing cost estimates,

any costs that are common to all options need not be considered for the purposes of comparison.

In practice, it will not be possible to undertake a full evaluation of all the costs in Table 5.3. Initially, it will be appropriate to be selective, taking account of the principal costs only, and to refine these estimates if necessary. For example, where the avoidance of significant network disruption is associated with an option then this cost alone is likely to be the determining cost.

To enable costs to be compared between options, a whole-life-cost is determined. The discount rates to be used for the appraisal of long term effects of climate change do need careful thought. The approach

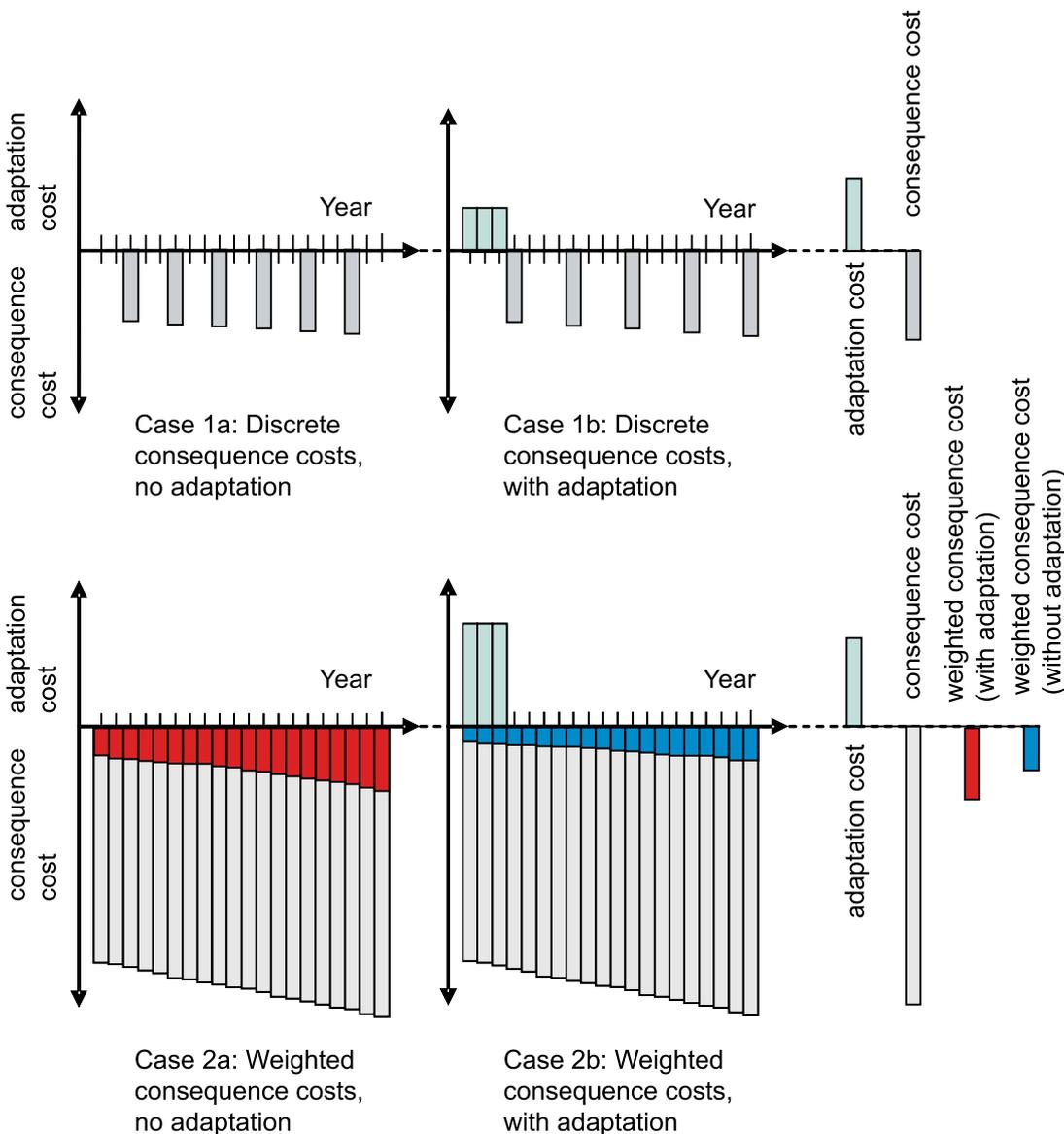


Figure 5.4: Illustration of consequence and adaptation costs (undiscounted)

Aspect	Key questions
Estimated whole-life-cost	What is the estimated whole-life-cost of the option? What has been included in its evaluation?
Uncertainties	Has it been necessary to make assumptions, predictions and simplifications in assessing the option? If so, what is the level of confidence in them?
Sensitivity to assumptions, predictions and simplifications	How sensitive is the expected outcome to the assumptions, predictions and simplifications made in assessing the option?
Risks	What are the risks to the Highways Agency of implementing the option? What could happen if the assumptions, predictions and simplifications are inaccurate?
Sustainability	Is the option consistent with the Highways Agency's approach to sustainability?
Interfaces	Will the option impact on other areas of Highways Agency network or operations?
Ancillary benefits	Would the option bring additional benefits to the Highways Agency network or operations?
Alignment with investment framework	What approach does the Highways Agency use for assessing investments decisions in the relevant area of activity? Is it appropriate to take the method or criteria used into account in determining the preferred option?

Table 5.4: Aspects considered in identifying preferred options

currently recommended by HM Treasury (2003) is to use declining discount rates for very long term costs where this reflects uncertainty about the future. It is understood that the HM Treasury guidance is currently under review to take account of climate change.

As highlighted above, it will typically be appropriate to define the expected outcome as either a series of discrete actions at predicted intervals or as a reduction in the likelihood and/or severity of an extreme weather-related incident or event. If the former approach is adopted, consequence costs will be those directly associated with the series of actions. If the later approach is adopted, the consequence cost in any year should be determined as the product of the consequence cost if the event occurs and the probability of it occurring. This value is termed the weighted consequence cost. These two approaches are illustrated in Figure 5.4.

### Determination of preferred option

The identification of the preferred option requires judgement, balancing the relative importance of the aspects given in Table 5.4. Their importance will vary between areas of Highways Agency activity and operations, and advice from a range of specialists will often be required to establish the preferred option. In establishing this balance of relative importance, reference should be made to the way in which

Highways Agency investment decisions are made in the relevant field.

For all the options consistent with the Highways Agency's sustainability requirements, the preferred option will ideally be the one that has minimum whole-life-cost, greatest certainty of outcome and lowest risks. Within the assessment of the sustainability of options, it will be important to consider their potential wider implications for climate change, since, for example, over-engineering designs could have negative climate change mitigation impacts.

If the preferred option is not clear then the next step is to identify whether this lack of clarity could be addressed through adopting a more refined approach to the options assessment, for example, by using more sophisticated methods to reduce the level of uncertainty or undertaking some more rigorous sensitivity analysis, in which case the option assessment should continue (see Figure 5.1). Alternatively, it may be appropriate to select an interim option that involves research or monitoring, the outcomes of which can be used subsequently in a more refined options assessment.

Once the preferred option is identified, an adaptation action plan is developed.

## 5.4 Development and implementation of adaptation action plans

The purpose of an adaptation action plan is to translate the preferred option determined through the options analysis into a detailed plan of what is to be done, when and by whom. The adaptation action plan should be sufficiently comprehensive to ensure that the investment of resources is effectively planned and managed. Its level of detail will be commensurate with the level of investment and risk.

An adaptation action plan template is included in Annex C3. A summary of the information contained in an adaptation action plan is given in Table 5.5.

Following its agreement, responsibilities for the implementation of an adaptation action plan will accord with those defined within the plan itself, with overall

progress monitored by Climate Change Adaptation Programme Manager (see Chapter 6).

One risk to the successful implementation of the actions plans will be that, once in competition with other works or activities for funding, they do not secure sufficient resources through the relevant investment appraisal mechanism (e.g. PAR). This particular risk<sup>1</sup> will need to be monitored carefully.

Section	Content
Introduction	<ul style="list-style-type: none"> <li>• Description of vulnerability (based on Options Analysis Report)</li> <li>• Action-plan version and history of updates</li> <li>• References to any related action plans</li> </ul>
Objectives	<ul style="list-style-type: none"> <li>• Objective of action-plan in supporting delivery of Highways Agency corporate objectives, and mitigating associated risks (see Table 4.1)</li> </ul>
Overview of methodology	<ul style="list-style-type: none"> <li>• General description of the adaptation methodology, its scope and planned approach to delivery</li> </ul>
Breakpoints and reviews	<ul style="list-style-type: none"> <li>• Details of breakpoints and reviews, for example to undertake refined options analysis following research or monitoring</li> <li>• Associated criteria for their identification</li> </ul>
Activities	<ul style="list-style-type: none"> <li>• Detailed and comprehensive list of all activities required, considering development and implementation stages</li> </ul>
Budget	<ul style="list-style-type: none"> <li>• Estimated budget for each of the required activities, either by cost or as hours by staff grade</li> </ul>
Deliverables	<ul style="list-style-type: none"> <li>• Summary of deliverables from each of the required activities</li> </ul>
Programme	<ul style="list-style-type: none"> <li>• Delivery programme</li> </ul>
Staff resources	<ul style="list-style-type: none"> <li>• Details of roles and responsibilities of Highways Agency staff</li> </ul>
Stakeholders	<ul style="list-style-type: none"> <li>• Details of stakeholders</li> </ul>
Governance	<ul style="list-style-type: none"> <li>• Details of how the delivery of the adaptation plan will be overseen, for example by the Climate Change Adaptation Programme Manager, steering group, TPB, etc.</li> </ul>
Annex A: Risk Register	<ul style="list-style-type: none"> <li>• Summary of risks to the successful delivery of the adaptation plan, mitigations employed and steps taken to manage residual risk</li> </ul>
Annex B: Options Analysis Report	<ul style="list-style-type: none"> <li>• Copy or reference to latest version</li> </ul>

Table 5.5: Contents of Adaptation Action Plan

<sup>1</sup> Investment appraisal was identified as a vulnerability during the application of Stages 3 and 4 of the HAAFM (see Section 4.7), indicating that it is an activity, the approach to which may need to be modified to enable the Highways Agency to adapt to a changing climate.

## 6 Delivery of the adaptation programme

This Chapter provides an overview of the overall approach to the management of the delivery of the adaptation Framework. It explains the role of the Climate Change Adaptation Programme Manager and provides a summary of the responsibilities of other role-holders for the delivery of the HAAFAM.

### 6.1 Programme management

The HAAFAM has been designed to provide a coordinated approach to meet the challenges of climate change. It establishes clear responsibilities for developing and implementing adaptation action plans in specific areas of activity. Importantly, through the role of the Climate Change Adaptation Programme Manager, the HAAFAM also provides strategic oversight of progress and overarching management of residual risk.

As Stage 7 of the HAAFAM, the Climate Change Adaptation Programme Manager will draw together key information from the adaptation action plans into an overall adaptation programme thereby providing transparency, supporting coordination and facilitating the ongoing review of progress. This information will form a part of the annual Climate Change Adaptation Progress Review Report, that will be developed by the Climate Change Programme Manager on behalf of the Highways Agency Board.

This report will review progress, set targets and define a programme of work for the next year. It will provide a summary of work undertaken in connection with each of the stages of the HAAFAM, such as updating climate changes trends information in response to advances in climate science (Stage 2) or the periodic review of Highways Agency vulnerabilities (Stage 3). It will also review challenges encountered, make recommendations for remedies, and summarise residual risks to the Highways Agency.

The Climate Change Adaptation Programme Manager will have responsibility for the overall management of the implementation of the HAAFAM. Key responsibilities will include:

- monitoring legislative and other policy developments;
- dissemination and communication;
- developing training materials for technical and operational specialists;

- monitoring developments and updating climate trends information;
- maintaining the vulnerabilities schedule;
- agreeing an annual programme of work with Divisional Directors for options analysis and the development of adaptation action plans; and,
- producing the Climate Change Adaptation Progress Review Report.

### 6.2 Roles and responsibilities

The HAAFAM establishes the Highways Agency Board, Climate Change Programme Manager, Divisional Directors and technical and operational specialists as role-holders. Table 6.1 provides a summary of the stages of the HAAFAM for which these role-holders have specific responsibilities. It also provides references to the sections of this document where those responsibilities are explained. In addition, Table 6.1 identifies the Volumes of the adaptation Framework which need to be understood by the role-holders.

Role	Knowledge and understanding			Implementation of HAAF						
	Volume 1	Volume 2	Volume 3	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Highways Agency Board	✓			✓ 2.2						✓ 2.2, 6.1
Climate Change Programme Manager	✓	✓	✓		✓ 2.2, 3.3	✓ 2.2, 4.1	✓ 2.2, 4.3-4.6	✓ 2.2, 5.1-5.3	✓ 2.2, 5.4	✓ 2.2, 6.1
Divisional Director (or as delegated)	✓	(✓)				✓ 2.2, 4.1	✓ 2.2, 4.3-4.6	✓ 2.2, 5.1-5.3	✓ 2.2, 5.4	
Technical and operational specialists	✓	✓	(✓)			✓ 2.2, 4.1	✓ 2.2, 4.3-4.6	✓ 2.2, 5.1-5.3	✓ 2.2, 5.4	

Table 6.1: Summary of roles and responsibilities

## 7 References

- Department for Transport (2005) *The Changing Climate: its impact on the Department for Transport*, [Online], Available: [www.dft.gov.uk](http://www.dft.gov.uk) [27 March 2008].
- Gedney et al.(2006) Detection of a direct carbon dioxide effect in continental river runoff records, *Nature*, 439, 835-838.
- Hallegatte S., J-C. Hourcade, P. Ambrosi (2007) Using climate analogues for assessing climate change economic impacts in urban areas, *Climatic Change*, Volume 82, Numbers 1-2.
- Highways Agency (2007) Sustainable Development Action Plan 2007-2008, [online], Available from: [www.highways.gov.uk](http://www.highways.gov.uk) [27 March 2008].
- HM Treasury (2003) *The Green Book', Appraisal and Evaluation in Central Government*, Stationery Office Books, [Online], Available: [greenbook.treasury.gov.uk](http://greenbook.treasury.gov.uk) [27 March 2008]
- Hulme,M., Jenkins,G.J., Lu,X., Turnpenny,J.R., Mitchell,T.D., Jones,R.G., Lowe,J., Murphy,J.M., Hassell,D., Boorman,P., McDonald,R. and Hill,S. (2002) *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK, pp. 120.
- IPCC (2007a) *Fourth Assessment Report. Climate Change 2007: Synthesis Report*
- IPCC (2007b) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 996.
- Jenkins, Perry, and Prior (2007) *The Climate of the United Kingdom and recent trends*, UKCIP08, December 2007.
- Jonsson and Hanna (2007) A new day to day pressure variability index as a proxy of Icelandic storminess and complement to North Atlantic Oscillation Index, 1823-2005, *Meteorologische Zeitschrift* 16(1), 25-36.
- Kopf S., M. Ha-Duong, S. Hallegatte (2007) *Using analogues to assess uncertainty in urban-area climate relocation*, PRUDENCE Poster.
- Milly et al. (2002) Increasing risk of great floods in a changing climate, *Nature*, 415, 514-517.
- Stern (2007) *Stern Review on the economics of climate change*, HM Treasury, [Online], Available: [www.hm-treasury.gov.uk](http://www.hm-treasury.gov.uk) [27 March 2008].
- Stott et al. (2000) External control of twentieth Century Temperature variations by natural and anthropogenic forcings. *Science*, 15.
- UKCIP (2002) *Climate change scenarios for the United Kingdom*, UKCIP02 Briefing Report, UK Climate Impacts Programme.
- UKCIP (2003) *Climate adaptations: Risk, uncertainty and decision-making*. UKCIP Technical Report. UK Climate Impacts Programme, Willows, R.I. and Connell, R.K. (ed.), Oxford.
- UKCIP (2008) *UK 21st Century Climate Scenarios* (known as UKCIP08), [online], To be available later in 2008 from: [www.ukcip.org.uk](http://www.ukcip.org.uk)
- Wilby (2006) *When and where might climate change be detectable in UK river flows?*, Geophysical Research Letters, 33, L19407.





